



DETERMINATION OF THE ANATOMICAL CHARACTERISTICS OF SOME WOODY SPECIES GROWING IN ARID AND SEMI-ARID AREAS

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Please cite this article as: Akgün B. (2025) Determination of the anatomical characteristics of some woody species growing in arid and semi-arid areas. *Turkish Journal of Forest Science*, 9(2), 240-252.

ESER BİLGİSİ / ARTICLE INFO

Araştırma Makalesi / Research Article

Geliş 25 Ağustos 2025 / Received 25 August 2025

Düzeltilmelerin gelişi 09 Ekim 2025 / Received in revised form 09 October 2025

Kabul 11 Ekim 2025 / Accepted 11 October 2025

Yayınlanma 27 Ekim 2025 / Published online 27 October 2025

ABSTRACT: In this study, the wood and stem structures of selected woody species employed in afforestation practices in the Central Anatolia Region, one of the arid and semi-arid zones of Turkey, were examined under natural conditions. The species investigated included black locust (*Robinia pseudoacacia* L.), Arabian almond (*Amygdalus arabica* L.), and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Their anatomical attributes conferring resistance to drought stress were assessed. Wood samples obtained from these species were prepared as permanent slides, and both xylem anatomical features and fiber morphological characteristics were analyzed. In conclusion, due to its possession of numerous and small-sized tracheae, its short and thick fiber structure, and its high abundance of bordered pits, *Atriplex canescens* can be prioritized for use in this and similar areas. The findings indicate that *Robinia pseudoacacia* and *Amygdalus arabica* are ecologically capable of tolerating drought and may therefore be utilized in afforestation programs in comparable environments. Moreover, their fiber structure and the abundance of bordered pits suggest a capacity for rapid adaptation to such conditions. Collectively, these results demonstrate the ability of these species, which naturally occur in arid regions, to withstand adverse environmental factors, and highlight their potential for use in future rehabilitation and plantation projects due to their favorable resilience traits.

Keywords: Xylem anatomy, arid and semi-arid regions, Central Anatolia, Karapınar/Konya.

KURAK VE YARIKURAK ALANLARDA YETİŞEN BAZI ODUNSU TÜRLERİN ANATOMİK ÖZELLİKLERİNİN BELİRLENMESİ

ÖZET: Bu çalışmada, Türkiye'nin kurak ve yarı kurak alanlarından biri olan İç Anadolu Bölgesinde yapılan ağaçlandırma çalışmalarında kullanılan bazı odunsu türlerde, yalancı akasya (*Robinia pseudoacacia* L.), arap bademi (*Amygdalus arabica* L.) ve tuz çalısının (*Atriplex canescens* (Pursh) Nutt.) doğal koşullarda odun ve gövde yapısı araştırılmış, kuraklık stresine karşı anatomik olarak dayanıklılık özellikleri tespit edilmiştir. Bu türlerden alınan odun örnekleri ile kalıcı preparatlar oluşturulmuş, ksilem anatomileri ve lif morfolojik özellikleri araştırılmıştır. Sonuç olarak çok sayıda ve küçük boyutta trahe bulundurması, kısa ve kalın lif yapısına sahip olması ve çok sayıda kenarlı geçit bulundurması açısından *Atriplex canescens* öncelikli olarak bu ve benzeri alanlarda kullanılabilir. *Robinia pseudoacacia* ve *Amygdalus arabica* türlerinin de ekolojik olarak kuraklığa dayanabildiği ve benzer alanlardaki ağaçlandırmalarda kullanılabileceği sonucuna varılmıştır. Aynı zamanda lif yapısı ve kenarlı geçit sayısı bakımından benzer alanlara kolay uyum sağlayabildikleri belirlenmiştir. Böylelikle, kurak bölgelerde yetişen bu türlerin olumsuz koşullara adaptasyonu ortaya konmuş, gelecekte yeni tesis edilecek rehabilitasyon ve plantasyonlarda bu üç türün pozitif dayanıklılık özellikleri ile kullanımları uygun bulunmuştur.

