Maderas-Cienc Tecnol 23(2021):67, 1-20
Ahead of Print: Accepted Authors Version

DOI:10.4067/S0718-221X2021005XXXXXX

COMPARISON OF SOME WOOD PROPERTIES OF JUVENILE BLACK PINES OF DIFFERENT ORIGIN PLANTED IN THE SAME HABITAT

Mustafa Burak Arslan[1]*, Erkan Avcı[2], Ayhan Tozluoğlu[3], Turgay Birtürk[3], Akın Saraçbaşı[4], Erdal Örtel[1]

[1] General Directorate of Forestry, Ege Forestry Research Institute, İzmir, Turkey.
[2]Muğla Sıtkı Koçman University, Faculty of Technology, Muğla, Turkey.
[3]Düzce University, Faculty of Forestry, Düzce, Turkey.
[4]General Directorate of Forestry, Foreign Relations, Training and Research Department, Ankara, Turkey.

***Corresponding author:** mustafaburakarslan@ogm.gov.tr
Received: July 10, 2020
Accepted: August 13, 2021
Posted online: August 13, 2021

ABSTRACT

Black pine (*Pinus nigra*) is a significant raw material source for the forest products industry in Turkey. The purpose of this research was to study some chemical, anatomical, physical, and mechanical properties of wood obtained from juvenile black pines planted in Kavaklıdere - Muğla, originating from five different locations: Muğla, Balıkesir, Denizli, Bursa, and Kütahya. Although pines originating from Muğla and Balıkesir were good in terms of wood properties, those from Denizli, Bursa, and Kütahya exhibited no remarkable features. Black pine of Muğla origin was recommended for planting in Kavaklıdere and similar habitats, whereas pines of Denizli, Bursa, and Kütahya origins were not recommended. However, pine of Balıkesir origin may be an alternative to that of Muğla origin for black pine plantations at Kavaklıdere and similar sites.

Keywords: Anatomical properties, chemical properties, juvenile wood, mechanical properties, physical properties, wood properties.

INTRODUCTION

The general geographical distribution of black pine (*Pinus nigra*) covers Anatolia, Crimea, south of the Carpathians, the Balkan Peninsula, and Cyprus. In Turkey, on the inner slopes of the North Anatolian Mountains, on the northern borders of Western Anatolia (especially the Taurus Mountains), and in South Anatolia it establishes pure forests, or mixed forests with Turkish red pine, Scots pine, cedar, juniper, fir, beech, and oak taxa (Yaltırık and Efe 1994). According to the latest official statistics of the Republic of Turkey General Directorate of Forestry, about 19 % of the 22,740,297 hectares of forest areas in Turkey consist of black pine. Additionally, after Turkish red pine (*Pinus brutia* Ten.), it is the coniferous species with the second highest distribution in Turkey (Republic of Turkey General Directorate of Forestry 2019). It is also the most frequently planted species in Turkey after Turkish red pine (Acar *et al.* 2011). Black pine is of great importance for forestry and the forest products industry in Turkey due to its wide distribution area and good wood properties.

The population growth and technological developments emerging since the second half of the twentieth century have led to the establishment and expanding development of the forest products industry, resulting in the increased demand for wood raw material. Because large-diameter old trees in natural forests are not enough to meet the raw material needs, juvenile wood, made available in a short time by plantation forestry, has gained in importance. During the first years of the growth period of the trees (approximately 5 - 20 years), the texture of the wood extending from the pith to the exterior is defined as juvenile wood, whereas the part formed after the transition period is called mature wood (Arslan and Aydemir 2009). Juvenile wood differs from mature wood anatomically (Bao *et al.* 2001, Oluwafemi 2007), chemically (Bao *et al.* 2001, Yeh *et al.* 2006), and in terms of physical and mechanical properties (Bao *et al*. 2001, Passialis and Kiriazakos 2004, Pikk and Kasr 2006).

One of the most important differences between juvenile wood and mature wood is the higher angle of the cellulose microfibrils in the secondary wall S2 layer with the longitudinal axis of the cell (Lichtenegger *et al*. 1999, Deresse *et al*. 2003, Alteyrac *et al*. 2006). Microfibril angle plays a significant role in determining the mechanical properties of wood (Reiterer *et al*. 1999).

In coniferous trees, compared to mature wood, juvenile wood has higher lignin and extractive contents and lower cellulose content, tracheid length, cell wall thickness, density, and mechanical strength (Kretschmann 1998, Larson *et al*. 2001, Pikk and Kasr 2006, Yeh *et al*. 2006, Oluwafemi 2007, Bal *et al*. 2012).

Guler *et al*. (2007) studied the physical and mechanical properties of juvenile black pine planted in Düzce, and other studies have investigated the wood properties of mature black pine naturally grown in Dursunbey and Elekdağ (Göker 1969), and Yenice (Erten and Sözen 1994, Gündüz 1999). In addition, a number of studies have been carried out to determine the anatomical and chemical properties of black pine mature wood (Erten and İlter 1995, Ateş 2004, Hafızoğlu and Usta 2005, Sarıusta 2007) and juvenile wood (Akgül and Tozluoğlu 2009).

Guler *et al*. (2007) and Akgül and Tozluoğlu (2009) determined some characteristics of juvenile black pine wood; however, their studies did not mention the origins of the juvenile black pine trees that were planted in the Düzce region. In contrast, in our study, as well as finding regional differences, the tree origins were identified and compared. Thus, the aim was to reveal the origins of trees that can be planted in Kavaklıdere and similar growing environments in order to achieve superior wood properties.

Consequently, this study aimed to examine some chemical, anatomical, physical, and mechanical properties of wood from juvenile black pines of five different origins planted in Kavaklıdere – Muğla, Turkey, and to determine the best provenance in terms of wood properties.

