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Wood anatomy of Aleppo pine (*Pinus halepensis* Miller) grown naturally in Turkey

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Abstract

Pinus halepensis Mill. (Aleppo pine) is the least grown pine species in Turkey with two small forests. A total of 18 wood samples, 6 samples from northern slope and 6 from southern slope of Sırtlandağı in Milas-Muğla and 6 samples from the forest in Yumurtalık-Adana were collected. Tracheid and ray dimensions were measured on the photos of thin wood sections. As result, diameters of the earlywood tracheids in Aleppo pine are similar in both Adana and Muğla, while diameters of latewoods are wider especially on north aspect of the site in Muğla than Adana. The reason for this difference may probably be that the annual precipitation in Muğla is twice higher than that in Adana. Supporting the effect of lower precipitation in Adana, tracheid lengths are shorter, and tracheid frequencies are higher for a safety water transportation. All comparisons with the woods from Spain and Greece may be evaluated that the growing site conditions in Turkey are more favorable for the species and may be used in plantations. Furthermore, wood features in both Turkish and Aleppo pine species are very similar and their separation is almost impossible.

Keywords: Aleppo pine, wood elements, Mediterranean climate zone, ecological wood anatomy.

Introduction

Five native pine species in Turkey (*Pinus sylvestris* L., *Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe, *Pinus brutia* Ten, *Pinus pinea* L. and *Pinus halepensis*) constitute great forests on a total area of 12,117,122.5 ha, including high and coppice forests in general forest areas of Turkey (OGM, 2013). Particularly *Pinus nigra*, *P. sylvestris* and *P. brutia* have valuable woods, while *P. pinea* is preferring for its cones. *P. halepensis* is not well-known in Turkey, because of having two very small stands.

In the native pine species sapwood is yellowish or reddish white, and their heartwood is reddish brown. Because of large amount of resin canals, they can be seen with naked eye. Generally, pine wood has medium weight (D_{12}=0.52 g/cm^3), moderate shock resistance, high modulus of elasticity and bending resistance, and is a medium soft, easily processed, well glued, good nail holding

material. Pine wood is used as construction timber, lumber, bridge material that comes into contact with soil and water when impregnated, mine pole, wire pole, flag pole, fence stakes and sleepers in aircrafts, ship deck floorings, packing box making, paper and cellulose industry (Bozkurt and Erdin, 1997).

Pinus halepensis is the least grown pine species in Turkey with a total distribution area of 715 ha, including 465 ha normal and 250 ha damaged high forests (OGM, 2013). Its natural distribution area starts from Western Portugal and reaches the Eastern Mediterranean. Its main distribution is in the Western Mediterranean coasts, unlike *Pinus brutia*. It establishes forests between 0-1700 m in the Mediterranean basin (especially the Western Mediterranean). It grows on coastal dunes, on almost every soil type in hilly areas and especially on calcareous soils. In Turkey, there are local distribution areas between Adana-Kadirli, Milas-Bodrum, around İzmir-Urla and Aydın-Selçuk (Coode and Cullen, 1965). Aleppo pine which has a natural distribution in limited areas, is in the VU (vulnerable) hazard category according to the International Union for Conservation of Nature hazard categories.

It is an evergreen forest tree, 10-15 m tall, with a curved trunk, pointed in youth, with a scattered crown when old. The red brown - grayish brown bark of the trunk remains smooth and uncracked for a long time, later light gray barks are in the form of scales. Shoots are light gray in color. Buds are small and resin free. The needles, which are mostly double and sometimes triple, are light green - bright green colored and thin; 6-15 cm long, delicate and have fine teeth on the edges. Lengths of cones are 8-18 cm, narrow and conical. Cone has a long, curved and thick stalk, therefore the tips of cones point down, unlike red pine. Cone stalk is up to 1-2 cm in length. The apophysis protrudes in a horizontal direction. The cones are bright brown and easily distinguished from red pine trees with red-chestnut color and stalkless cones (Coode and Cullen, 1965; Akkemik, 2014).

Annual ring boundaries are distinct. The transition from earlywood to latewood is gradual to abrupt. They have thin walled resin canals. There is no helical thickening and axial parenchyma. Rays are heterogeneous and usually uniseriate, rarely biseriate, Ray height is 1-25 cell. Ray tracheids are generally dentate. Cross-field pitting is pinoid and number of pits per cross-field 1-4. It is difficult and almost impossible to distinguish from Turkish pine (Akkemik and Yaman, 2012).