Anahtar kelimeler: Ksilem anatomisi, kurak ve yarı kurak alanlar, Orta Anadolu, Karapınar-Konya

INTRODUCTION

Climate change is causing changes in wood structure in angiosperm and gymnosperm plants. Global warming and changes in climate conditions, along with water scarcity or the unavailability of suitable water for plants, directly affect the structure of transport elements (such as diameter, wall thickness, etc.). In a study that examines the relationships between the ecology and wood anatomies of woody species in the southwest of Australia, mesomorphy and vulnerability values were determined for different growth environments (swamp shrubs, water's edge shrubs, heathlands, desert shrubs, and understory shrubs) by considering tracheid characteristics (tracheid diameter, number of tracheids per mm²). In the study, the mesomorphy value measured in the species ((Tracheid Diameter / number of tracheids per mm²) x Tracheid Cell Length) being 75 or lower was considered an indicator of xeromorphism, indicating that the western flora of Australia has a highly xeromorphic (drought-resistant) character (Carlquist, 1977). The development of relationships between ecological, physiological, and systematic characteristics in species belonging to the Gnetales (*Ephedra*, *Gnetum*, and *Welwitschia*) family has been examined. In cross-sectional images obtained with the aid of a light microscope, vascular bundles, different cell structures, and the anatomical structure of the bark were studied, and their resistance in relation to different ecological characteristics was revealed (Carlquist, 1996).

In another study, anatomical features such as vessel element length, vessel diameter, vessel grouping, vessel wall thickness, and helical thickenings of the woody flora from temperate and arid regions of Israel and neighbouring areas were compared with those of the humid cold temperate flora of Northwestern Europe, tropical rainforest flora, and monsoon forest flora of Java. It was determined that species growing in arid regions form thicker vessel walls and produce smaller vessel diameters compared to those growing in temperate regions (Baas et al.,

1983). Plants exhibit anatomical adaptations to diverse ecological conditions, enabling their persistence in critical habitats. In certain woody species inhabiting desert and subtropical regions, the proportion of scalariform perforation plates and tracheid fibers is relatively low, whereas simple perforation plates and libriform fibers are more abundant (Merev, 2003). Environmental factors influence the dimensions of wood elements, and such changes significantly affect the mechanical and technological properties of wood (Serdar, 2003).

Consequently, understanding the effects of climatic variation on both leaf (Domec et al., 2015) and wood anatomy has become increasingly important, with ecological wood anatomy receiving growing attention in recent decades. In ecological wood anatomy, relationships between wood anatomical traits and ecological variables are often assessed using indices such as “mesomorphy” and “vulnerability,” calculated from vessel characteristics (vessel lumen width, vessel wall thickness, and vessel density per mm²). These indices are applied at species, genus, or family levels, or across entire regional floras (Carlquist, 1988; Bak, 1999). Some studies incorporate geographical parameters such as altitude and latitude, examining variation either intraspecifically (within species) or interspecifically (among genera or families) (Bak, 1999). In the Salicaceae family, encompassing *Salix alba*, *S. viminalis*, *S. cinerea*, *S. purpurea*, *Populus alba*, *P. nigra*, *P. tremula*, and *P. euphratica*, comparative analyses of anatomical traits revealed distinct structural differences attributable to ecological conditions (Schweingruber, 1990). Within the Rosaceae, habitus was found to directly influence helical thickening, while macroclimatic factors exerted a direct effect on vessel element length (Zhang et al., 1992). A study of 51 angiosperm species from California’s coastal ranges assessed ecological correlations between wood density and vessel characteristics. Measurements from five individuals per species included wood density, mean vessel area, vessel density, and total sapwood area. Reduced Major Axis (RMA) regression analysis indicated that ecological factors, particularly maximum plant height and soil water content, directly influenced wood density and vessel traits. Taller species possessed wider vessels but lower vessel densities compared to shorter species (Preston et al., 2006). Investigations into 14 dicot species in Turkey identified perforated ray cells and wood cell characteristics. Perforated ray cells, occurring singly or in groups depending on the taxon, were located within the stem portion of multiseriate rays and at the termini of uniseriate and multiseriate rays. These cells were generally larger than adjacent cells, with perforation types resembling those of vessel perforation plates (Merev et al., 2005).

