Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2016) 40: 397-406
© TÜBİTAK
doi:10.3906/tar-1508-95

Effect of altitude and aspect on various wood properties of Oriental beech (*Fagus orientalis* Lipsky) wood

Elif TOPALOĞLU[1,*], Nurgül AY[2], Lokman ALTUN[3], Bedri SERDAR[3]
[1]Department of Architecture and Urban Planning, Technical Sciences Vocational School, Giresun University, Giresun, Turkey
[2]Department of Forest Industry Engineering, Faculty of Forestry, Karadeniz Technical University, Trabzon, Turkey
[3]Department of Forest Engineering, Faculty of Forestry, Karadeniz Technical University, Trabzon, Turkey

Received: 26.08.2015 • **Accepted/Published Online:** 01.02.2016 • **Final Version:** 18.05.2016

Abstract: In this study it was proposed to investigate the effect of altitude and aspect on anatomical properties, wood density, and mechanical properties of Oriental beech (*Fagus orientalis* Lipsky) growing in Sinop, Turkey. Five altitude steps (0–200, 200–400, 400–600, 600–800, and 800–1000 m) and two aspect groups (north and south) were created in the research area. A total of 20 trees were cut from each altitude step and the north and south aspects. To determine the anatomical properties of wood, permanent slides were prepared and Schultze's method was used for measurement of fibers. Wood density and mechanical properties were examined according to appropriate standards. As the altitude increased, the diameter of vessels narrowed, the number of vessels in 1 mm^2 increased, and the vessel length and fiber length decreased. It was determined that trees growing in the third altitude step (400–600 m) had the highest density values, and those in first altitude step (0–200 m) had the lowest density values. Additionally, most of the mechanical properties and hardness values of the wood were lowest in the first altitude step (0–200 m), while these values were highest in the third altitude step (400–600 m). When using categories of Oriental beech wood in the forest products industry, the altitude factor should be taken into consideration more than the aspect factor. Knowledge of anatomical, physical, and mechanical properties of Oriental beech wood according to altitude and aspect can be useful in forest products industry.

Key words: Altitude, aspect, Oriental beech, wood anatomy, wood density, wood mechanics

1. Introduction

Genetic, environmental, and anthropogenic factors affect the structure and properties of wood during the formation of wood cells and tissue (Wodzicki, 2001). Environmental factors can be classified as climatic factors (light intensity, temperature, air humidity, precipitation, and wind), physiographic factors (altitude, aspect, slope, and side slope), edaphic factors (soil characteristics), and biotic factors (humans, animals, plants, and microorganisms) (Cepel, 1995). As altitude increases, land area narrows and atmospheric pressure and air temperature decrease (Körner, 2007). Another physiographic factor of importance is the aspect, which particularly affects temperature and rainfall climate of the land. Beech forests spread a lot more on shaded aspects and on northern slopes of mountains during the vegetation season. For beech to grow in the most favorable conditions temperature should decrease by a certain amount and rainfall should increase. These conditions are associated with altitude. Oriental beech (*Fagus orientalis* Lipsky), starting in the West Balkans, stretches to Anatolia, the Caucasus, the north of the Elburz Mountains, and the Crimean peninsula in the north of the Black Sea region (Atalay, 1992). Beech wood has economic importance for Turkey today, it is hard and heavy, and it has a wide variety of usages. It is used for furniture, flooring, veneer, plywood, toys, packaging, tool handles, shoe heels, and impregnated railway sleepers. It is also used for mining poles and firewood (Bozkurt and Erdin, 1997). There are various studies in the literature about the effects of ecological factors on wood characteristics. The majority of these studies are associated with the altitude and the relationships among wood properties. Many researchers have determined that there is a significant relationship between wood anatomical properties and ecological factors, as has been reported for *Alnus nepalensis* by Noshiro et al. (1994), for *Rhododendron* by Noshiro et al. (1995), and for *Quercus pontica* by Yılmaz et al. (2008). It has been reported that there is no important relationship between the anatomical properties of wood and altitude for *Dodonaea viscosa* by Liu and Noshiro (2003), for the genus *Castanopsis* by Pande et al. (2005), and for *Buddleja cordata* by Aguilar-Rodriguez et al. (2006). Many studies

* Correspondence: elif.topaloglu@giresun.edu.tr

have focused on understanding the relationship between wood density and altitude. In particular, Govorcin et al. (2003) determined that wood density of *Fagus sylvatica* L. decreases with increasing altitude. For *Quercus pubescens* Barij et al. (2007) and for *Carpinus betulus* L. Kiaei (2011, 2012) determined that wood density increases with increasing altitude. Hernandez and Restrepo (1995) determined that there is no change in density of the wood with increasing altitude for *Alnus acuminata*. In the literature, there are very few studies regarding the effect of altitude on the mechanical properties of wood. Barij et al. (2007) found that the compression strength of *Quercus pubescens* Willd. increases with increasing altitude. Kahveci (2012) determined that bending strength, modulus of elasticity, compressive strength parallel to grain, and dynamic bending strength of *Alnus glutinosa* subsp. *barbata* (C.A.Mey.) Yalt. decreases with increasing altitude.