Along with the studies on the properties of Aleppo pine wood, studies on the wood formation is associated with climate (Attolini et al., 1990; Borghetti et al., 1998; Luis et al., 2007; Luis et al., 2011a, 2011b; Sanchez-Salguero et al., 2010; Olivar et al., 2012; Pasho et al., 2012; Novak et al., 2013;) are also increasing. Regarding the Aleppo pine species, which has a very limited distribution in Turkey, the physical and mechanical properties of its wood were determined by Erten and Sözen (1997), but no study has been conducted on the anatomical features of this species in detail (As et al., 2002). The aim of this study is to determine the wood anatomical features of Aleppo pine that grows naturally in Turkey.

Materials and method

The wood samples were collected from two different growing areas where are Muğla-Milas and Adana-Yumurtalık (Fig. 1). These two native areas have very limited distribution of Aleppo pine in Turkey and have hot and dry summers and warm-rainy in winters. According to the information

given by the General Directorate of Meteorology from the measurements of the last 90 years between 1929-2019, in Muğla the annual mean temperature is 15.1 °C, annual precipitation is 1214.8 mm; in Adana, annual mean temperature is 19.1 °C and annual precipitation is 671.3 mm (MGM, 2020).

Figure 1. The sampling points from Muğla-Milas and Adana-Yumurtalık.

A total of 18 wood samples, 6 samples from northern slope and 6 from southern slope of Sırtlandağı in Milas-Muğla and 6 samples in Yumurtalık-Adana were collected. Cylindrical wood samples with a diameter of 2 cm (Fig. 2) from west direction of the trees were taken from 1.30 m height by using a professional drill (see Biricik and Akkemik, 2017). Furthermore, increment cores were extracted with an increment borer to find the ages of the sampled trees. Tree diameters were also measured by a caliper (Table 1).

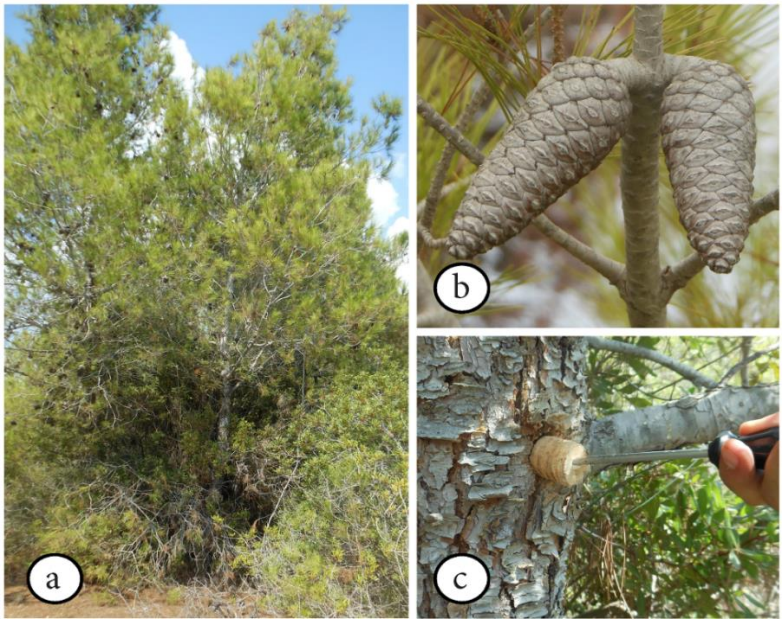

Figure 2. Photos of Aleppo pine; a) General view of a tree, b) cones, c) taking a wood specimen.

Table 1. The study areas, and some information about the sampled trees.

Code	Aspect	Altitude (m)	Tree diameter (cm)	Tree height (m)	Tree age	Latitude (N)	Longitude (E)
MN1	North	50	26	10	19	37.174099	27.561788
MN2	North	35	23	8	18	37.174172	27.561541
MN3	North	32	20	9	19	37.174146	27.561462
MN4	North	29	24	10	18	37.173969	27.560717
MN5	North	39	30	12	24	37.174085	27.561072
MN6	North	35	26	10	20	37.173805	27.560214
MS1	South	36	22	8	16	37.162039	27.553871
MS2	South	13	26	11	21	37.164361	27.550836
MS3	South	35	30	13	25	37.162268	27.553276
MS4	South	30	20	9	18	37.163721	27.577389
MS5	South	32	22	8	20	37.164055	27.576290
MS6	South	23	24	9	16	37.168850	27.573711
AS1	South	0	27	12	22	36.741598	35.624809
AS2	South	0	23	15	19	36.741607	35.624798
AS3	South	1	24	16	22	36.742292	35.625202
AS4	South	2	20	15	19	36.742166	35.625198
AS5	South	1	28	12	25	36.742264	35.625235
AS6	South	1	24	8	22	36.742173	35.625068

