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Morphological Responses of *Cedrus atlantica, Pinus halepensis,* and *Tetraclinis articulata* in Different Pedoclimatic Conditions

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ABSTRACT

Plants are exposed to a variety of abiotic factors during their growth, such as climatic conditions and soil qualities. These factors have varying effects on the physiological and morphological characteristics of plant species. The present study was aimed at evaluating the physiological and morphological responses of *Cedrus atlantica, Pinus halepensis,* and *Tetraclinis articulata* seedlings cultivated in different pedoclimatic conditions. The study was carried out at two sites in central Morocco: Beni Souhane and Taddout. Seedlings of *C. atlantica, P. halepensis, and T. articulata* were grown in a greenhouse. Stem height, collar diameter, vigor factor, shoot and root dry matter, shoot to root dry matter ratio, and Dickson quality index (DQI) were all measured. Principal component analysis (PCA) and Pearson correlation were used to determine the relationship between variables. The results showed that *P. halepensis* cultivated in Taddout station had the highest stem height and collar diameter, while *T. articulata* of the Beni Souhane station was found to have the highest vigor quotient. There was high correlation level of stem height and collar diameter with the DQI, particularly for *T. articulata* cultivated in Beni Souhane station. The PCA revealed that the *T. articulata* of Ben Souhane station was found in the positive section of PC1 and characterized by its homogeneity of DQI and ratio. The findings of this study demonstrate the morphological and physiological elements involved in determining the quality of the plants under study. However, a further in-depth research is required to confirm these results.

Keywords: *Cedrus atlantica*, Correlation analysis, Growth, Morphology, Physiology.

Introduction

Plant species must endure harsh environmental conditions including various prevalent biotic and abiotic stresses because they are sessile.[1] These abiotic stressors include extreme temperatures, high levels of soil salinity, water deficiency, and/or excess nutrients that can have detrimental impacts on plant physiology, morphology, growth, and productivity.[2] Concerns about how climate change could intensify already-existing stresses have developed in recent years.[2,3] It is therefore essential to increase plant stress tolerance.[1] However, the first step is to understand how these plants react morphologically and physiologically to the stressors.

The first step in the plant cycle is the germination of seeds and the growth of seedlings.[4] Seeds germinate and produce small seedlings that require specific nutrients and suitable conditions.[5] The proper development of seedlings is controlled by numerous biotic and abiotic factors closely dependent on the quality of seeds and their capacity for resistance under stress.[6] The most significant influences on seedling growth and development are water, soil nutrients, climate, and pests.[7,8]

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Numerous physiological and morphological factors, including stem height, collar diameter, vigor quotient, and others, are used to determine a plant's quality.[9,10] These variables are greatly influenced by pedoclimatic conditions and cultivation techniques.[11] The soil provides nutrient for plants and protect roots from desiccation and adverse weather, such as hot temperatures and icy conditions that impact the absorption capacity of roots.[12,13] The cultivation techniques, such as hydroponic, which do not require the use of soil, greenhouse (controlled environment), and container gardening have different effects and advantages on plants.[14–16] However, in nature there is no place for controlled conditions and the plant must face variable conditions of climate, soil and hydric regimes.[17]

Native plants grow in forests under natural conditions, including weather, soil, and climate, which are generally variable depending on the seasons and geographic region.[18,19] Natural forests and their stands are currently severely degraded by climate change and wildfires. Therefore, afforestation is required to prevent the complete degradation of the world's green lungs, especially in North Africa, which is characterized by low vegetation density and the vulnerability of forest stands.[20,21] The production of seedlings and their development, on the other hand, are important steps in the afforestation process for forest stands. Under normal conditions, forest plants respond to environmental modifications to maintain their balance throughout the photosynthetic process producing numerous chemicals and different metabolites.[11] The ability to identify all variables that promote the growth and performance of seedlings is one of several challenges confronted by seedling producers.[22] Therefore, the analysis of morphological parameters of priming is the most important step in determining the best production techniques and planting conditions to ensure the good quality of seedlings.[23,24]