The aims of this study were to investigate the effects of altitude and aspect on the anatomical properties, wood density, and mechanical properties of Oriental beech wood, and to inform readers about appropriate use of Oriental beech growing in Sinop.

2. Materials and methods

2.1. Determination of research area and sample trees

The research area is located between 41°27′00″N and 42°05′33″N and between 34°46′37″E and 35°24′34″E in the Black Sea region of Turkey. Pure Oriental beech forests in this research area are spread between 50 and 1400 m in altitude. Soil texture class varies from sandy clay loam to clay loam. The mean annual precipitation and temperature of the research area are 680.2 mm and 13.9 °C, respectively. Climate data were provided by the Sinop meteorological station at 32 m a.s.l. and were collected for the 1975–2010 time period. Mean annual precipitation and temperature data for each altitude step were calculated in accordance with the Thornthwaite method (Cepel, 1995). Mean annual temperature for the first and fifth altitude steps is 13.7 °C and 9.2 °C, respectively. Mean annual precipitation for the first and fifth altitude steps is 700.9 and 1104.6 mm, respectively. More detailed information on the research area was described by Topaloğlu (2013). Altitude values determined at each study site of the research area were controlled by the value on the topographic map. According to this, the research area was divided into five altitude steps: 1 (0–200 m), 2 (200–400 m), 3 (400–600 m), 4 (600–800 m), and 5 (800–1000 m). A total of 20 study sites (5 altitude steps × 2 aspects × 2 study sites) were selected from every altitude step and from two different aspect groups (north aspect and south aspect). Sites were carefully chosen in such a way that they had normal frequency and closeness. A sample tree was selected from each study site for destructive sampling, representing the average diameter class. Sample trees were selected by avoiding extreme cases such as excessively knotty trees and the presence of reaction wood (International Organization for Standardization, 1982). From every altitude step and each aspect, a total of 20 trees were identified and numbered. The diameter at breast height of the sampled trees was measured and recorded before felling. Each tree was felled and the tree height was measured by cleaning off the branches. Details of the study sites and sample trees are given in Table 1.

2.2. Preparation of test samples

Each felled tree was destructively cut from 1.30, 2.30, and 4.30 m up the stem. For determination of wood density and anatomical properties, 15-cm-thick disks were taken at 1.30 m in height. Logs 2 m in length were taken from tree heights of 2.30 to 4.30 m and were used for the determination of the mechanical properties. Excluding samples that were used to determine the anatomical properties, all the prepared test specimens were conditioned in the conditioning room at 20 ± 2 °C and 65% relative humidity according to ISO 554 (International Organization for Standardization, 1976a).

2.3. Measurement of anatomical properties

For wood anatomical study, strips of 2 cm in width were cut from pith to bark at 1.30 m in height and according to aspect group (north and south directions) of each sample tree. Ten annual rings between the 40th and 50th annual rings of wood strips were used, depending on the age of the sampled tree. Wood samples of approximately 1 × 1 × 2 cm in size were cut, boiled in water, and sectioned using a microtome to a thickness of about 15–20 µm. Sections were stained with safranin before preparing permanent slides via various chemical processes. After staining, the sections were washed with distilled water and then washed with a solution of 50% alcohol. After this process, transversal and longitudinal tangential sections were converted into permanent slides in glycerol-gelatin (Ives, 2001). Wood samples were macerated using Schultze's method for determination of fiber properties (Bendre and Kumar, 2010). Anatomical properties measured were tangential and radial vessel diameter, vessel number per mm^2, ray number per mm, multiseriate ray height, multiseriate ray width, vessel length, fiber length and width, fiber lumen width, and fiber wall thickness. Twenty-five measurements or counts were performed for each anatomical property. Nomenclature was determined in accordance with microscopic terminology for hardwood identification (IAWA Committee on Nomenclature, 1989).

2.4. Measurement of wood density and mechanical properties

For wood density measurements 15-cm-thick disks that were taken at 1.30 m in height were used. Blocks

Table 1. Information related to study sites and sample trees.

Study site and sample tree numbers	Study site properties				Sample tree properties		
	Altitude (m)	Aspect (°)	Aspect group	Slope (%)	Diameter (cm) (at 1.30 m)	Height (m)	Age (at 1.30 m)
1	70	75	N	40	35.0	19.0	94
2	15	10	N	20	49.0	27.3	86
3	93	125	S	20	38.2	25.1	78
4	93	210	S	35	40.5	23.5	95
5	357	20	N	25	32.5	27.1	88
6	247	350	N	60	31.0	20.1	49
7	283	160	S	15	35.0	31.3	87
8	270	270	S	50	33.2	21.0	53
9	425	90	N	40	35.0	22.6	63
10	465	340	N	30	27.0	22.7	60
11	430	170	S	60	38.2	25.2	56
12	505	180	S	60	32.0	23.3	61
13	715	40	N	80	32.0	30.1	77
14	620	50	N	50	32.0	22.3	80
15	780	210	S	50	33.5	22.0	99
16	723	160	S	40	27.0	20.9	50
17	1010	310	N	25	42.0	25.4	86
18	960	90	N	50	35.0	28.8	84
19	995	280	S	15	37.5	27.5	75
20	910	170	S	50	28.5	25.5	101