In the Laboratory of Tree-Ring Researches and Wood Anatomy of Faculty of Forestry Department of Forest Botany in Istanbul University-Cerrahpaşa, microscopic sections having a thickness of 30 micron were taken from three directions of the woods as transversal, radial and tangential sections by Leica Mikrotome SM 2010R, and microscope slides were prepared after standard chemical processes (Gartner and Schweingruber, 2013). Photos of wood elements from three different sections were taken with a Leica microscope and camera (DM2500), and all measurements and counts were performed on these photos by using the LAS Software of Leica System program (Fig. 3 and 4).

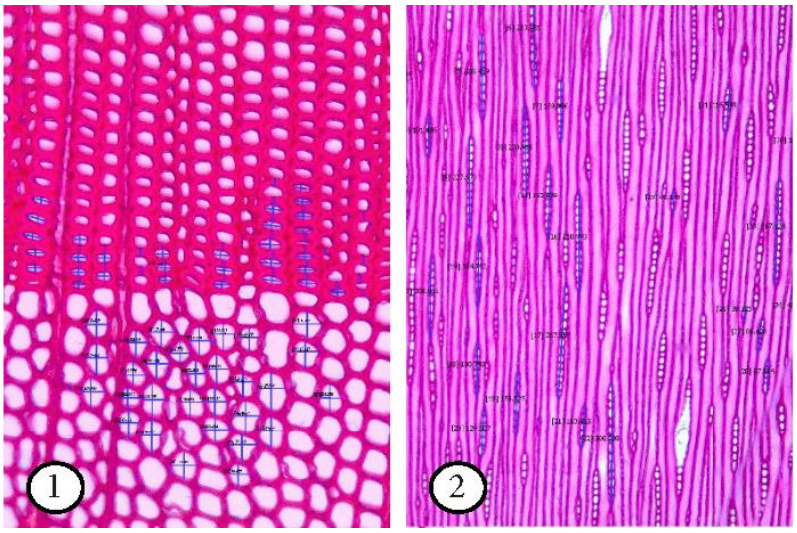

Figure 3. Measurements on (1) transversal and (2) tangential sections of Aleppo pine wood.