MATERIAL AND METHODS

The wood samples of juvenile black pines (*Pinus nigra* Arn.) were obtained from the section numbered 242 belonging to the Sub-district Directorate of the Kavaklıdere Forest District Directorate under the Muğla Forest Regional Directorate. The pines of different origins were planted in 1993 as 0-2-year-old seedlings at a spacing distance of 2,50 m – 1,25 m. No pruning or thinning was carried out in the area until the trees were cut down. The slope of the field is over 30 %. Table 1 displays the characteristics of the study area from where the samples were taken.

Table 1: Characteristics of study area (Acar *et al*. 2019).

Location	Kavaklıdere – Muğla (Turkey)
Latitude	37º 22´ 38.6″ North
Longitude	28º 21´ 50.4″ East
Altitude	1230 m
Mean temperature*	15,42 °C
Average precipitation*	1165,20 mm
Soil type	loam / clay loam
Bedrock	limestone / phyllite
* Average value between 1993 and 2017	

For this study, pines of five origins were selected from among those of nineteen origins. These included those originating from Balıkesir, Bursa, Denizli, Kütahya, and Muğla (Fig. 1), which were chosen as representative of different parts of the Aegean Region and considering criteria such as the tree trunk flatness and diameter dimensions. A total of thirty juvenile black pines, consisting of six trees of each origin, were felled on 08 December 2016 in compliance with TS 4176 (TSE 1984). All felled trees were twenty-five years old. When selecting the trees, we made sure that they were normal and healthy in terms of trunk and crown formation, displayed natural wood color, had fibers parallel to each other that did not show curling, and finally, that they were not suffering from insect or fungal damage. Care was taken to ensure that the trees were representative of the region. Table 2 gives information about the origins of the juvenile black pines.

Table 2: Origin information of Black pine trees.

SS* National Code	**Origin Name**	**Average diameter (cm)**	**Regional Directorate**	**District Directorate**	**Series**	**Latitude/ Longitude**	**Altitude (m)**
70	Balıkesir	16,15	Balıkesir	Alaçam	Değirmeneğrek	39° 24′ 40″ / 28° 33′ 15″	1500
83	Bursa	14,50	Bursa	Mustafa Kemal Paşa	Burhandağı	39° 54′ 10″ / 28° 43′ 00″	1000
91	Denizli	14,90	Denizli	Denizli	Merkez	37° 40′ 50″ / 29° 04′ 20″	1250
94	Kütahya	13,60	Kütahya	Domaniç	Dereçarşamba	39° 51′ 30″ / 29° 29′ 00″	1400
369	Muğla	15,50	Muğla	Yılanlı	Yılanlı	37° 11′ 23″ / 28° 31′ 53″	1100

*SS: Seed Stan

For the physical and mechanical tests, logs were taken from the tree height of 2,00 m – 4,00 m. For chemical analyses, discs were obtained from the bottom, middle, and peak points of the logs. Discs were collected at chest height (about 1.30 m) of the logs for the anatomical measurements (Fig. 2).

The wood flour was obtained from the discs taken from the bottom, middle and peak sections according to TAPPI T 257 om-85 (TAPPI 1985), mixed homogeneously, and then mixed homogeneously for each origin separately. The main chemical components consisted of holocellulose (Wise and Karl 1962), α-cellulose (TAPPI T 203 os-71 (TAPPI 1975)), lignin (TAPPI T 222 om-88 (TAPPI 1988)), and ash (TAPPI T 211 om-93 (TAPPI 1993)). Solubility properties were then determined, including for alcohol-benzene (TAPPI T 204 cm-97 (TAPPI 1997)), 1% NaOH (TAPPI T 212 om-98 (TAPPI 1998)), and hot and cold water (TAPPI T 207 cm-93 (TAPPI 1993)).

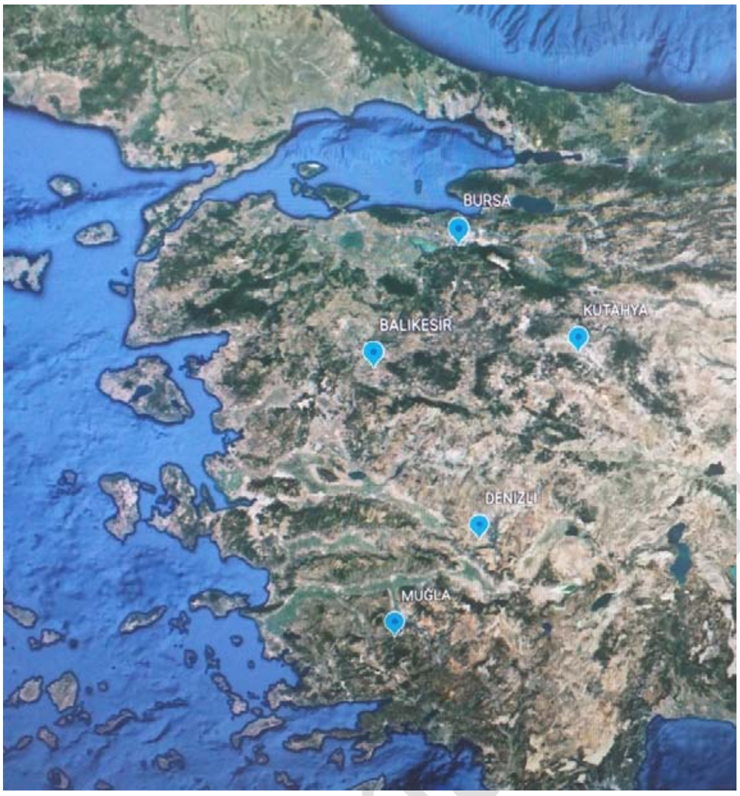

Figure 1: Map of origins of Black pine trees.