Research on 23 *Quercus* taxa in Turkey, across different regions and altitudinal gradients, demonstrated both intraspecific (species-level) and interspecific (genus-level) variation. Quantitative wood element traits were directly associated with elevation (Merev et al., 2000). Similarly, a detailed anatomical survey of 42 exotic Gymnospermae taxa in the Trabzon region involved transverse, radial, and tangential sections, producing microphotographs and an illustrated wood atlas to highlight distinctive anatomical structures (Gerçek et al., 2011). In *Camellia sinensis* (L.) Kuntze populations cultivated in the Eastern Black Sea Region, four regions and 16 sites were studied to characterize ecological conditions and analyse wood and leaf anatomy. Vessel density per mm² increased with elevation, an effect linked to climatic factors. In high-rainfall, humid environments, conductive elements exhibited structural adaptations, supporting superior growth performance (Gerçek, 1984). Comparative analyses between C₄ and C₃ woody plants revealed that conductive elements in C₄ species tend to be smaller in diameter but more numerous than those in C₃ species (Kocaçınar & Sage, 2004).

The present study aimed to improve afforestation success by identifying relationships between xylem anatomical features and drought-tolerant species in the field. Results demonstrated that species used in afforestation, revegetation, and restoration in arid, semi-arid, and barren areas of Turkey exhibit distinct drought-resistance and ecophysiological traits. The scarcity of studies integrating both physiological and anatomical data for these species underscores the significance of this work. Overall, the findings clearly indicate that drought stress-a key climatic factor-directly influences wood anatomical properties.

MATERIALS AND METHODS

Study Area and Characteristics

Samples were collected from afforestation sites in the Karapınar region of the Central Anatolia Region, Turkey. Historically, Karapınar's arid climate has rendered it unsuitable for forest growth, favouring primarily pasture vegetation. However, recent severe droughts, climate change, overgrazing, and land degradation have significantly diminished vegetation cover. The clayey and dusty soil surfaces have been extensively eroded by strong winds, transforming the landscape into a black sand dune area. During the summer months, potential evapotranspiration exceeds precipitation, particularly from May to October, coinciding with the active growing season. This results in severe water deficits and high water stress on plants. Consequently, many woody species have either been completely extirpated from this area or persist only through highly specialized adaptations, such as those observed in the species investigated in this study. The mean annual precipitation in the area is approximately 287 mm/m², with virtually no rainfall during the summer. High summer temperatures further exacerbate soil moisture depletion and intensify plant water deficits. The average annual temperature in the region is 10.9 °C (Avcı, 2004).

Plant Materials

Three woody species naturally present or utilized in afforestation efforts at the Karapınar Research Station were selected for this study: black locust (*Robinia pseudoacacia* L.), Arabian almond (*Amygdalus arabica* L.), and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Wood samples were collected from five individuals per species of the same age. Detailed anatomical analyses were conducted to compare interspecific differences and assess the suitability of these species for use in arid and semi-arid afforestation projects (Figure 1-3)



Figure 1. *Robinia pseudoacacia* L.



Figure 2. *Amygdalus arabica* L.



Figure 3. *Atriplex canescens* (Pursh) Nutt.)

Measurements

For anatomical studies, wood samples collected from the study area were fixed in FAA solution (formalin, acetic acid, and alcohol). Subsequently, samples were removed from FAA and sequentially rinsed in 50%, 70%, and 90% ethanol solutions for 20 minutes each. Using paraffin embedding, the wood samples were stabilized in cassettes, and transverse sections were cut with an RM-2255 microtome (Leica GmbH, Wetzlar, Germany). The sections were dehydrated by washing with 100% ethanol and then cleared in xylene for 20 minutes. Sections were stained for one hour in a solution of 1% safranin mixed with 95% ethanol, washed with 100% ethanol, and counterstained with 1% fast green (Fast green, Sigma-Aldrich Chemie GmbH, Munich, Germany) in 95% ethanol for 5 minutes. Following a final wash with 100% ethanol, permanent slides were prepared using Permunt mounting medium (Sigma-Aldrich, Munich, Germany) (Kocaçınar, 2004).