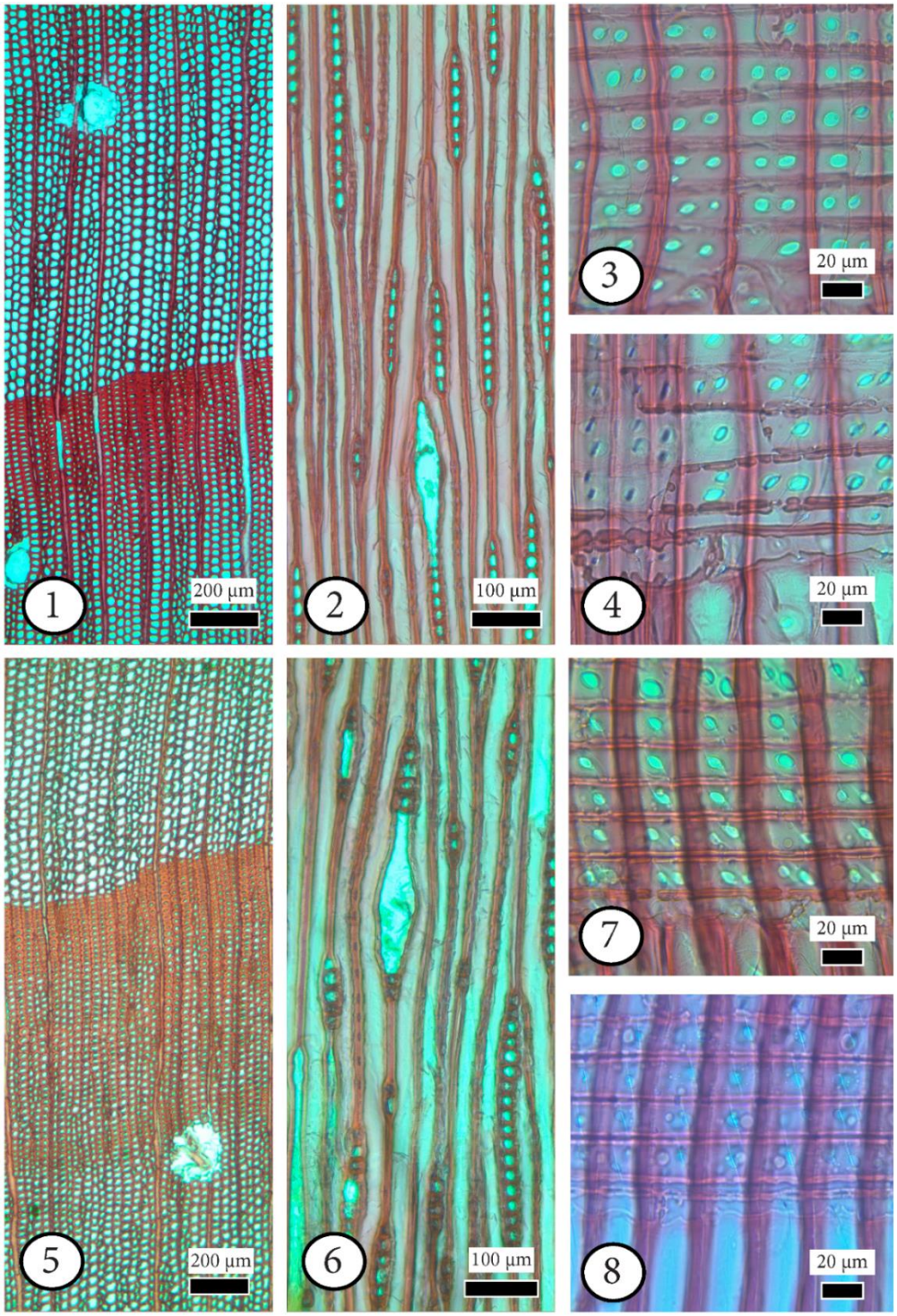

Figure 4. Wood thin sections of Aleppo pine. 1-4) Transversal, tangential and radial sections (Yumurtalık-Adana); 5-8) Transversal, tangential and radial sections (Milas-Muğla).

On the transversal sections of wood, tangential and radial lumen diameters and double wall thicknesses in both earlywood and latewood tracheids were measured. Tracheid number per square mm was counted. On the tangential sections of wood, ray heights and widths were measured; ray cell heights and ray number per mm were counted. Wood samples were separated into wood elements by Shultze maceration method (Sharma, 2005) and lengths of tracheids

obtained were measured. Based on suggestion of the IAWA Committee (2004), 30 measurements were performed for each feature in each sample, and finally a total of 7470 measurements were carried out.

By using the SPSS Program, similarities and differences between the sampling sites were determined. For this, Duncan test was performed in the measurements having a homogeneous of variance and normal distribution. Dunnett T3 test was performed in the measurements having normal distribution but no homogeneous of variance. Kruskal-Wallis Test was applied for the group with features that did not show normal distribution, and Mann-Whitney Test was applied for the pairs for those with differences.

Results

In the studied wood samples of Aleppo pine, average of tracheid tangential lumen diameter in earlywood was measured as 27.6 µm; radial diameter was 28.5 µm. They are 18.5 µm and 7.7 µm in latewood (Table 2). The highest double cell wall thickness was measured as 9.17 µm in Adana, and the lowest one was 8.04 µm in northern slopes of Muğla. Average earlywood tracheid double wall thickness was measured as 4.11 µm in Adana, it was found higher with 6.18 µm in the north and 6.37 µm in the south slopes of Muğla. While the highest average tracheid length was obtained in the northern aspect of Muğla with 3975 µm (it was 3694 µm in the south aspect), the lowest value was found as 3038 µm in Adana. The highest number of tracheids per square mm was measured as 1232 in the woods from Adana (Table 2; Fig. 5).