were cut from disks. Small pieces (2 × 2 × 3 cm) were cut from blocks. Wood density at 12% moisture content was determined according to the principles of ISO 3131 (International Organization for Standardization, 1975a). Logs measuring 2 m in length taken from tree heights of 2.30 to 4.30 m were used to determine mechanical properties. From each log, 8-cm-thick boards were sawn. Afterwards, small and clear specimens were cut from the boards according to the relevant standards. Compression strength parallel to the grain, modulus of rupture, modulus of elasticity, impact bending (shock strength), shear strength (tangential and radial section), and Brinell hardness values (as per the transverse section, tangential section, and radial section) were investigated using a universal testing machine. Experiments were conducted according to the principles of ISO 3787 (International Organization for Standardization, 1976b), ISO 3133 (International Organization for Standardization, 1975b), ISO 3349 (International Organization for Standardization, 1975c), ISO 3348 (International Organization for Standardization, 1975d), ISO 3347 (International Organization for Standardization, 1976c), and ISO 3350 (International Organization for Standardization, 1975e). Thirty measurements were performed to determine wood density and each mechanical property.

2.5. Statistical analysis

Altitude steps were divided into five classes as 1 (0–200 m), 2 (200–400 m), 3 (400–600 m), 4 (600–800 m), and 5 (800–1000 m). Aspect groups were encoded as north (N) and south (S). A total of 10 groups were created as N1, N2, N3, N4, N5, S1, S2, S3, S4, and S5 for statistical analysis. SPSS was used and the data for each group were analyzed on the basis of the 95% confidence interval. Multiple analyses of variance were run to examine the effect of altitude and aspect on wood properties. Significant differences between altitude levels were determined by Duncan's homogeneity groups.

3. Results and discussion

3.1. Anatomical properties

The mean and standard deviation values of the anatomical properties are shown in Table 2. A maximum value of 54.05 µm and a minimum value of 41.20 µm for the tangential diameter of vessels were found in the first altitude step in

Table 2. Mean and standard deviation values of anatomical properties.

Anatomical properties	Mean and standard deviation values related to groups									
	1st altitude step (0–200 m)		2nd altitude step (200–400 m)		3rd altitude step (400–600 m)		4th altitude step (600–800 m)		5th altitude step (800–1000 m)	
	N1	S1	N2	S2	N3	S3	N4	S4	N5	S5
TVD	54.05 (8.86)[x]	50.48 (11.56)	51.84 (9.24)	47.34 (8.68)	48.77 (9.31)	43.34 (6.08)	44.41 (9.07)	49.62 (7.67)	44.41 (8.95)	41.20 (9.24)
RVD	65.26 (12.13)	59.26 (13.00)	60.62 (9.22)	52.26 (11.09)	57.19 (12.22)	48.62 (8.97)	50.98 (10.79)	55.33 (9.65)	53.83 (9.61)	49.76 (11.92)
VN	98 (7)	84 (14)	100 (8)	88 (16)	104 (14)	95 (14)	106 (11)	97 (14)	108 (13)	105 (17)
RN	5 (2)	7 (2)	6 (2)	7 (2)	6 (2)	6 (2)	5 (2)	5 (2)	6 (1)	5 (2)
MRH	608.00 (157.26)	604.52 (145.22)	661.90 (156.26)	665.38 (169.96)	618.43 (161.71)	589.45 (165.38)	454.12 (147.78)	676.10 (174.46)	488.60 (133.99)	568.00 (143.86)
MRW	53.61 (16.62)	55.64 (15.31)	50.14 (15.82)	61.73 (17.27)	50.72 (12.84)	53.03 (14.22)	46.37 (11.70)	58.54 (14.32)	57.96 (14.63)	51.87 (13.12)
VEL	616.40 (110.08)	619.88 (86.75)	588.87 (93.84)	565.98 (96.66)	560.47 (128.42)	563.37 (105.81)	567.14 (116.91)	575.25 (111.40)	554.97 (102.13)	594.38 (101.64)
FL	1278.79 (262.45)	1258.79 (222.45)	1296.51 (274.08)	1301.65 (257.49)	1289.08 (259.71)	1250.22 (194.50)	1222.22 (215.68)	1282.79 (249.35)	1148.51 (253.37)	1193.08 (196.97)
FW	17.21 (2.94)	17.42 (2.85)	18.85 (3.46)	18.78 (3.12)	18.28 (3.35)	17.35 (2.69)	17.78 (3.18)	16.85 (2.79)	18.71 (2.93)	19.64 (3.83)
FLW	5.28 (1.94)	4.71 (1.68)	5.28 (1.94)	5.28 (2.07)	5.00 (1.90)	4.36 (1.49)	4.57 (1.91)	4.42 (1.54)	6.14 (2.39)	6.14 (2.28)
FWT	5.96 (1.46)	6.35 (1.09)	6.78 (1.35)	6.75 (1.09)	6.64 (1.25)	6.50 (1.18)	6.60 (1.36)	6.21 (1.20)	6.28 (1.31)	6.75 (1.58)