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Atlas cedar (*Cedrus atlantica*) is widely used for the production of timber. This plant has significant cultural, scientific, and economic perspectives. It currently covers 132,000 acres in the Rif, Middle, and High Atlas.[25] The loss of its forests was caused by the strong demand for Atlas cedar for the production of timber. Additionally, the severity of infestations of Atlas cedar forests is becoming more severe. Recently, different reforestation strategies with Atlas cedar have been undertaken for many purposes accounting for the survival rate.[26] Other Mediterranean tree species, including *Pinus halepensis* and *Tetraclinis articulata,* are thought to be affected by water deficiency and drought.[27] The quality of seedlings is evaluated based on numerous factors, including shoot height, root and stem diameter, the ratio of the shoot to root, as well as dry and fresh matter.[22] Three plants: Atlas cedar (*Cedrus atlantica*), *Pinus halepensis,* and *Tetraclinis articulata* were chosen for this investigation based on their abundance in North Africa and around the Mediterranean basin.[21] Also, their critical situation in North Africa,[28,29] and their potential roles in the reforestation of impacted ecosystems,[30–32] were considered. Atlas cedar (*C. atlantica*) is only found in the Mountains of the Middle Atlas and Rif chains (Morocco), the massifs of Belezma, El Hodna, and the Aurès (Algeria).[33] In contrast, *Tetraclinis articulata* and *Pinus halepensis* are found in southern Europe, which includes France and Spain, and North Africa, which includes Morocco and Algeria.[34,35]

The aim of this study was to evaluate the morphological and physiological characteristics of *Cedrus atlantica*, *Pinus halepensis,* and *Tetraclinis articulata* under different climatic conditions.

Materials and Methods

Study areas

This study was conducted in two sites located in central Morocco; Beni Souhane and Taddout. Beni Souhane is located in Ighezrane (east of Fez city) and has an elevation of around 500-700 meters above sea level. Taddout is located in Skoura M'Daz, in the Middle Atlas mountainous chains, at an altitude of 1,000 m above sea level. Both stations have similar climatic conditions and belong to the Fez-Meknes region.

Experimental design

This investigation was conducted in controlled environmental conditions in Rural Sciences Center at Beni Souhane and Taddout stations. Seedlings of *Cedrus atlantica, Pinus halepensis, and Tetraclinis articulata* were grown in polypropylene tubes. The vigor quotient, stem height, collar, diameter, shoot dry matter (SDM), root dry matter (RDM), and Dickson quality index (DQI) were all evaluated. Concerning shoot and root dry matter, leaves and roots were placed separately and dried at 70°C for 72 h. The results are expressed as g/plant. For the determination of seedling quality, the DQI was employed, which is a good tool to examine the quality of the seedlings using different parameters as determined by the following formula:[22,36,37]

$$DQI = \frac{TDM(g)}{(\frac{SH(cm)}{SBD(mm)}) + (\frac{SDM(g)}{RDM(g)})}$$

DQI: Dickson quality index, SH: shoot height, SBD: Stem base diameter, SDM: Shoot dry matter, RDM: Root dry matter.

Statistical analysis

Graph Pad Prism software was used to perform statistical analysis. Comparison of different parameters was carried out by one-way analysis of variance (ANOVA), followed by the Tukey test and Pearson correlation coefficient (r) at a significance level of 95% ($p<0.05$). The principal component analysis (PCA) was performed using PAST 3 software.

Results and Discussion

Impact of different pedoclimatic conditions on morphological parameters

The results of the morphological parameters of the three plants under study that were grown in various pedoclimatic settings are presented in Table 1. Three plants were measured for height, and it was discovered that the *Tetraclinis articulata* had the highest recorded height value and the greatest disparity in height among the other two plants under the same pedoclimatic conditions (Beni Sohane). Meanwhile, in the Taddout zone, *Pinus halpensis* was the tallest plant with a height of 17.20±1.02 cm and the *Cedrus atlantica* was the shortest with a plant height value of 9.80±1.33 cm. When comparing the collar diameter of various plants in the two study stations, *Pinus halepensis* displayed the highest value in both locations. *Cedrus atlantica* had the lowest collar diameter (0.90–0.10 mm) in the Beni Sohane station. *Tetraclinis articulata* and *Pinus halepensis* had significantly higher plant vigor than the other species in both studied zones although differences among these species were not statistically different (Table 1).