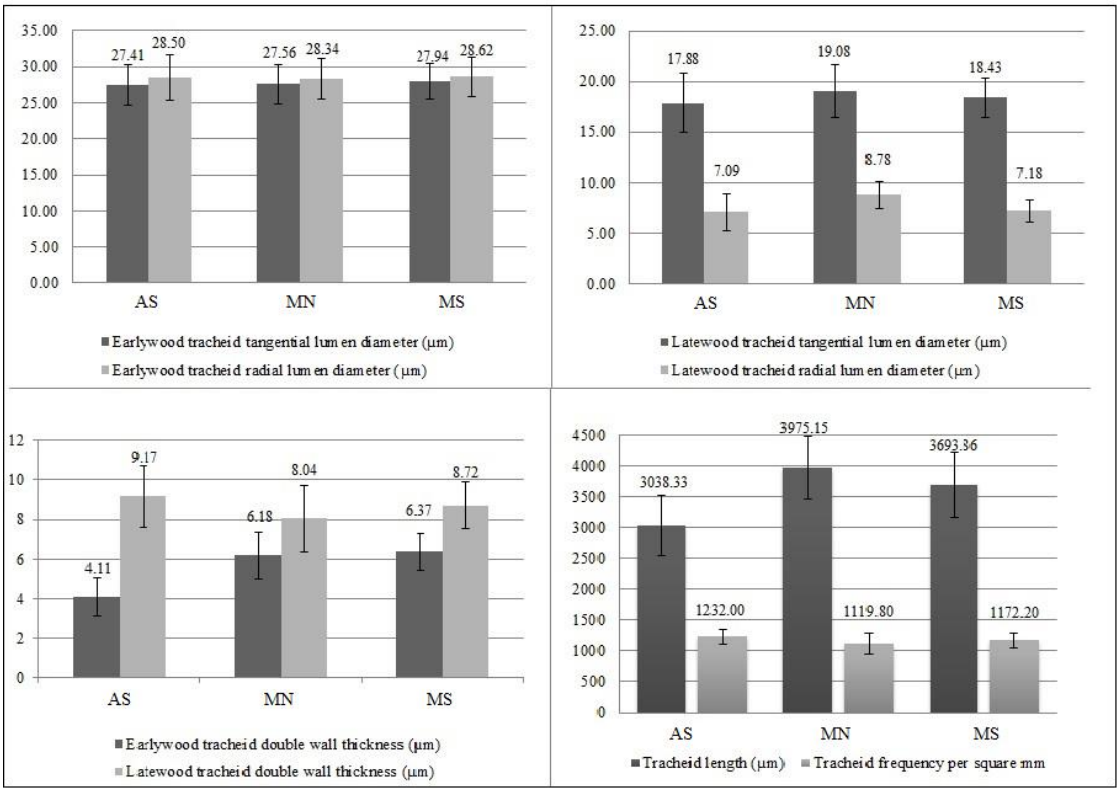

Figure 5. Tracheid properties of Aleppo pine (sample codes AS: south of Adana, MN: north slopes of Muğla, MS: south slopes of Muğla).

Table 2. Tracheid measurements and counts of Aleppo pine for different growing sides of Tu