TVD: Tangential vessel diameter (µm); RVD: radial vessel diameter (µm); VN: vessel number per mm^2; RN: ray number per mm; MRH: multiseriate ray height (µm); MRW: multiseriate ray width (µm); VEL: vessel length (µm); FL: fiber length (µm); FW: fiber width (µm); FLW: fiber lumen width (µm); FWT: fiber wall thickness (µm); N: north; S: south.
[x] Values in parentheses indicate standard deviations.

the north aspect and in the fifth altitude step in the south aspect, respectively (Table 2). The highest value of the radial diameter of vessels (65.26 µm) was determined in the first altitude in the north aspect, while the minimum value (48.62 µm) was determined in the third altitude step in the south aspect. The maximum vessel number in 1 mm^2 (108) was found in the fifth altitude step in the north aspect, while the minimum value (84) was found in the first altitude step in the south aspect. The maximum (676.10 µm) and minimum (454.12 µm) values for multiseriate ray height were found in the fourth altitude step in the south aspect and in the fourth altitude step in the north aspect, respectively. The maximum value for multiseriate ray width (61.73 µm) and the minimum value (46.37 µm) were found in the south and north aspects, respectively. The maximum (1301.65 µm) and minimum (1148.51 µm) values of fiber length were found in the second and fifth altitude steps, respectively. The highest value (619.88 µm) and the lowest value (554.97 µm) for vessel length were found in the first and fifth altitude steps, respectively. The maximum (19.64 µm) and the minimum (16.85 µm) values of fiber width were determined in the fifth and fourth altitude steps, respectively. The highest value (6.14 µm) and the lowest value (4.36 µm) of the fiber lumen width were determined in the fifth and third altitude steps, respectively. The maximum (6.78 µm) and the minimum (5.96 µm) values of fiber wall thickness were determined in the second and first altitude steps, respectively. According to the results of the multiple variance analysis, altitude and aspect had an effect on the tangential diameter of vessels, radial diameter of vessels, vessel number in 1 mm^2, ray number in 1 mm, and multiseriate ray height at the 95% confidence interval. Altitude had no effect on multiseriate ray width, while aspect did have an effect. Altitude affected fiber length, vessel length, fiber width, fiber lumen width, and fiber wall thickness while aspect had no effect. From these results, it can be concluded that altitude had more effect than aspect on the anatomical features of the Oriental beech wood growing in Sinop. Table 3 shows Duncan's homogeneity groups of anatomical properties.

According to Table 3, the first altitude step had the highest tangential and radial diameter of vessels, and the fifth altitude step had the lowest tangential and radial diameter of vessels. While the fifth altitude step had the highest vessel number in 1 mm^2, the first and second altitude steps had the lowest number. According to these results, as altitude increased, diameters of vessels were minimized and vessel number in 1 mm^2 increased. As altitude increased, air temperature for every 100 m of rise fell by 0.4–0.6 °C (Cepel, 1995). Depending on the drop in temperature, the water intake of the plants reduced and plants minimized the vessel diameters for the safety of water supply, because the low temperature of high altitudes hampered water intake (Carlquist, 1988). In the present study, it was determined that vessel number in 1 mm^2 increased as vessel diameters narrowed due to the increase in altitude. This result showed parallelism with the results of studies by Noshiro et al. (1994) for *Alnus nepalensis*, Noshiro et al. (1995) for *Rhododendron*, and Yılmaz et al. (2008) for *Quercus pontica*. Yaman (2008) found that while vessel diameters tend to decrease, the number of vessels per group tends to increase with increasing

Table 3. Duncan's homogeneity groups for anatomical properties.

Anatomical properties	Altitude steps	Mean	Anatomical properties	Altitude steps	Mean
TVD	5	42.80 a*	VEL	3	561.92 a
	3	46.05 b		4	571.20 a
	4	47.02 b		5	574.67 a
	2	49.59 c		2	577.43 a
	1	52.26 d		1	618.14 b
RVD	5	51.80 a	FL	5	1170.80 a
	3	52.91 a		4	1252.51 b
	4	53.16 a		1	1268.79 b
	2	56.44 b		3	1269.65 b
	1	62.26 c		2	1299.08 b
VN	1	91 a	FW	4	17.31 a
	2	94 a		1	17.31 a
	3	99 b		3	17.81 a
	4	101 b		2	18.81 b
	5	107 c		5	19.17 b
RN	4	5 a	FLW	4	4.50 a
	5	5 a		3	4.68 a
	2	6 b		1	5.00 ab
	3	6 b		2	5.28 b
	1	6 b		5	6.14 c
MRH	5	528.31 a	FWT	1	6.16 a
	4	565.11 ab		4	6.41 ab
	3	603.94 b		5	6.52 ab
	1	606.26 b		3	6.57 b
	2	663.64 c		2	6.77 b

* The letters indicate homogeneity groups.

altitude in *Juglans regia*. Moreover, Sanlı (1978) studied the relationship between ecological factors and anatomical properties of Oriental beech growing in different regions and altitudes in Turkey, and found that vessel number in 1 mm^2 increased with increasing altitude. In contrast to these results, Sarıbaş and Yaman (2009) indicated that diameters of the latewood vessels got higher from low altitudes to high altitudes during their xylological research on *Celtis australis* L. This situation could be related to the high altitudes which were more humid in the summer months due to a specific type of the Mediterranean climate. Additionally, Gerçek et al. (1998) determined that there was no relationship between tangential diameter of vessel and vessel number in 1 mm^2, and altitude, in their research on the ecological wood anatomy of *Ostrya carpinifolia* Scop in Turkey. Also, there was not a significant relationship between altitude and anatomical features of wood, as was reported for *Dodonaea viscosa* species by Liu and Noshiro (2003), for *Castanopsis* genus by Pande et al. (2005), and for *Buddleja cordata* species by Aguilar-Rodriguez et al. (2006).