The normal growth of seedlings is controlled by numerous factors, such as nutrients, water, and climate, which strongly affect the culture yield.[38,39] The successful cultivation of plants is highly associated with seedling quality and their ability to resist and grow in critical conditions.[7,40] The ability to identify different conditions required to anticipate seedling yield and performance constitutes the first problem faced by producers of seedlings.[22] Several studies have been conducted to examine the relationship between growth parameters and the DQI of different seedlings including *Eucalyptus grandis, Pinus elliottii* var. *elliottii, Pentas lanceolate,* and *Melia volkensii*.[11,36,41–43] In this study, morphological parameters in *Cedrus atlantica*, *Pinus halepensis*, and *Tetraclinis articulate* were measured. The results obtained are consistent with those reported for seedlings of *Pinus halepensis* grown in North Africa,[44] seedlings of Taurus cedar (*Cedrus libani* A. Rich.) grown in the eastern Mediterranean basin,[45] and *Cedrus atlantica* grown in North Africa,[46] and *Tetraclinis articulata* grown in Morocco,[47] and South of Europe.[48]

Impact of different pedoclimatic parameters on Dickson quality index

The findings from calculating Dickson indices and aerial and root part weights are shown in Table 2. *Tetraclinis articulata* had the highest aerial part weight, followed by *Pinus halpensis* and *Cedrus atlantica*, with values of 1.440.19, 1.210.03, and 0.360.03 g, respectively, in the Beni Sohane station, according to the analysis of the results. Table 2 displays the results of measuring aerial parts, root weights, and Dickson indexes. *Tetraclinis articulata* had the highest areal part weight, followed by *Pinus halpensis* and *Cedrus atlantica*, with values of 1.44±0.19, 1.21±0.03, and 0.36±0.03 g, respectively, in the Beni Sohane station. In the Taddout station, *Tetraclinis articulata* came in second place behind *Pinus halepensis* and *Cedrus atlantica,* which is not for the lowest aerial part weight as shown in the first station (Beni Sohane). Regarding root weights, it was observed that all plants showed weaker root weights at the Beni Sohane station than at the Taddout station. *Tetraclinis articulata* and *Cedrus atlantica* had the highest values of 1.78±0.17 and 1.88±0.15 g, respectively. Considering the ratios of aerial part/root to the response of plants in different pedoclimatic conditions, *Tetraclinis articulata* in Beni Sohane station and *Pinus halepensis* in Taddout station were the plants that showed the highest ratios than the other studied plants.

The results of the DQI of the three plants under study are presented in Table 2. This parameter reflects the capacity of the plant to survive and grow adequately. *Tetraclinis articulata* of the Beni Sohane station exhibited the highest DQI value with a significant difference from other plants. Meanwhile, the three studied plants that were grown at the Taddout station did not show comparable DQI values that differed significantly ($p>0.05$). The plant quality using morphological and performance attributes (stem height, collar diameter, vigor quotient, shoot dry matter, root dry matter, SDM/RDM ratio, and DQI were evaluated in this study. The most essential factors in determining how well seedlings grow are generally agreed to be morphological characteristics.[22] In our case, all correlation coefficients between stem height and other tested variables were positive, which is in agreement

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with the findings of Dushimimana *et al*.,[42] in seedlings of *Melia volkensii* Gürke before field planting, and by Vieira *et al*.,[49] in the Brazilian pine tree seedlings. The quantification of plant biomass accounting for shoot dry matter and root dry matter is often considered an indicator for the evaluation of seedlings' survival. In our case, the highest value of shoot dry matter represents the efficiency of the photosynthetic process of the plant.[50] In this context, the obtained results revealed that *Tetraclinis articulata* and *Pinus halepensis* have the highest values of shoot dry matter, which could be explained by their better quality and better growth ability as presented in Table 2.

Correlation between morphological characteristics and quality of the three studied plants

An excellent statistical method to establish the relationship between a wide variety of variables in multivariate analysis, may be used to determine the distribution and homogeneity of the researched characteristics in the three plants. Figure 1 shows the results that were obtained via the multivariate analysis during our study. Principal component 1 (PC1) explained a total of 55.66%. Collar diameter, stem height, SDM, vigor quotient, ratio, and DQI were placed in the positive portion of the first component (PC1), whereas RDM was located in the negative part of PC1. The second principal component (PC2) explained a total of 35.021% and had the following parameters in its positive part: collar diameter, stem height, SDM, and RDM, while vigor quotient, ratio, and DQI were found in the negative part of PC2. The ability to distinguish between all plants growing at various stations was also noted, which allowed the division of samples into two groups. Group 1 had TCa, TT, BPh, and TPh, which were found in the positive part of PC2, while group 2 contained BT and BCa. TPh is characterized by its homogeneity in terms of collar diameter, stem height, SDM, and vigor quotient, which are implicated in the positive correlation with RDM. The BT is characterized by its homogeneity in term of ratio and DQI, which are implicated in the negative correlation with RDM (r= -0.63365 and r= -0.54896, respectively) as shown in Table 3. The results of Pearson correlation between all of the examined parameters are presented in Table 3. All correlation coefficients were found to be positive after data analysis, except those between the following variables: RDM and vigor quotient, ratio and collar diameter, ratio and RDM, DQI and collar diameter, and DQO and RDM, which were all found to be negative. A significant correlation was observed between stem height and SDM, and the same observation was made between ratio and DQI.