Code	Earlywood Tangential diameter (µm)	Earlywood Radial diameter (µm)	Earlywood Tracheid double wall thickness (µm)	Latewood Tangential diameter (µm)	Latewood Radial diameter (µm)	Latewood Tracheid double wall thickness (µm)	Trach (µm)
MN1	28.66 (±3.41)	30.81 (±2.20)	5.22 (±1.01)	18.48 (±2.47)	9.75 (±1.28)	7.05 (±1.37)	3990
MN2	28.49 (±2.35)	28.50 (±1.81)	5.80 (±0.72)	21.04 (±2.60)	9.18 (±1.50)	6.71 (±1.06)	3807
MN3	26.80 (±1.75)	28.54 (±2.19)	5.40 (±0.81)	17.10 (±1.20)	8.18 (±0.69)	7.53 (±0.59)	4123
MN4	27.58 (±3.35)	29.20 (±3.52)	6.74 (±0.66)	19.45 (±1.59)	8.54 (±1.44)	9.86 (±1.64)	3922
MN5	26.44 (±2.18)	26.23 (±2.44)	7.50 (±1.01)	20.56 (±2.59)	8.45 (±1.07)	8.83 (±1.67)	4091
MN6	27.38 (±2.12)	26.77 (±1.98)	6.39 (±0.95)	17.82 (±2.41)	8.58 (±1.17)	8.28 (±1.07)	3914
MS1	28.83 (±3.43)	28.32 (±4.06)	6.58 (±0.99)	16.42 (±1.95)	7.38 (±0.91)	7.31 (±0.90)	3996
MS2	28.13 (±2.06)	28.10 (±2.23)	6.14 (±0.90)	18.12 (±1.48)	7.17 (±0.88)	8.93 (±1.01)	3731
MS3	28.56 (±1.81)	29.83 (±2.41)	7.10 (±0.76)	19.80 (±1.43)	8.35 (±0.95)	9.28 (±1.20)	3257
MS4	26.55 (±1.75)	27.74 (±2.07)	6.28 (±0.92)	18.50 (±1.60)	7.12 (±0.87)	8.58 (±1.00)	3659
MS5	28.22 (±1.97)	29.24 (±2.53)	6.19 (±0.99)	18.47 (±1.76)	6.82 (±0.86)	8.88 (±0.95)	3774
MS6	27.34 (±2.64)	28.48 (±2.44)	5.92 (±0.70)	19.29 (±1.63)	6.23 (±0.68)	9.31 (±0.96)	3743
AS1	26.82 (±3.13)	33.71 (±4.91)	3.64 (±0.76)	19.87 (±2.60)	8.43 (±1.46)	9.53 (±1.70)	2697
AS2	28.01 (±2.42)	32.64 (±4.62)	3.71 (±0.90)	19.23 (±2.31)	8.21 (±1.71)	8.50 (±0.95)	3050
AS3	27.44 (±3.14)	27.96 (±2.50)	4.66 (±1.03)	17.65 (±2.86)	7.06 (±2.11)	9.78 (±1.94)	3256
AS4	27.15 (±2.98)	26.97 (±2.59)	4.80 (±0.93)	16.35 (±3.90)	6.23 (±1.32)	8.53 (±1.26)	3158
AS5	28.24 (±2.85)	29.38 (±3.31)	3.78 (±0.76)	17.91 (±1.65)	7.14 (±1.34)	8.92 (±1.23)	3004
AS6	26.81 (±2.29)	27.34 (±2.70)	4.07 (±0.66)	16.25 (±2.04)	5.49 (±0.85)	9.75 (±1.60)	3062

Table 3. Ray measurements and counts of Aleppo pine from different growing sides of Turkey.

Code	Ray height (cell)	Ray height (µm)	Ray width (µm)	Ray frequency per mm
MN1	8.40 (±4.27)	168.20 (±71.26)	25.45 (±3.20)	7.73 (±1.20)
MN2	7.37 (±3.27)	168.53 (±63.46)	26.34 (±2.48)	7.53 (±1.04)
MN3	7.03 (±3.69)	170.71 (±69.89)	25.70 (±2.29)	6.87 (±1.04)
MN4	7.03 (±3.55)	166.98 (±56.15)	28.75 (±2.61)	8.27 (±1.08)
MN5	8.37 (±3.81)	168.50 (±58.44)	25.39 (±2.69)	7.50 (±0.90)
MN6	8.07 (±3.93)	164.51 (±58.53)	25.09 (±2.57)	7.37 (±1.19)
MS1	8.43 (±3.78)	160.93 (±65.17)	25.39 (±3.10)	7.57 (±1.04)
MS2	7.47 (±3.47)	164.25 (±59.73)	26.43 (±2.88)	7.27 (±1.23)
MS3	7.27 (±3.12)	158.30 (±56.83)	25.67 (±3.23)	6.80 (±1.10)
MS4	9.30 (±4.36)	163.91 (±71.22)	23.32 (±2.58)	7.50 (±1.01)
MS5	7.63 (±3.30)	157.68 (±65.16)	22.89 (±2.84)	7.43 (±1.19)
MS6	7.47 (±3.30)	160.71 (±59.80)	25.27 (±2.22)	7.70 (±1.12)
AS1	7.77 (±3.96)	155.10 (±70.51)	20.97 (±2.97)	8.50 (±0.94)
AS2	6.60 (±3.20)	131.50 (±50.53)	22.93 (±2.80)	7.70 (±0.88)
AS3	7.07 (±3.89)	153.36 (±79.11)	25.70 (±3.76)	7.87 (±0.90)
AS4	8.50 (±4.74)	156.79 (±83.80)	21.43 (±2.12)	10.47 (±1.10)
AS5	8.27 (±3.80)	151.92 (±66.16)	20.61 (±2.59)	8.07 (±1.01)
AS6	8.33 (±4.05)	155.34 (±71.88)	21.95 (±2.29)	8.50 (±1.07)

The ray cell heights are similar in all sites, when the ray widths are higher (26.12 µm) in Muğla, especially in the northern slopes. Average ray number per mm is 8.17 in Adana and 7.38 in the south slopes of Muğla (Fig. 6).