In the present study, it was observed that while fiber length was in the same homogeneous group in the first, second, third, and fourth altitude steps, it decreased in the fifth altitude step. It was determined that the maximum value of vessel length was in the first altitude step, and the second, third, fourth, and fifth altitude steps were involved in the same homogeneity group. Furthermore, both vessel length and fiber length decreased as altitude increased. Similar results were reported by Gerçek et al. (1998) in *Ostrya carpinifolia* Scop., and Noshiro et al. (2010) in *Rhododendron arboreum*. Also, Noshiro et al. (1994) in *Alnus nepalensis* and Noshiro et al. (1995) in *Rhododendron* species found that altitude showed a negative correlation with vessel element length and fiber-tracheid length. However, Şanlı (1978) found no significant relationship between altitude and vessel length in *Fagus orientalis* Lipsky. Hosseini (2006) investigated the effect of altitude on juvenile wood formation and fiber length of *Fagus orientalis* L. growing at intermediate altitudes (500–1000 m) and high altitudes (1000–1500 m) in the Caspian forests of Iran. He found that a difference in altitude of about 500 m had no significant effect on fiber length or juvenile wood rate production in Iranian beech trees.

3.2. Wood density and mechanical properties

The mean and standard deviation values of wood density and mechanical properties are shown in Table 4. The highest (0.77 g/cm^3) and lowest (0.69 g/cm^3) values of wood density were found in the third altitude step in the south aspect and in the first altitude step in the north aspect, respectively (Table 4). The lowest (56.71 N/mm^2) and highest (69.06 N/mm^2) values of compression strength parallel to grain were determined in the first altitude step in the north aspect and in the third altitude step in the south aspect, respectively. The lowest (6.44 J/cm^2) and highest (12.26 J/cm^2) values of impact bending were determined in the first altitude step in the south aspect and in the second altitude step in the south aspect, respectively. However, the lowest (110.80 N/mm^2) and the highest (137.10 N/mm^2) values of modulus of rupture were found in the first and third altitude steps, respectively. The lowest (102.75×10^2 N/mm^2) and the highest (119.27×10^2 N/mm^2) values of modulus of elasticity were found in the first and third altitude steps, respectively. The lowest (9.44 N/mm^2) and the highest (10.33 N/mm^2) values of shear strength in the tangential section were determined in the fourth altitude step in the north aspect and in the first altitude step in the south aspect, respectively. The lowest (8.11 N/mm^2) and the highest (9.85 N/mm^2) values of shear strength in the radial section were determined in the first and second altitude steps, respectively. The minimum (56.70 N/mm^2) and maximum (68.11 N/mm^2) values of Brinell hardness in transverse-sections were determined in the first altitude step and the second altitude step, respectively. The minimum (27.66 N/mm^2) and maximum (37.17 N/mm^2) values of Brinell hardness in the tangential section were determined in the first altitude step and the fourth altitude step, respectively. The minimum (37.49 N/mm^2) and maximum (45.39 N/mm^2) values of Brinell hardness in the radial section were determined in the first altitude step and the third altitude step, respectively. According to the results of the multiple variance analysis, it was determined that both altitude and aspect had an effect on wood density, compression strength parallel to grain, impact bending, and shear strength in the tangential section. Only altitude had an effect on modulus of rupture, modulus of elasticity, shear strength in the radial section, and Brinell hardness values (as per the transverse-section and tangential and radial sections), while aspect had no effect at the 95% confidence interval. According to this, altitude had more effect than aspect on the mechanical properties of the Oriental beech wood growing in Sinop. Table 5 shows Duncan's homogeneity groups for wood density and mechanical properties.

According to Duncan's homogeneity groups, the highest and lowest wood density values were determined in the third altitude step and in the first altitude step, respectively (Table 5). According to this, while getting from the first altitude step to the second and third altitude steps, wood density values grew and reached their highest value in the third altitude step, but they decreased from the third altitude step to the fourth and fifth altitude steps. Sopushynskyy et al. (2005) studied the effects of growth factors on the amount of moisture and density of European beech (*Fagus sylvatica* L.). They determined that trees that grew between the elevations of 600 and 950

Table 4. Mean and standard deviation values of wood density and mechanical properties.