It has been proved that the accumulation of matter in the studied seedlings is highly associated with photosynthesis, which permits the biosynthesis of organic elements necessary for plant appearance.[51] Additionally, root dry matter is a good parameter widely used to predict the growth quality of seedlings. It has been shown that nitrate controls dry matter partitioning between the root and shoot of plants.[52] The shoot and root dry matter ratio represents an excellent factor of seedlings' survival.[53] The obtained results revealed that the *Tetraclinis articulata* of Beni Souhane station exhibited the highest ratio (4.06±0.38), which indicates disproportionately high shoot biomass as compared to the roots.

Table 1: Average plant height, diameter, and vigor index measured at different stations.

Station	Plant	Stem height (cm)	Collar diameter (mm)	Vigor quotient (cm/mm)
Beni Sohane	*Cedrus atlantica*	4.20 ± 0.46^{b}	0.90 ± 0.10^{b}	4.80 ± 0.46^{b}
	Pinus halepensis	10.70 ± 1.42^{a}	2.00 ± 0,32^{a}	5.47 ± 0.28^{b}
	Tetraclinis articulata	13.40 ± 1.03^{a}	1.50 ± 0.16^{ab}	9.30 ± 1.20^{a}
Taddout	*Cedrus atlantica*	9.80 ± 1.33^{b}	1.80 ± 0.20^{a}	5.45 ± 0.39^{b}
	Pinus halepensis	17.20 ± 1.02^{a}	2.20 ± 0.20^{a}	7.97 ± 0.61^{a}
	Tetraclinis articulata	10.10 ± 0.83^{b}	1.72 ± 0.20^{a}	6.15 ± 0.71^{ab}

Table 2: Mean values of shoot and root dry matter, shoot/root ratios, and Dickson quality index.

Station	Plant	Shoot dry matter Ps PA (g)	Root dry matter Ps PR (g)	Ratio (Ps PA/Ps PR)	Dickson quality index DQI
Beni Sohane	*Cedrus atlantica*	0.36 ± 0.03^{b}	0.48 ± 0.04^{b}	0.76 ± 0.09^{b}	0.95 ± 0.08^{c}
	Pinus halepensis	1.21 ± 0.03^{a}	0.89 ± 0.05^{a}	1.39 ± 0.10^{b}	1.78 ± 0.09^{b}
	Tetraclinis articulata	1.44 ± 0.19^{a}	0.37 ± 0.06^{b}	4.06 ± 0.38^{a}	4.26 ± 0.38^{a}
Taddout	*Cedrus atlantica*	1.04 ± 0.09^{b}	1.88 ± 0.15^{a}	0.58 ± 0.08^{b}	1.13 ± 0.07^{a}
	Pinus halepensis	1.35 ± 0.05^{a}	1.18 ± 0.06^{b}	1.16 ± 0.04^{a}	1.03 ± 0.31^{a}
	Tetraclinis articulata	1.24 ± 0.03^{a}	1.78 ± 0.17^{a}	0.72 ± 0.08^{b}	1.24 ± 0.08^{a}

Table 3: Pearson correlation coefficients between all the studied parameters of different studied plants.

	Stem height	Collar diameter	Vigor quotient	SDM	RDM	Ratio	DQI
Stem height	1	0.055	0.066	0.023*	0.839	0.453	0.565
Collar diameter	0.801	1	0.587	0.074	0.323	0.88222	0.851
Vigor quotient	0.780	0.282	1	0.100	0.552	0.050806	0.097
SDM	0.870	0.767	0.72914	1	0.69595	0.31895	0.315
RDM	0.107	0.490	-0.30794	0.2056	1	0.17674	0.259
Ratio	0.383	-0.078	0.809	0.494	-0.633	1	0.001*
DQI	0.298	-0.099	0.733	0.497	-0.548	0.981	1