Anatomical measurements including average vessel diameter, vessel lumen width, vessel wall thickness, maximum vessel diameter, and vessel density per mm² were conducted and visualized using a light microscope equipped with a digital camera (Eclipse 90i, Nikon Instruments Europe B.V., Amstelveen, Netherlands) coupled with NIS-Elements software (NIS-Elements, Nikon Instruments Europe B.V., Amstelveen, Netherlands).

Additionally, wood samples were longitudinally sectioned using a razor blade and examined under a scanning electron microscope (SEM) (Zeiss, Oberkochen, Germany) at 10,000× magnification at K.S.Ü. ÜSKİM laboratory. The number of bordered pits per mm², as well as radial and tangential diameters and pit apertures were measured on vessel walls. Vessel and fiber measurements were conducted on 30 replicates (n=30). The sample sizes and counting

protocols followed standards suggested by Carlquist (1988a, 1988b), IAWA Committee (1933, 1989), Terrazas et al. (2008), and Tutuş et al. (2015), considering between 25 to 50 measurements per sample.

Fiber Morphological Measurements

Vessel fibers were isolated using the maceration method described by Tutuş et al. (2015). The resulting fiber suspension was mounted as temporary slides between a microscope slide and cover slip and observed under a light microscope at 10× and 40× magnifications. Measurements of fiber length, fiber lumen width, and fiber wall thickness were conducted accordingly.

RESULTS

Xylem Anatomy

Microscopic examination of the transverse sections revealed distinct vessel arrangement patterns among the studied species. *Robinia pseudoacacia* exhibited a ring-porous xylem structure characterized by very wide vessel lumina in earlywood and thick vessel walls in latewood. Similarly, *Amygdalus arabica* demonstrated ring-porous anatomy with wide earlywood vessel lumina and narrower lumina in latewood vessels. In contrast, *Atriplex canescens* displayed a diffuse-porous structure, with vessels aggregated in groups at the boundaries of annual rings.

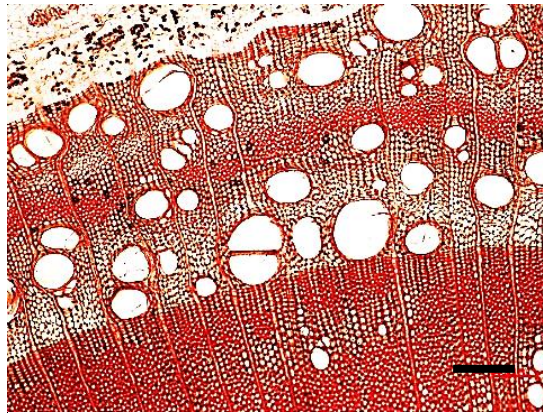


Figure 4. Transverse Section of *Robinia pseudoacacia* Stem Observed Under Light Microscopy. Scale Bar: 100 µm.



Figure 5. Transverse Section of *Amygdalus arabica* Stem Observed Under Light Microscopy, Scale Bar: 100 μm .

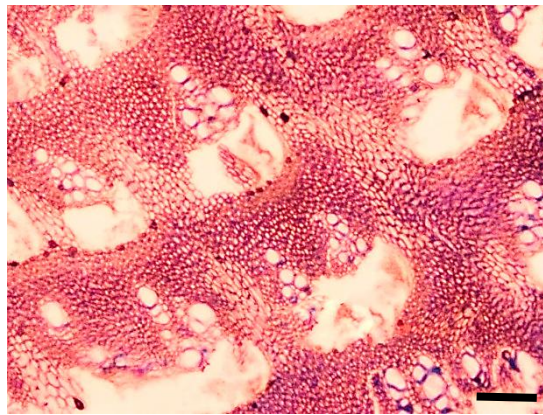


Figure 6. Transverse Section of *Atriplex canescens* Stem Observed Under Light Microscopy. Scale Bar: 100 μm .