Wood properties		Mean and standard deviation values related to groups									
		1st altitude step (0–200 m)		2nd altitude step (200–400 m)		3rd altitude step (400–600 m)		4th altitude step (600–800 m)		5th altitude step (800–1000 m)	
		N1	S1	N2	S2	N3	S3	N4	S4	N5	S5
Wood density (g/cm^3)		0.69 (0.02)[x]	0.70 (0.04)	0.76 (0.02)	0.74 (0.01)	0.76 (0.03)	0.77 (0.02)	0.75 (0.02)	0.74 (0.04)	0.74 (0.02)	0.72 (0.03)
Compression strength (N/mm^2)		56.71 (4.43)	60.45 (3.82)	67.35 (7.50)	65.47 (2.12)	67.35 (7.56)	69.06 (4.68)	66.59 (3.79)	67.52 (3.32)	63.65 (4.72)	66.25 (7.17)
Modulus of rupture (N/mm^2)		110.80 (10.79)	113.82 (10.85)	122.35 (6.83)	122.36 (11.60)	137.10 (9.84)	132.74 (12.08)	122.58 (9.35)	122.11 (12.31)	117.45 (17.62)	119.17 (14.64)
Modulus of elasticity (N/mm^2) (×10^2)		103.58 (9.25)	102.75 (12.37)	111.63 (11.14)	112.11 (10.14)	119.27 (9.28)	117.02 (13.85)	103.66 (9.75)	111.01 (8.90)	103.59 (14.62)	104.52 (9.70)
Impact bending (J/cm^2)		7.86 (0.97)	6.44 (0.97)	11.75 (1.72)	12.26 (0.86)	10.76 (1.43)	9.55 (1.12)	9.70 (1.11)	9.41 (1.00)	9.10 (1.42)	8.96 (0.94)
Shear strength (N/mm^2)	Tangential section	9.90 (0.59)	10.33 (0.16)	10.20 (0.34)	10.27 (0.45)	9.96 (0.36)	10.01 (0.36)	9.44 (0.23)	9.98 (0.24)	9.55 (0.50)	9.53 (0.20)
	Radial section	8.23 (1.23)	8.11 (0.94)	9.85 (0.79)	8.85 (2.00)	9.02 (0.64)	9.03 (1.11)	9.03 (1.15)	8.61 (0.94)	8.13 (1.07)	9.22 (0.76)
Brinell hardness values (N/mm^2)	Transverse section	56.70 (5.94)	60.46 (7.43)	65.44 (5.57)	68.11 (10.40)	67.49 (9.03)	65.14 (9.14)	63.63 (5.01)	66.40 (7.09)	62.88 (5.45)	62.62 (6.24)
	Tangential section	30.36 (3.51)	27.66 (4.25)	31.24 (3.38)	33.81 (4.92)	35.87 (5.26)	35.90 (4.09)	34.81 (4.73)	37.17 (4.56)	33.45 (4.24)	30.35 (3.51)
	Radial section	37.49 (4.34)	38.18 (7.15)	40.37 (4.93)	43.27 (7.47)	45.39 (5.46)	42.94 (5.40)	42.61 (5.06)	44.49 (4.87)	40.98 (4.02)	39.39 (6.75)

N: North; S: south.

[x] Values in parentheses indicate standard deviation.

m had the highest density and moisture values due to the temperature and amount of precipitation between these elevations being the most appropriate for growth of *Fagus sylvatica*. Another reason for this result might be narrower vessel diameters in the third altitude step. Martinez-Cabrera et al. (2011) in Angiospermae determined that there was a negative relationship between vessel diameters and wood density. Denne and Hale (1999) observed that trees with lower mean density had thinner fiber walls and wider vessel lumens than those with higher mean density trees.

The lowest compression strength parallel to grain was found in the first altitude step and the highest value in the third altitude step. Wood density affects the mechanical properties of the wood. The results indicated that the change in wood density and compression strength of beech wood according to the altitude steps in Sinop was the same. According to Duncan's homogeneity groups, the lowest impact bending was in the first altitude step and the highest value was in the second altitude step. Berkel (1970) indicated that the high participation rate of the vessel, tracheid and parenchyma cells in leaved trees, and thin walls of the libriform fibers have a lowering effect on impact bending. In this study, it was found that fiber wall thickness of beech wood was lowest in the first altitude step and highest in the second altitude step. This fact explained the changing of impact bending in these altitude steps. Modulus of rupture increased from the first altitude step to the higher altitudes and reached its highest value in the third altitude step; thereafter, the value decreased as altitude increased. Modulus of elasticity increased with altitude; from its lowest value in the first altitude step, it continued to increase with altitude and reached its highest value in the third altitude step. The change in the modulus

Table 5. Duncan's homogeneity groups for wood density and mechanical properties.

Wood properties	Altitude steps	Mean	Wood properties		Altitude steps	Mean
Wood density	1	0.69 a*	Shear strength parallel to grain	Tangential section	5	9.54 a
	5	0.73 b			4	9.71 b
	4	0.74 c			3	9.99 c
	2	0.75 c			1	10.11 cd
	3	0.77 d			2	10.23 d
Compression strength	1	58.58 a		Radial section	1	8.17 a
	5	64.95 b			5	8.68 b
	2	66.41 bc			4	8.82 b
	4	67.05 c			3	9.03 bc
	3	68.21 c			2	9.35 c
Modulus of rupture	1	112.31 a	Brinell hardness values	Transverse section	1	58.58 a
	5	118.31 b			5	62.75 b
	4	122.35 b			4	65.01 bc
	2	122.36 b			3	66.32 c
	3	134.92 c			2	66.78 c
Modulus of elasticity	1	103.17 ($\times 10^2$) a		Tangential section	1	29.01 a
	5	104.05 ($\times 10^2$) a			5	31.90 b
	4	107.34 ($\times 10^2$) a			2	32.53 b
	2	111.87 ($\times 10^2$) b			3	35.89 c
	3	118.14 ($\times 10^2$) c			4	35.99 c
Impact bending	1	7.15 a		Radial section	1	37.84 a
	5	9.03 b			5	40.18 b
	4	9.56 c			2	41.82 bc
	3	10.15 d			4	43.55 cd
	2	12.00 e			3	44.16 d