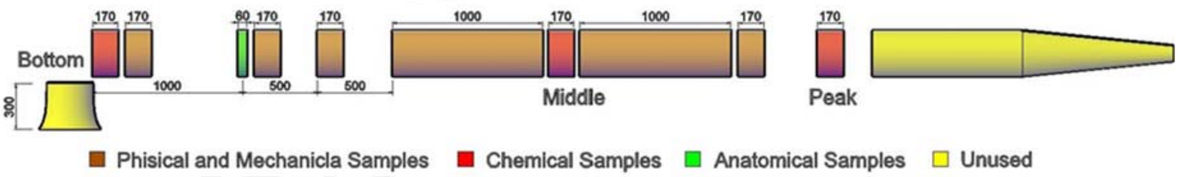

Figure 2: Scheme of sampling specimens from logs.

For anatomical measurements and amounts, the wood samples were boiled in distilled water and immersed in a solution containing equal amounts of alcohol-glycerin-distilled water. Sections taken using a sliding microtome were stained with safranin O made in continuous preparations (Gerçek 1984, Gerçek 1997, Merev 1998 - referring to Normand (1972), Merev 1998, Ives 2001). The Schultze method (potassium chlorate-nitric acid) was used for the maceration process. For the sample preparations the released wood elements were washed with distilled water, filtered, rinsed with alcohol, and stained with safranin O. Anatomical properties like tracheid length, tracheid width, tracheid cell-wall thickness, tracheid lumen width, number of tracheids per mm, ray cell height, and number of ray cells per mm were investigated.

To determine physical and mechanical properties, test samples were taken from the logs and discs according to TS 2470 (TSE 1976). In the cutting of the test samples, care was taken that no pith or wood defects were included. Physical properties were tested, including air-dry density, oven-dry density, volume-density (TS 2472 (TSE 1976)), shrinkage (TS 4083 (TSE 1983), TS 4085 (TSE 1983)), and swelling (TS 4084 (TSE 1983), TS 4086 (TSE 1983)) and mechanical properties such as bending strength (TS 2474 (TSE 1976)), modulus of elasticity (TS 2478 (TSE 1976)), and compression strength (TS 2595 (TSE 1977)).

The data obtained from the physical and mechanical tests, chemical analyses, and anatomical measurements and amounts were subjected to one-way analysis of variance (ANOVA). The Duncan's test was then performed to determine separate groups among the origins that differed according to the arithmetic means.

RESULTS AND DISCUSSION

The results of the arithmetic means and statistical analyses for the chemical properties of the juvenile black pine woods of different origins together with results of some previous studies on juvenile and mature black pine are displayed in Table 3. Significant differences were found in the main chemical compounds and solubility ratios of the wood samples obtained from juvenile black pines of different origins. The highest cellulose and lignin contents were in the wood of Balıkesir origin and the highest holocellulose content in that of Muğla origin. However, the lowest cellulose and lignin ratios were found in the samples of Muğla origin, and the lowest holocellulose ratio in those of Kütahya origin. Moreover, the Denizli origin samples stood out for their extractives content.

Table 3: Chemical properties of juvenile black pine of different origins.

Chemical Properties (%)		No. of Samples	Pr	Balıkesir	Bursa	Denizli	Kütahya	Muğla	JTW	MTW
Holocellulose		3	p<0,001	61,80±0,81 C	62,50±1,05 C	60,50±0,38 B	59,00±0,75 A	64,20±0,74 D	64,70	72,20
α-cellulose		3	p<0,001	37,30±0,06 C	35,00±0,13 A	35,10±0,06 A	36,60±0,10 B	34,90±0,24 A	35,50	-
Lignin		3	p<0,001	35,30±1,23 C	34,30±0,34 BC	33,80±0,72 B	35,20±0,18 C	26,00±0,71 A	33,00	28,50
Ash		3	p<0,05	0,62±0,02 B	0,68±0,07 B	0,71±0,12 B	0,55±0,07 AB	0,42±0,02 A	0,90	-
Solubility	Alcohol-benzene (2/1)	3	p<0,05	3,28±0,70 AB	4,00±0,62 BC	4,89±1,10 C	3,53±0,74 AB	2,68±0,76 A	2,51	6,07
	1% NaOH	3	p<0,001	18,40±0,68 B	20,50±0,91 C	22,80±0,62 D	18,80±0,85 B	15,60±0,34 A	19,00	12,20
	Hot water	3	p<0,001	3,53±0,52 A	4,85±0,09 B	5,09±0,46 B	4,44±0,36 B	3,20±0,24 A	2,25	4,71
	Cold water	3	p<0,01	1,41±0,25 A	3,22±0,30 D	2,29±0,41 C	2,21±0,39 BC	1,55±0,49 AB	3,88	-

JTW: Juvenile Tree Wood (Akgül and Tozluoğlu 2009), MTW: Mature Tree Wood (Usta 1993), ± indicates standard deviation. Values with the same letter are statistically the same at the 0,05 significance level (Duncan's test).

The cellulose and lignin contents of samples of all provenances except for Muğla were found to be compatible with the results for juvenile black pine obtained by Akgül and Tozluoğlu (2009). However, only the Muğla samples exhibited holocellulose contents similar to their results, with the samples of other origins found to be lower. Except for the cold-water solubility, the extractive contents of the wood of different origins in this study were generally found to be close to or higher than the results reported by Akgül and Tozluoğlu (2009).