Quantitative anatomical parameters, including mean vessel lumen width, vessel wall thickness, maximum vessel diameter, and vessel frequency per mm^2 , were measured using light microscopy. Among the species, *R. pseudoacacia* exhibited the largest mean vessel lumen width ($235.77 \pm 10.03 \mu\text{m}$), with a vessel wall thickness of $3.54 \pm 0.72 \mu\text{m}$, maximum vessel diameter of $255.16 \mu\text{m}$, and vessel frequency of $36 \pm 4 \text{ mm}^{-2}$. *A. arabica* had a mean vessel lumen width of $72.45 \pm 6.12 \mu\text{m}$, vessel wall thickness of $4.40 \pm 0.60 \mu\text{m}$, maximum vessel diameter of $80.68 \mu\text{m}$, and vessel frequency of $104 \pm 9 \text{ mm}^{-2}$. *A. canescens* exhibited the smallest mean vessel lumen width ($20.14 \pm 3.49 \mu\text{m}$), thickest vessel walls ($4.71 \pm 0.31 \mu\text{m}$), maximum vessel diameter of $27.39 \mu\text{m}$, and the highest vessel frequency at $121 \pm 14 \text{ mm}^{-2}$ (Table 1). Representative photomicrographs of vessel arrangements are presented in Figures 4–6.

Table 1. Quantitative Vessel Anatomical Traits of *R. pseudoacacia*, *A. arabica*, and *A. canescens*. Values are Presented as Mean $\pm$ standard error ($n = 30$).

Species	Mean Vessel Lumen Width (μm)	Mean Vessel Wall Thickness (μm)	Maximum Vessel Diameter (μm)	Vessel Frequency (mm^{-2})
<i>R. pseudoacacia</i>	235.77 ± 10.03	3.54 ± 0.72	255.16	36 ± 4
<i>A. arabica</i>	72.45 ± 6.12	4.40 ± 0.60	80.68	104 ± 9
<i>A. canescens</i>	20.14 ± 3.49	4.71 ± 0.31	27.39	121 ± 14

Wood Fiber Morphology

Wood fibers obtained via the maceration (chlorite) method were examined under a photomicroscope. Measurements of fiber lumen width, fiber wall thickness, and fiber length were conducted on 30 replicates per species. The mean values, standard deviations, and standard errors were calculated. Photomicrographs of fiber morphology for *R. pseudoacacia*, *A. arabica*, and *A. canescens* are shown in Figures 7–9.



Figures 7. Wood Fibers of *R. pseudoacacia* Scale Bar: 100 μm



Figures 8. Wood Fibers of *A. arabica* Scale Bar: 100 μm



Figures 9. Wood Fibers of *A. canescens* Scale Bar: 100 μm

R. pseudoacacia exhibited a mean fiber lumen width of $7.75 \pm 1.51 \mu\text{m}$, fiber wall thickness of $3.83 \pm 0.20 \mu\text{m}$, and fiber length of $0.742 \pm 0.06 \text{ mm}$. *A. arabica* showed a fiber lumen width

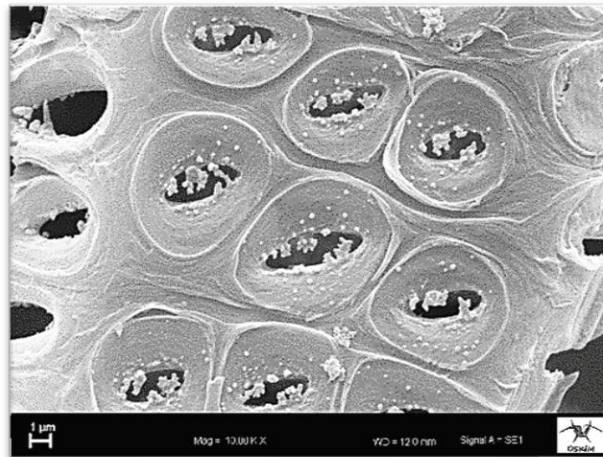
of $8.33 \pm 1.16 \mu\text{m}$, fiber wall thickness of $4.00 \pm 0.18 \mu\text{m}$, and fiber length of $0.571 \pm 0.05 \text{ mm}$. *A. canescens* displayed the narrowest fiber lumen width ($5.82 \pm 0.62 \mu\text{m}$), the thickest fiber walls ($8.50 \pm 0.38 \mu\text{m}$), and the shortest fiber length at $0.220 \pm 0.03 \text{ mm}$ (Table 2). Notably, C_3 photosynthetic pathway species (*R. pseudoacacia* and *A. arabica*) showed longer fiber lengths and wider fiber lumina compared to the C_4 species (*A. canescens*). Conversely, fiber wall thickness was greater in the C_4 species, indicating a tendency toward harder and more resilient wood fibers.