* Letters indicate homogeneity groups.

of rupture and modulus of elasticity according to the altitude steps was parallel with the change in wood density values according to the altitude steps. Shear strength in the tangential section decreased from the first and second altitude steps in the same homogeneous group up to the higher altitudes. While the lowest shear strength value in the radial section was in the first altitude step, it increased with increasing altitude and reached the highest value in the second altitude step, and then it began to decrease with increasing altitude. As altitude increased, Brinell hardness in transverse-sections increased and reached its highest value in the second altitude step, where it began to decrease with increasing altitude. At first, hardness in the tangential section increased from the first altitude step up to the higher ones, and then it was observed that it decreased from the third altitude step and up to the subsequent ones. Hardness in radial sections increased from the first altitude step up to the higher ones, reached its highest value in the third altitude step, and then decreased as altitude increased. In general, it was observed that changes in hardness values according to altitude corresponded with changes in density values. Accordingly, it could be said that Brinell hardness values of beech wood growing in Sinop were associated with the density values of wood. Barij et al. (2007) indicated that wood density and compression strength of *Quercus pubescens* Willd. growing in Italy increased with increase in elevation. In Sinop, while altitude increased, vessel number in 1 mm^2 increased due to narrowing diameters of vessels. The change in mechanical properties according to altitude steps may be related to the change in anatomical properties. Indeed, Leclercq (1980) indicated that the fiber length had an important influence on the modulus of rupture, impact bending, and compression strength. Additionally, Sonderegger et al. (2008) in *Picea abies* (L.) Karst. determined that not only the density of the wood but also the microfibril angle and fiber length had an effect on modulus of rupture and modulus of elasticity. As a result, while altitude increased in Sinop, vessel number in 1 mm^2 increased due to decreasing vessel diameters of beech wood, and vessel and fiber length decreased. The altitude factor must be taken into account in this region for evaluating beech trees in the forest products industry as vessel diameters play an important role in wood impregnation, gluing, and processing properties. The highest density of trees was within the 400–600 m altitude step and the lowest density of trees was within the 0–200 m altitude steps. Additionally, many of the mechanical properties of the wood and the hardness values were lowest between 0 and 200 m and highest between 400 and 600 m, similarly to density values. Bowyer et al. (2007, p. 241) stated that "within any species there is considerable variation in clear wood strength, which corresponds to the variation in density and to the density-strength relationship for that property". Based on the results of this study, beech trees growing between altitudes of 400 and 600 m in Sinop should be preferred where high strength is required, such as in construction and lumber products.

3.3. Conclusions

In this study, effects of altitude and aspect on wood density and anatomical and mechanical properties of Oriental beech were investigated. Altitude had a strong effect on all wood properties except for multiseriate ray width, while aspect had a weak effect. As altitude increased, diameters of vessels narrowed, vessel number in 1 mm^2 increased, and vessel and fiber lengths decreased. Wood density and mechanical properties had minimum values in the first altitude step and maximum values in the third altitude step. Further research and sample trees are necessary to further interpret our results and to better explain the relationship between ecological factors and wood properties of Oriental beech.

Acknowledgements

The authors would like to thank the Scientific and Technological Research Council of Turkey (TÜBİTAK, Project No. TOVAG-107O752) for financial support and the personnel of the Sinop Forest Management Directorate for contributions in the land studies.

References

Aguilar-Rodriguez S, Terrazas T, Lopez-Mata L (2006). Anatomical wood variation of *Buddleja cordata* (Buddlejaceae) along its natural range in Mexico. Trees-Struct Funct 20: 253-261.

Atalay İ (1992). Kayın (*Fagus orientalis* Lipsky) Ormanlarının Ekolojisi ve Tohum Transferi Yönünden Bölgelere Ayrılması. Ankara, Turkey: Ministry of Forestry, Forest Trees and Seeds Breeding Research Directorate Publications (in Turkish).

Barij N, Stokes A, Bogaard T, Van Beek R (2007). Does growing on a slope affect tree xylem structure and water relations? Tree Physiol 27: 757-764.

Bendre AM, Kumar A (2010). A Text Book of Practical Botany - 1. 9th ed. Meerut, India: Rastogi Publications.

Berkel A (1970). Ağaç Malzeme Teknolojisi. İstanbul, Turkey: İstanbul University (in Turkish).

Bowyer JL, Shmulsky R, Haygreen JG (2007). Forest Products and Wood Science: An Introduction. 5th ed. Ames, IA, USA: Blackwell Publishing.