When our juvenile pines of different origins were compared with mature black pine, it was determined that holocellulose (72,3 % – Usta 1993; 69,25 % – Erten and İlter 1995; 72,34 % – Ateş 2004; 72,57 % – Kılıç *et al*. 2010) and cellulose ratios (43,55 % – Ateş 2004; 46,80 % – Hafızoğlu and Usta 2005; 46,5 % – Kılıç *et al*. 2010) were lower and lignin rates (28,50 % – Usta 1993; 26,40 % – Ateş 2004; 27,90 % – Hafızoğlu and Usta 2005; 26,74 % – Kılıç *et al*. 2010) were higher, except for the Muğla samples. One notable finding in this study was that the lignin content of the Muğla origin sample was near to that of mature black pine. The extractive contents procured from mature black pine by Usta (1993), Ateş (2004), Hafızoğlu and Usta (2005), and Kılıç *et al*. (2010) were similar to or lower than those of the juvenile pine samples of different origins in this study.

Table 4 presents the arithmetic means and statistical analyses pertaining to anatomical features together with those of previous works on black pine. Except for tracheid cell wall thickness, significant differences were determined in the anatomical parameters of wood samples taken from the juvenile black pine of different origins.

Table 4: Anatomical properties of juvenile black pine of different origins.

Anatomical parameters	**No, of Samples**	**Pr**	**Balıkesir**	**Bursa**	**Denizli**	**Kütahya**	**Muğla**	**JTW**	**MTW**
Tracheid length (µm)	180	p<0,000	2678,95 ± 685,88 AB	2868,08± 691,10 C	2568,28± 611,40 A	2846,26± 621,17 C	2747,64± 621,49 BC	1120	3473,80
Tracheid width (µm)	180	p<0,010	40,74±9,43 A	40,64±8,40 A	42,92±8,96 B	41,46±7,98 AB	43,25±9,65 B	36,12	43,45
Tracheid lumen width (µm)	180	p<0,09	29,54±8,74 AB	28,84±8,77 A	31,14±9,09 BC	29,69±7,89 AB	31,74±9,28 C	26,23	27,75
Tracheid cell wall thickness (µm)	180	p<0,732	5,60±2,09 A	5,90±2,55 A	5,89±2,60 A	5,88±2,52 A	5,75±2,39 A	4,95	15,20
Ray cell height (µm)	180	p<0,000	185,07± 44,73 B	166,48± 37,10 A	172,38± 46,43A	167,45± 40,42 A	197,01± 51,63 C	-	176,10
Number of tracheids / mm²	180	p<0,048	811,67± 89,83 C	802,12± 96,30 AB	783,27± 98,71 A	787,80± 97,75 A	796,94± 105,21 AB	-	6156,60
Number of ray cells / mm	180	p<0,061	3,73±1,32 AB	3,53±0,93 A	3,85±1,06 B	3,78±1,10 B	3,81±1,16 B	-	4,60

JTW: Juvenile Tree Wood (Akgül and Tozluoğlu 2009), MTW: Mature Tree Wood (Sarıusta 2007), ± indicates standard deviation. Values with the same letter are statistically the same at the 0,05 significance level (Duncan's test).

The highest tracheid length was detected in the samples of Bursa origin, the highest tracheid width, tracheid lumen width, and ray cell height in those of Muğla origin, the maximum number of tracheids per mm^2 in those of Balıkesir origin, and the maximum number of ray cells per mm in those of Bursa origin. In contrast, the lowest tracheid length was found in samples of Balıkesir origin, the lowest tracheid width, tracheid lumen width, ray cell height, and minimum number of ray cells per mm in those of Bursa origin, and the minimum number of tracheids per mm^2 in those of Denizli origin.

It was observed that the tracheid length, tracheid width, and tracheid cell wall thickness values of the juvenile black pine from the origins in this study were higher than the values found by Akgül and Tozluoğlu (2009). İstek *et al*. (2010) stated that the tracheid fiber properties of black pine significantly improve until the age of 90. Passialis and Kiriazakos (2004) reported that the tracheid length of juvenile wood of naturally grown fir trees was shorter compared to mature wood. The tracheid length and width of mature black pine were respectively found by Ataç (2007) as 2390 and 42,00 µm and Ateş (2004) as 2770 µm and 40,60 µm. These values are close or lower than those of our juvenile wood of differing origins. Other studies of mature black pine (Göker 1969; Erten and İlter 1995) found higher tracheid length and width than in our juvenile pine. The lumen widths obtained from this study, when compared with mature black pine values in the literature, were determined to be similar (30,40 µm - Ataç 2009), higher (27,32 µm - Ateş 2004; 27,75 µm - Sarıusta 2007), or lower (41,50 µm - Erten and İlter 1995). Juvenile wood in our study showed values lower than the ray cell height (176,10 µm) and number of ray cells per mm (4,60) reported by Sarıusta (2007) for mature black pine. Göker (1969) determined 998 and 1030 tracheids per mm^2 for mature black pines grown in Dursunbey and Elekdağ, respectively. Gündüz (1999) published the number of tracheids per mm^2 as 1187 in Yenice mature black pine. These results were higher than the number of tracheids per mm^2 of the juvenile black pine in this study.

The arithmetic means and statistical analyses for the physical properties are displayed in Table 5. Other than for tangential shrinkage, longitudinal shrinkage, and longitudinal swelling, significant differences were detected in the physical properties of wood samples obtained from the juvenile black pine of different origins.

Table 5: Physical properties of juvenile black pine of different origins.