*: significant at $p < 0.05$

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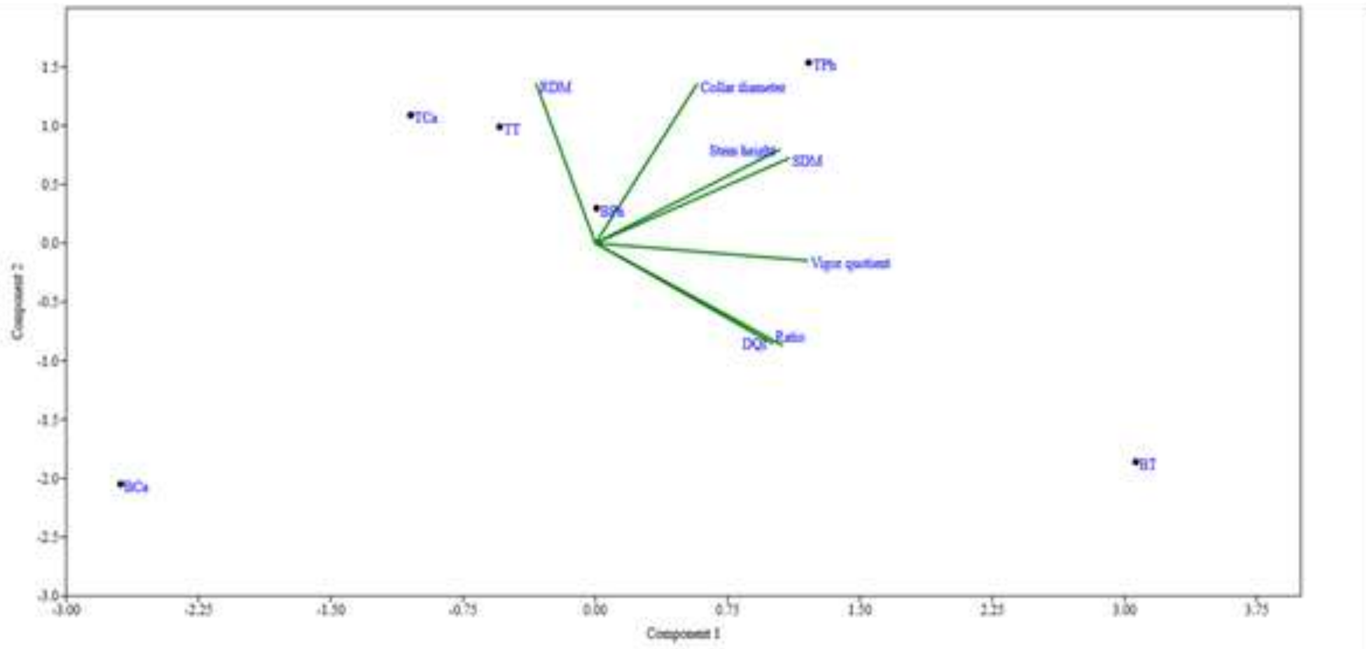

Figure 1: Distribution and homogeneity of studied parameters in the three plants.

In another study conducted by Kuan-Hung *et al*,[52] they found that the highest shoot and root dry matter ratio is related to the disparity of water distribution and the lowest quality of the plant.[51] In contrast, the lowest ratios could be explained by the insufficient shoot growth, type, and age of the plant.[51] The Pearson correlation coefficient for ratio, SDM, and RDM is considered an effective and safe index to examine seedlings' quality,[22] as the correlation was found positive (Table 3). Growing research suggests that the root system has a direct impact on dry matter, stem diameter, growth behavior, and root absorption area.[52,54]

The DQI value provides information on the stability and equilibrium of the biomass distribution in the seedlings under study.[51] DQI is a multifaceted factor that also makes it possible to predict the fertility of the soil (Thompson). The results showed that the highest DQI value was recorded for *Tetraclinis articulata* of Ben Souhane station. In this study, a high positive correlation was observed between DQI and stem height, vigor quotient, SDM, and ratio (R^2= 0.29856, R^2=0.73332, R^2=0.49755, and R^2=0.98118, respectively). In contrast, a negative correlation was observed between DQI and collar diameter and RDM (R^2= -0.099267 and R^2= -0.54896, respectively) as presented in Table 3.

Conclusion

The present study provides new insights into the morphological and DQI of *Cidrus atlantica, Pinus halepensis, and Tetraclinis articulata* grown in two different stations. Collar diameter and stem height are the most highly correlated parameters with the DQI. The findings of this study show the morphological and physiological factors involved in the perception of the quality of the studied plants as well as their future growth in various locations. However, further in-depth studies are required to confirm these results and to clarify how these parameters vary under given conditions, such as under biotic and abiotic stressors, which are widely encountered in the natural environment.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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