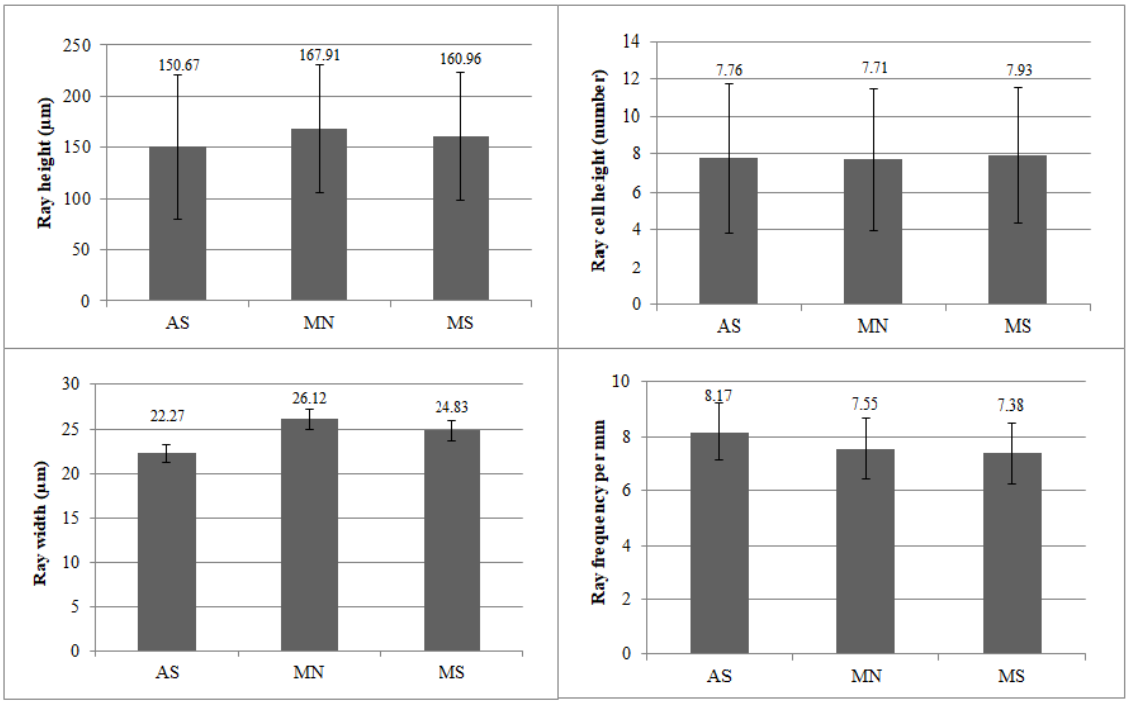

Figure 6. Ray properties of Aleppo pine.

The statistical results showed that wood features in three different growing sites are mostly similar with some important differences (Table 4). Particularly earlywood tracheid tangential and radial diameters fallen into the same group and no significant differences between them. Because they are the main water conducting elements, this result showed the presence of similar spring and early summer conditions in three sites.

Regarding the latewood tracheid diameters, while the sites in Adana and in south aspect of Muğla fall into the same group, the site in north aspect of Muğla shows a different group. This result indicated that some differences can be seen in summer conditions. Aspect in dry sites are important in respect of water storage and evaporation. Because north aspect relatively has lower evaporation and higher water storage, the water conducting elements (tracheids) showed a different group and their diameters are higher. On the contrary, in Adana and in south aspect in Muğla, tracheid diameters are lower and fallen into the same group. This result indicated that south aspect is drier than the north aspect of growing sites of Aleppo pine in Turkey.