Physical properties	No. of Samples	Pr	Balıkesir	Bursa	Denizli	Kütahya	Muğla	JTW	MTW
Air-dry density (kg/m^3)	60	p<0,000	524 ±33 C	470 ±29 A	467 ±40 A	502 ±65 B	501 ±37 B	464	-
Oven-dry density (kg/m^3)	60	p<0,000	496 ±34 C	438 ±27 A	439 ±40 A	474 ±63 B	473 ±37 B	431	515
Volume-density (kg/m^3)	60	p<0,000	439 ±28 C	390 ±22 A	391 ±33 A	420 ±51 B	418 ±29 B	381	470
Tangential shrinkage (%)	60	p<0,088	6,32±0,64 A	6,24±0,88 A	6,00±0,68 A	5,99±1,01 A	6,34±1,24 A	7,78	6,67
Radial shrinkage (%)	60	p<0,000	4,10±0,82 C	3,70±0,53 AB	3,52±0,46 A	3,94±0,85 BC	3,87±0,56 BC	3,70	3,94
Longitudinal shrinkage (%)	60	p<0,364	0,44±0,38 A	0,51±0,30 A	0,51±0,26 A	0,44±0,26 A	0,43±0,29 A	-	-
Volumetric shrinkage (%)	60	p<0,07	10,56 ±1,01 B	10,18 ±1,06 AB	9,76 ±0,93 A	10,09 ±1,52 AB	10,35 ±1,40 B	11,50	10,35
Tangential swelling (%)	60	p<0,043	6,80±1,08 A	6,89±0,81 AB	6,67±0,76 A	6,78±1,05 A	7,17±0,91 B	6,19	7,20
Radial swelling (%)	60	p<0,000	4,87±0,72 B	4,25±0,53 A	4,29±0,63 A	4,66±0,96 B	4,70±0,63 B	4,04	4,11
Longitudinal swelling (%)	60	p<0,305	0,78±0,32 A	0,87±0,32 A	0,79±0,20 A	0,80±0,25 A	0,78±0,25 A	-	-
Volumetric swelling (%)	60	p<0,002	12,89 ±1,49 BC	12,40 ±1,07 AB	12,12 ±1,27 A	12,66 ±1,83 ABC	13,09 ±1,39 C	10,24	11,60

JTW: Juvenile Tree Wood (Guler *et al*. 2007), MTW: Mature Tree Wood (Erten and Sözen 1994), ± indicates standard deviation. Values with the same letter are statistically the same at the 0,05 significance level (Duncan's test).

The highest air-dry density, oven-dry density, volumetric density, radial shrinkage, volumetric shrinkage, and radial swelling were found in samples of Balıkesir origin and the highest tangential swelling and volumetric swelling were in those of Muğla origin, whereas the lowest air-dry density, radial shrinkage, volumetric shrinkage, tangential swelling, and volumetric swelling were in samples of Denizli origin and the lowest oven-dry density, volumetric-density, and radial swelling appeared in those of Bursa origin.

The density (air-dry and oven-dry) and volume density values reported by Guler *et al*. (2007) in juvenile black pine were lower than in the samples of Balıkesir, Muğla, and Kütahya origins, and close to those of Denizli and Bursa origins. In addition, the wood-water relation of the juvenile wood in this study indicated lower volumetric shrinkage and higher volumetric swelling compared to the values published by Guler *et al*. (2007) in juvenile black pine. Bal *et al*. (2012) stated that the density of juvenile Taurus cedar wood was lower than that of mature wood. Additional, Bao *et al*. (2001) reported that, except for loblolly pine and slash pine, the density of other mature woods of 10 tree species that grow naturally and in plantations was higher than in juvenile wood. Göker (1969) determined the densities of mature black pine (air-dry and oven-dry) grown in Dursunbey and Elekdağ as 560 kg/m^3 and 520 kg/m^3 and 550 kg/m^3 and 517 kg/m^3, respectively. Gündüz (1999) found the air-dry and oven-dry densities of the mature black pine in Yenice as 590 kg/m^3 and 540 kg/m^3. The densities of the juvenile wood samples in our study were distinctively lower than the values of Göker (1969) and Gündüz (1999). Although the shrinkages of our juvenile samples were lower than in the mature black pine in Dursunbey and Elekdağ (13,19 % and 12,50 % - Göker 1969), they were close to the values of mature black pine in some studies (10,35 % – Erten and Sözen 1994; 10,56 % – Gündüz 1999; 9,93 % – Döğdü 2006). Moreover, when comparing the swelling percentages, our juvenile samples demonstrated higher values than those of mature black pine (11,60 % – Erten and Sözen 1994; 11,31 % – Gündüz 1999; 10,42 % – Döğdü 2006).

It can be said that the densities of juvenile black pine of different origins were compatible with those found in the literature, although their swelling properties were not (Bao *et al*. 2001, Pikk and Kasr 2006, Bal *et al*. 2012). It was expected that the wood originating from Balıkesir, with the highest number of tracheids per mm^2, would also have the highest density.

The arithmetic means and statistical analyses of the mechanical properties are presented in Table 6. Significant differences were determined in the mechanical properties of wood samples taken from the juvenile black pine of different origins.

Table 6: Mechanical properties of juvenile black pine of different origins.

Mechanical properties	No. of Samples	Pr	Balıkesir	Bursa	Denizli	Kütahya	Muğla	JTW	MTW
Bending strength (MPa)	36	p<0,000	74,59±9,54 BC	71,11±9,21 B	66,12±8,12 A	72,57±14,75 B	78,01±9,89 C	79,01	119,91
Modulus of elasticity (MPa)	36	p<0,000	6756,07± 1559,50 B	6543,04± 1097,26 B	5666,02± 1290,83 A	6664,04± 1730,85 B	7571,68± 1430,39 C	-	7061,75
Compression strength (MPa)	36	p<0,000	47,79±8,31 C	43,57±4,89 B	36,38±5,24 A	45,49±8,71 BC	45,01±6,74 BC	42,4	56,93

JTW: Juvenile Tree Wood (Guler *et al*. 2007), MTW: Mature Tree Wood (Gündüz 1999), ± indicates standard deviation. Values with the same letter are statistically the same at the 0,05 significance level (Duncan's test).