Table 2. Fiber Anatomical Characteristics of The Studied Species. Values Are Expressed as Mean $\pm$ standard error (n = 30).

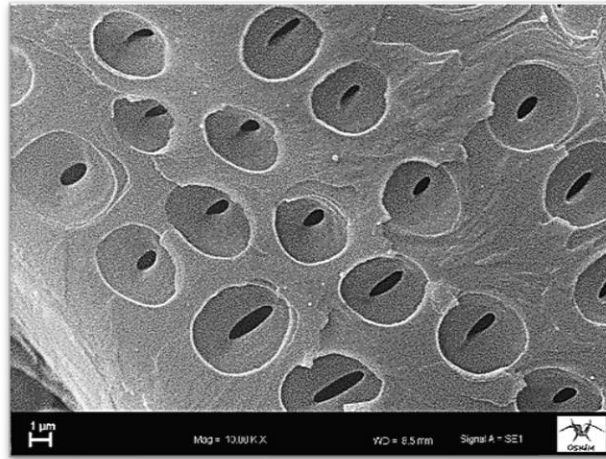
Species	Mean Fiber Length (mm)	Mean Fiber Lumen Width (μm)	Mean Fiber Wall Thickness (μm)
<i>R. pseudoacacia</i>	0.742 ± 0.06	7.75 ± 1.51	3.83 ± 0.20
<i>A. arabica</i>	0.571 ± 0.05	8.33 ± 1.16	4.00 ± 0.18
<i>A. canescens</i>	0.220 ± 0.03	5.82 ± 0.62	8.50 ± 0.38

Anatomical Features of Bordered Pits

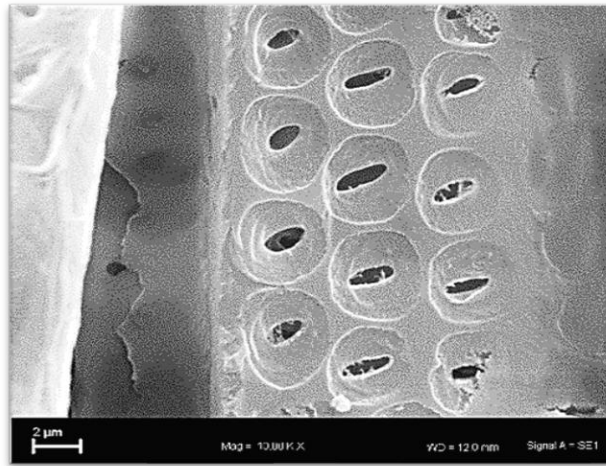
Radial walls of vessel elements were gold-coated and imaged using scanning electron microscopy (SEM) at $\times 10,000$ magnification. Six samples per species were analysed for the number of bordered pits per mm^2 , average pit membrane area, and pit aperture size (Figures 10–13).



Figures 10. Pits on The Vessels of *R. pseudoacacia*, (Scanning Electron Microscope $\times 10000$)



Figures 11. Pits on The Vessels of *A. arabica*, (Scanning Electron Microscope x10000)



Figures 12. Pits on The Vessels of *A. canescens*, (Scanning Electron Microscope x10000)

R. pseudoacacia had an average of 36 ± 5 bordered pits per mm^2 , mean pit membrane area of $28.07 \pm 2.14 \mu\text{m}^2$, and mean pit aperture of $2.95 \pm 0.24 \mu\text{m}^2$. *A. arabica* exhibited 38 ± 6 bordered pits per mm^2 , mean pit membrane area of $15.62 \pm 1.27 \mu\text{m}^2$, and mean aperture size of $1.26 \pm 0.10 \mu\text{m}^2$. *A. canescens* showed the highest bordered pit frequency ($48 \pm 4 \text{ mm}^{-2}$), with the smallest pit membrane area ($11.33 \pm 0.43 \mu\text{m}^2$) and aperture size ($0.86 \pm 0.04 \mu\text{m}^2$) (Table 3). These results suggest that C_4 species (*A. canescens*) possess a greater number of smaller bordered pits, which likely enhance water transport efficiency and reduce water loss under arid conditions compared to C_3 species (*R. pseudoacacia* and *A. arabica*).