Discussion

Lumen diameters of the earlywood tracheids in Aleppo pine are similar in both Adana and Muğla, while diameters of latewoods are wider in especially on north aspect of the site in Muğla than Adana. The reason for this difference may probably be that the annual precipitation in Muğla (1,215 mm) is two times higher than that in Adana (671 mm). Supporting the effect of lower precipitation in Adana, double wall thicknesses of the latewood tracheid are higher, tracheid lengths are longer, their frequencies are higher in Adana for a safety water transportation. On the other hand, heights and widths of rays are lower and ray frequencies are higher in Adana, as well.

Esteban et al. (2010) have studied wood anatomy of Aleppo pine from three Mediterranean region of Spain. In Inland Catalonia, Southern Spain and Balearic Islands, annual precipitation is 539 mm, 584 mm and 451 mm, respectively. The lengths of tracheids 583.55 µm, 632.07 µm, 659.76 µm; lumen diameters 20.16 µm, 21.52 µm, 20.20 µm; wall thicknesses 4.18 µm, 2.77 µm, 2.93 µm for earlywood tracheids respectively. In Turkey's Mediterranean region, precipitation is higher as 1215 mm in Muğla and 671 mm in Adana, and lengths of tracheids 3835 µm and 3038 µm; lumen diameters 27.75 µm and 27.41 µm for earlywood, 18.76 µm and 17.88 µm for latewood; wall thicknesses 3.14 µm and 2.06 µm for earlywood, 4.19 µm and 4.59 µm for latewood tracheids, respectively (Fig. 3). Because of being more precipitation in Turkey, tracheid lengths are longer, lumen diameters are wider and wall thicknesses are thinner than those in Spain.

Pacheco et al. (2015) found average tracheid wall thickness 4.14 µm and lumen diameters 24.82 µm for Aleppo pine growing in the Middle Ebro Basin (Spain), which have an annual precipitation as 313 mm. Although precipitation is lower than Turkey, wood features are very similar to Turkish Aleppo pine woods. They also remarked that wet and warm late-winter and summer conditions were associated with wider wall thickness in Aleppo pine as Muğla compared with Adana.

Foti et al. (2018) studied tracheid length and wood density of Aleppo pine and their relations to cambial age and growth rate in Thessaloniki-Greece. They found average tracheid length 2550 µm (1250-3640 µm) for 21-23 ages. Their shorter lengths might depend on xeric climate conditions than those of Turkey. All comparisons with the woods from Spain and Greece may be evaluated that the growing site conditions in Turkey are more favorable for the species and may be used in plantations.

Table 4. Statistical results of wood features from three different sites and their compariso

	Earlywood tracheids tangential diameter[1++]	Earlywood tracheids radial diameter[1+]	Latewood tracheids tangential diameter[1++]	Latewood tracheids radial diameter[2]	Earlywood tracheids double wall thickness[1++]	Latewood tracheids double wall thickness[2]	Tracheid number per square mm[1++]	Tracheid length[1+]	Ray height
Adana	27,41a	28,50a	17,88a	7,09a	4,11a	9,17c	1232,00b	3038,33a	150,67a
Muğla-North site	27,56a	28,34a	19,07b	8,78b	6,18b	8,04a	1119,80a	3975,15c	167,90b
Muğla-South site	27,94a	28,62a	18,43a	7,18a	6,37b	8,72b	1172,20a	3693,86b	160,96ab

1= Normal distribution, + Variance homogenous (Duncan Test), ++ Variance no homogenous (Dunnett T3 test), 2= No normal
was applied within the group, and the Mann-Whitney Test was applied for the pair in those with a difference).

The species with the closest characteristics and habitat requirements to Aleppo pine is Turkish pine (*Pinus brutia* Ten.). Bozkurt et al. (1993) studied wood anatomy of Turkish pines grown in Datça and found diameters of tracheids as 40 µm, lumen widths 26.5 µm, cell wall thicknesses 6.8 µm, tracheid lengths 2880 µm for earlywood, 3210 µm for latewood. Furthermore, Ay (1993) determined diameters of tracheids as 44.16 µm, lumen widths 35.56 µm, cell wall thicknesses 4.7 µm, earlywood tracheid lengths 3230 µm and latewood tracheid lengths 3800 µm for woods of Turkish pines grown in Alanya. Diameters of wood elements are about the similar in both Turkish and Aleppo pines. Together with diameters, as stated by Schweingruber (1988) and Akkemik and Yaman (2012), growth rings, tracheid shapes, resin canals, cross-field pits and ray tracheids in both Turkish and Aleppo pine species are also very similar to each other, and their separation in wood identification is almost impossible.

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