The highest bending strength and elasticity module were seen in the samples of Muğla origin and the highest-pressure strength in those of Balıkesir origin, whereas the poorest mechanical properties were found in those of Denizli origin.

It was revealed that the bending strength of juvenile black pine reported by Guler *et al*. (2007) was similar to that of the wood of Muğla origin, but higher than the bending strength found for samples of the other origins. The compression strength was higher than in the wood of Denizli origin, close to the wood of Bursa origin, and lower than found in samples of the other origins.

Gündüz (1999) reported the bending strength of mature black pine grown in Yenice as 119,90 MPa and Göker (1969) reported bending strength in mature black pine in Dursunbey and Elekdağ as 107,50 MPa and 92,87 MPa, respectively. The bending strength reached in both studies was much higher than seen in our juvenile pine samples. However, the bending strength of mature black pine (61,85 MPa) found by Erten and Sözen (1994) was lower than in the juvenile black pine in this study. The elasticity module values (8995 MPa – 13242,30 MPa) determined in black pine wood samples taken from different altitudes and bedrocks in the Alaçam mountains by Sevgi *et al*. (2010) were higher than the values found in the juvenile black pine in our work.

The compression strength of the samples of Balıkesir, Kütahya, and Muğla origins were higher than in Göker's (1969) Dursunbey mature black pine (43,74 MPa) and close to that of Elekdağ mature black pine (46,97 MPa). In addition, the compression strength determined in Yenice mature black pine (56,93 MPa) by Gündüz (1999) was higher than found in the juvenile black pine in our study.

In general, juvenile wood has lower mechanical properties than mature wood (Bao *et al*. 2001, Passialis and Kiriazakos 2004, Pikk and Kasr 2006, Bal *et al*. 2012). Our results were similar to those in the literature.

CONCLUSIONS

The trees originating in Muğla and Balıkesir were superior in terms of wood properties, whereas no prominent features were exhibited by the trees of Bursa and Kütahya origins and those of Denizli origin yielded the lowest density and strength values.

Juvenile wood is not sufficient for the log and timber industry because its diameter and strength properties are lower than in mature wood. However, it is suitable for other industries where wood raw material is used. When the chemical, anatomical, physical, and mechanical wood properties of our juvenile black pine were considered in terms of their origins, all of them were found to be suitable for use in pulp and paper production and composite-board manufacturing. However, wood of Muğla origin was found to be best for pulp and paper production and that of Balıkesir origin for composite board manufacturing. Furthermore, only Muğla and Balıkesir origins were seen as the best sources for small-diameter poles suitable for usage as mine poles, telephone poles, and such.

Considering wood properties and areas of usage, the pines originating in the Muğla region were recommended for black pine plantations in Kavaklıdere and similar habitats. However, because of their good wood properties, it was understood that those of Balıkesir origin might be an alternative to the Muğla origin pines. Thus, the pines of Balıkesir origin were the second choice after those of Muğla origin for industrial black pine plantations. The proximity of Muğla to Kavaklıdere and the genetic characteristics of the pines originating in Balıkesir may have enabled the trees of these two provenances to exhibit better wood characteristics. On the other hand, the wood properties of the Bursa and Kütahya pines indicated no priority usage areas and the wood properties of the Denizli pine were prominently lower than for the wood of the other origins. Thus, black pines of Denizli, Bursa, and Kütahya origins were not recommended for industrial planting in Kavaklıdere or similar environments.

ACKNOWLEDGEMENTS

This study was supported by the Republic of Turkey General Directorate of Forestry with the project number 15.7101. The authors would like to thank the team of the project entitled "Provenance trials of Turkish black pine (*Pinus nigra* Arn. subsp. *nigra* var. *caramanica*) in Ege Region" and the staff of Kavaklıdere Forest District Directorate for the black pine seedling planting and maintenance. The authors would also like to thank Bilal Altun, the Forest Sub-district Director, for his contribution in the felling, barking, and transporting of trees to the laboratory.

REFERENCES

Acar, F.C.; Altun, Z.G.; Boza, A. 2011. Provenance trials of Turkish black pine (Pinus nigra Arn. subsp. nigra var. caramanica) in Ege Region: Fifteenth year results. Ege Forestry Research Institute, Technical Bulletin No: 50. İzmir, Turkey. (in Turkish). https://yayin.ogm.gov.tr/index.php?yay=443&secA=1

Acar, F.C.; Altun, Z.G.; Boza, A.; Örtel, E. 2019. Provenance trials of Turkish black pine (Pinus nigra Arn. subsp. nigra var. caramanica) in Ege Region: Twentieth- and twenty-fifth-year result. Ege Forestry Research Institute, Project Interim Report, 15.1704. İzmir, Turkey. (in Turkish, unpublished).