Table 3. Bordered Pit Characteristics in Vessel Elements as Determined by SEM Analysis ($n = 30$). Values Are Given as Mean $\pm$ Standard Error.

Species	Bordered Pit Frequency (mm^{-2})	Mean Pit Membrane Area (μm^2)	Mean Pit Aperture Size (μm^2)
<i>R. pseudoacacia</i>	36 ± 5	28.07 ± 2.14	2.95 ± 0.24
<i>A. arabica</i>	38 ± 6	15.62 ± 1.27	1.26 ± 0.10
<i>A. canescens</i>	48 ± 4	11.33 ± 0.43	0.86 ± 0.04

DISCUSSION

The data indicate that vessel frequency increases under drought stress, while wetter environments favor fewer vessels per unit area. To maintain safe water transport under arid conditions, vessel diameters decrease to reduce cavitation risk, consistent with previous findings (Cihan & Akkemik, 2013). Among the studied species, *A. canescens* exhibited narrow vessel lumina with thick walls, typical of drought-adapted C₄ species, enhancing hydraulic safety and efficiency.

Although *R. pseudoacacia* had the widest vessels, larger diameters increase the risk of embolism according to the Hagen-Poiseuille equation, where flow rate is proportional to the fourth power of vessel radius (Holbrook & Zwieniecki, 2005). Thus, species with narrow but more numerous vessels, such as *A. canescens*, mitigate embolism risk by distributing water conduction across many conduits.

Fiber morphology also varied with photosynthetic pathways; C₄ species showed shorter, narrower-lumen, and thicker-walled fibers, suggesting more mechanically resilient wood compared to C₃ species. This is consistent with findings that drought-resistant species develop robust fibers to withstand environmental stress (Bozkurt and Erdin, 2000).

Bordered pit analysis further supported the functional differences between C₃ and C₄ species. *A. canescens* displayed a higher density of smaller pits, which likely improves water conduction efficiency and limits water loss, beneficial traits in xeric habitats (Kocaçınar, 2004).

CONCLUSION

Adaptations to heat and drought at the anatomical level enhance plant survival in arid environments by optimizing water transport and mechanical support. Species naturally occurring or used in afforestation efforts in the study area, such as *Robinia pseudoacacia*, *Amygdalus arabica*, and *Atriplex canescens*, exhibit distinct xylem and fiber traits that confer drought and salinity tolerance. These species are suitable candidates for restoration and reforestation in similar dry, saline, and semi-arid regions.

Prior to afforestation in such areas, careful selection of species based on anatomical and ecophysiological compatibility, alongside soil texture and structure assessments, is recommended to maximize success. The combination of C₄ and C₃ photosynthetic pathway species with traits such as high vessel frequency, thick fibers, and abundant bordered pits should be prioritized to improve water transport efficiency and structural resilience under drought stress. The ecophysiological characteristics of these woody species under natural conditions will enhance the success of selecting appropriate species and techniques for future initiatives. Determining species-specific photosynthetic rates, transpiration rates, stomatal conductance, water-use efficiency, water potential, as well as leaf and stem anatomical traits, will provide valuable insights for restoration and rehabilitation efforts planned in similar marginal areas.

AUTHOR CONTRIBUTIONS

Only one author contributed to the study.

FUNDING STATEMENT

The study received no financial support.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

ACKNOWLEDGMENT

The author would like to thanks Karapınar Desertification Centre Director, Dr Emre YAZAR, Phd student Oğuzhan BİLGİLİ and Assoc.Prof Dr. Ferit KOCAÇINAR for their help.

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