Akgül, M.; Tozluoglu, A. 2009. Some chemical and morphological properties of juvenile woods from beech (*Fagus orientalis* L.) and pine (*Pinus nigra* A.) plantations. *Trends Appl Sci Res* 4(2): 1-10. https://doi.org/10.3923/tasr.2009.116.125

Alteyrac, J.; Cloutier, A.; Zhang, S.Y. 2006. Characterization of juvenile wood to mature wood transition age in black spruce (*Picea mariana* (Mill.) B.S.P.) at different stand densities and sampling heights. *Wood Sci Technol* 40(2): 124–138. https://doi.org/10.1007/s00226-005-0047-4

Arslan, M.B.; Aydemir, D. 2009. Juvenile wood and its properties. *Journal of Bartin Faculty of Forestry* 11(16): 25-32. (in Turkish). https://dergipark.org.tr/tr/pub/barofd/issue/3398/46801

Ataç, Y. 2009. Examination of some softwood and hardwood trees in terms of paper properties of their sapwood and heartwood. Ph.D. Thesis, Bartın University, Bartın, Turkey (in Turkish). http://hdl.handle.net/11772/140

Ateş, S. 2004. Comparative regression models on experimental designing the kraft pulping conditions of Anatolian black pine *(Pinus nigra* Subsp. *pallasiana)* wood. Ph.D. Thesis, Karadeniz Technical University, Trabzon, Turkey (in Turkish).

Bal, B.C.; Bektaş, İ.; Kaymakçı, A. 2012. Some physical and mechanical properties of juvenile wood and mature wood of *Taurus cedar*. *KSU J Eng Sci* 15(2): 17-27. (in Turkish). http://jes.ksu.edu.tr/en/pub/issue/19361/205324

Bao, F.C.; Jiang, Z.H.; Jiang, X.M.; Lu, X.X.; Luo, X.Q.; Zhang, S.Y. 2001. Different in wood properties between juvenile wood and mature wood in 10 species grown in China. *Wood Sci Technol* 35(4): 363-375. http://dx.doi.org/10.1007/s002260100099

Deresse, T.; Shepard, R.K.; Shaler, S.M. 2003. Microfibril angle variation in red pine (*Pinus resinosa* Ait.) and its relation to the strength and stiffness of early juvenile wood. *Forest Prod J* 53(7): 34-40. https://www.proquest.com/docview/214638606/fulltextPDF/3460B7D09D6D4110PQ/1?accountid=17248

Döğdü, Y.C. 2006. Some technological properties of (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) and determining the kiln drying schedules. M.Sc. Thesis, Zonguldak Karaelmas University, Bartın, Turkey. (in Turkish).

Erten, A.P.; İlter, E. 1995. Studies on the determination of chemical components of Austrian pine *(Pinus nigra Arnold.) wood.* Turkish Forestry Research Institute, Technical Bulletin No: 250. Ankara, Turkey. (in Turkish). https://yayin.ogm.gov.tr/?yay=250&secA=1

Erten, P.; Sözen, R. 1994. Studies on the determination of some physical and mechanical properties of *Pinus pinea, Pinus nigra Arnold* and *Acer platanoides* wood. Central Anatolia Forestry Research institute, Technical Bulletin No: 266. Ankara, Turkey. (in Turkish). https://yayin.ogm.gov.tr/?yay=266&secA=1

Gerçek, Z. 1984. The interior morphological characteristics of [*Camellia sinensis* (L.) Kuntze] grown in Turkey and the effect of different growing conditions upon these characteristics. Ph.D. Thesis, Karadeniz University, Trabzon, Turkey. (in Turkish).

Gerçek, Z. 1997. *Doğu karadeniz bölgesindeki egzotik angiospermae (kapalı tohumlular) taksonlarının odun atlası*. Karadeniz Teknik Üniversitesi Basımevi. Trabzon, Turkey. (in Turkish).

Göker, Y. 1969. A study of some physical and mechanical properties and use possibilities of (*Pinus nigra* Arnl. var. *pallasiana*) from Elekdağ and Dursunbey. *J Fac For Istanbul U* 19(2): 91-135. (in Turkish).

Guler, C.; Çopur, Y.; Akgul M.; Buyuksari, Ü. 2007. Some chemical, physical and mechanical properties of juvenile wood from black pine (*Pinus nigra* Arnold) plantations. *J Appl Sci* 7(5): 755-758. https://doi.org/10.3923/jas.2007.755.758

Gündüz, G. 1999. Anatomic, technological and chemical properties of Camiyanı Black Pine *(Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana)*. Ph.D. Thesis, Zonguldak Karaelmas University, Bartın, Turkey. (in Turkish).

Hafızoğlu, H.; Usta, M. 2005. Chemical composition of coniferous wood species occurring in Turkey. *Holz Roh Werkst* 63(1): 83-85. https://doi.org/10.1007/s00107-004-0539-1

İstek, A.; Gülsoy, S.K.; Eroğlu, H. 2010. The comparison of fiber properties of sapwood and heartwood of black pine. In Proceedings of Third National Black Sea Forestry Congress, May 20-22. Artvin Çoruh University, Faculty of Forestry, Artvin, Turkey, pp: 1916-1924. (in Turkish).

Ives, E. 2001. *A guide to wood microtomy: making quality microslides of wood sections*. Ipswich, United Kingdom.

Kılıç, A.; Sarıusta, S.E.; Hafızoğlu, H. 2010. Chemical Structure of Compression Wood of *Pinus sylvestris*, *P. nigra* and *P. brutia*. *Journal of Bartin Faculty of Forestry* 12(18): 33-39. (in Turkish). https://dergipark.org.tr/tr/pub/barofd/issue/3396/46779

Kretschmann D.E. 1998. *Properties of juvenile wood. techline, properties and use of wood, composites, and fiber products*. United States Department of Agriculture, Forest Service, Forest Products Laboratory: Washington, DC, USA. https://www.fpl.fs.fed.us/documnts/techline/properties-of-juvenile-wood.pdf

Larson, P.R.; Kretschmann, D.E.; Clark, III.A.; Isebrands, J.G. 2001. *Formation and properties of juvenile wood in Southern pines: A synopsis*. Gen. Tech. Rep. FPL-GTR-129. U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, WI, USA. https://doi.org/10.2737/FPL-GTR-129

Lichtenegger, H.; Reiterer, A.; Stanzl-Tschegg, S.E.; Fratzl, P. 1999. Variation of cellulose microfibril angles in softwoods and hardwoods-a possible strategy of mechanical optimization. *J Struct Biol* 128(3): 257-269. https://doi.org/10.1006/jsbi.1999.4194

Merev, N. 1998. *Doğu karadeniz bölgesindeki doğal angiospermae taksonlarının odun anatomisi*. Karadeniz Teknik Üniversitesi Basımevi. Trabzon, Türkiye (in Turkish).

Oluwafemi, O.A. 2007. Wood properties and selection for rotation length in Caribbean pine (*Pinus caribaea* Morelet) grown in Afaka, Nigeria. *American-Eurasian J Agric Environ Sci* 2(4): 359-363. https://www.idosi.org/aejaes/aejaes2(4).htm

Passialis, C.; Kiriazakos, A. 2004. Juvenile and mature wood of naturally-grown fir trees. *Holz Roh Werkst* 62(6): 476-478. https://doi.org/10.1007/s00107-004-0525-7

Pikk, J.; Kask, R. 2006. Mechanical properties of juvenile wood of Scots pine (*Pinus sylvestris* L.) on Myrtillus forest site type. *Balt For* 10(1): 72-78. https://www.balticforestry.mi.lt/bf/index.php?option=com_content&view=article&catid=14&id=224

Reiterer, A.; Lichtenegger, H.; Tschegg, S.; Fratzl P. 1999. Experimental evidence for a mechanical function of the cellulose microfibril angle in wood cell walls. *Philos Mag A* 79(9): 2173-2184. https://doi.org/10.1080/01418619908210415

Republic of Turkey General Directorate of Forestry. 2019. Forestry statistics. (in Turkish). https://www.ogm.gov.tr/ekutuphane/Sayfalar/Istatistikler.aspx?RootFolder=%2Fekutuphane%2FIstatistikler%2FOrmanc%C4%B1l%C4%B1k%20%C4%B0statistikleri&FolderCTID=0x012000301D182F8CB9FC49963274E712A2DC00&View={4B3B693B-B532-4C7F-A2D0-732F715C89CC}

Sarıusta, S.E. 2007. Investigations on anatomical and chemical properties of reaction wood of *Pinus sylvestris* (L.), *Pinus nigra* (Arnold.) and *Pinus brutia* (Ten.). M.Sc. Thesis, Zonguldak Karaelmas University, Bartın, Turkey (in Turkish).

Sevgi, O.; Yılmaz, Y.; Carus, S.; Dündar, T.; Kavgacı, A.; Tecimen, H.B. 2010. Growth – nutrition models and wood technology of black pine forests in relation with altitude at Alaçam Mountains. Turkish Scientific and Technical Research Council Project Last Report, 1040551.

Ankara, Turkey (in Turkish). https://app.trdizin.gov.tr/publication/project/detail/TVRBMU1URXg=

TAPPI. 1975. TAPPI T 203 os-71: Alpha, beta and gamma cellulose in pulp. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1985. TAPPI T 257 cm-85: Sampling and preparing wood for analysis. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1988. TAPPI T 222 om-88: Acid-insoluble lignin in wood and pulp. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1993. TAPPI T 207 cm-93: Water solubility of wood and pulp. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1993. TAPPI T 211 om-93: Ash in wood and pulp. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1997. TAPPI T 204 cm-97: Solvent extractives of wood and pulp. TAPPI Press. Atlanta, Ga, USA.

TAPPI. 1998. TAPPI T 212 om-98: One percent sodium hydroxide solubility of wood and pulp. TAPPI Press. Atlanta, Ga, USA.

Türk Standardları Enstitüsü. 1976. TS 2470: Wood - sampling methods and general requirements for physical and mechanical tests. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1976. TS 2472: Wood - determination of density for physical and mechanical tests. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1976. TS 2474: Wood - determination of ultimate strength in static bending. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1976. TS 2478: Wood - determination of modulus of elasticity in static bending. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1977. TS 2595: Wood - determination of ultimate stress in compression parallel to grain. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1983. TS 4083: Wood - determination of radial and tangential shrinkage. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü, 1983. TS 4084: Wood - determination of radial and tangential swelling. Turkish Standarts Institution, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1983. TS 4085: Wood - determination of volumetric shrinkage. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü, 1983. TS 4086: Wood - determination of volumetric swelling. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Türk Standardları Enstitüsü. 1984. TS 4176: Wood - sampling sample trees and long for determination of physical and mechanical properties of wood in homogeneous stands. TSE, Ankara, Turkey (in Turkish). https://intweb.tse.org.tr

Usta, M. 1993. Comparing wood and bark constituents of endemic species. In Proceedings Second Forest Products Symposium, September 6-9. Karadeniz Technical University, Faculty of Forestry, ORENKO 93, Trabzon, Turkey, pp: 288-292. (in Turkish).

Wise, L.E.; Karl, H.L. 1962. *Cellulose and hemicellulose in pulp and paper science and technology*. McGraw Hill Book Co, New York.

Yaltırık, F.; Efe A. 1994. Dendroloji ders kitabı, gymnospermae-angiospermae. İstanbul Üniversitesi Yayınları. İstanbul, Türkiye (in Turkish).

Yeh, T.F.; Braun, J.L.; Goldfarb, B.; Chang, H.M.; Kadla, J.F.; 2006. Morphological and chemical variations between juvenile wood, mature wood, and compression wood of loblolly pine (*Pinus taeda* L.). *Holzforschung* 60(1): 1-8. https://doi.org/10.1515/HF.2006.001