Bozkurt AY, Erdin N (1997). Ağaç Teknolojisi Ders Kitabı. İstanbul, Turkey: İstanbul University (in Turkish).

Carlquist S (1988). Comparative Wood Anatomy. London, UK: Springer-Verlag.

Cepel N (1995). Orman Ekolojisi. İstanbul, Turkey: İstanbul University (in Turkish).

Denne MP, Hale MD (1999). Cell wall and lumen percentages in relation to wood density of *Nothofagus nervosa*. IAWA Journal 20: 23-36.

Gerçek Z, Merev N, Anşin R, Özkan ZC, Terzioğlu S, Serdar B, Birtürk T (1998). Türkiye'deki Gürgen Yapraklı Kayacık (*Ostrya carpinifolia* Scop.)'nın Ekolojik Odun Anatomisi. In: Kasnak Meşesi ve Türkiye Florası Sempozyumu, İstanbul, Turkey, pp. 302-316 (in Turkish).

Govorcin S, Sinkovic T, Trajkovic J (2003). Some physical and mechanical properties of beech wood grown in Croatia. Wood Res-Slovakia 48: 39-52.

Hernandez RE, Restrepo G (1995). Natural variation in wood properties of *Alnus acuminata* H.B.K. grown in Colombia. Wood Fiber Sci 27: 41-48.

Hosseini SZ (2006). The effect of altitude on juvenile wood formation and fiber length, a case study in Iranian beech wood (*Fagus orientalis* L.). J Agric Sci Technol 8: 221-231.

IAWA Committee on Nomenclature (1989). IAWA list of microscopic features for hardwood identification. IAWA Bull 10: 219-332.

International Organization for Standardization (1975a). ISO 3131 Wood – determination of density for physical and mechanical tests. International Organization for Standardization. Switzerland.

International Organization for Standardization (1975b). ISO 3133. Wood – Determination of Ultimate Strength in Static Bending. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1975c). ISO 3349. Wood – Determination of Modulus of Elasticity in Static Bending. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1975d). ISO 3348. Wood – Determination of Impact Bending Strength. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1975e). ISO 3350. Wood – Determination of Static Hardness. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1976a). ISO 554. Standard Atmospheres for Conditioning and/or Testing: Specifications. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1976b). ISO 3787. Wood – Determination of Ultimate Stress in Compression Parallel to Grain. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1976c). ISO 3347. Wood – Determination of Ultimate Shearing Stress Parallel to Grain. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (1982). ISO 4471. Wood – Sampling Sample Trees and Logs for Determination of Physical and Mechanical Properties of Wood in Homogeneous Stands. Geneva, Switzerland: International Organization for Standardization.

Ives E (2001). A Guide to Wood Microtomy. Sproughton, UK: Nijhoff/Junk Publishers.

Kahveci E (2012). Farklı yetişme ortamı koşullarının sakallı kızılağaç (*Alnus glutinosa* subsp. *barbata* (C.A. Mey.) Yalt.) odununun bazı fiziksel ve mekanik özellikleri üzerine etkileri. MSc, Karadeniz Technical University, Trabzon, Turkey (in Turkish).

Kiaei M (2011). Basic density and fiber biometry properties of Hornbeam wood in three different altitudes at age 12. Middle-East Journal of Scientific Research 8: 663-668.

Kiaei M (2012). Effect of site and elevation on wood density and shrinkage and their relationships in *Carpinus betulus*. Forestry Studies in China 14: 229-234.

Körner C (2007). The use of 'altitude' in ecological research. Trends Ecol Evol 22: 569-574.

Leclercq A (1980). Relationship between beech wood anatomy and its physico-mechanical properties. IAWA Bulletin 1: 65-71.

Liu J, Noshiro S (2003). Lack of latitudinal trends in wood anatomy of *Dodonaea viscosa* (Sapindaceae), a species with a worldwide distribution. Am J Bot 90: 532-539.

Martinez-Cabrera HI, Schenk HJ, Cevallos-Ferriz SRS, Jones CS (2011). Integration of vessel traits, wood density, and height in angiosperm shrubs and trees. Am J Bot 98: 915-922.

Noshiro S, Ikeda H, Joshi L (2010). Distinct altitudinal trends in the wood structure of *Rhododendron arboreum* (Ericaceae) in Nepal. IAWA Journal 31: 443-456.

Noshiro S, Joshi L, Suzuki M (1994). Ecological wood anatomy of *Alnus nepalensis* (Betulaceae) in east Nepal. J Plant Res 107: 399-408.

Noshiro S, Suzuki M, Ohba H (1995). Ecological wood anatomy of Nepalese *Rhododendron* (Ericaceae). 1. Interspecific variation. J Plant Res 108: 1-9.

Pande PK, Chauhan L, Singh M (2005). Wood anatomical variations within the genus *Castanopsis*. J Trop For Sci 17: 366-371.

Şanlı I (1978). Doğu Kayını (*Fagus orientalis Lipsky*.)'nın Türkiye'de Çeşitli Yörelerde Oluşan Odunları Üzerinde Anatomik Araştırmalar. İstanbul, Turkey: İstanbul University (in Turkish).

Sarıbaş M, Yaman Ö (2009). Xylological study on hackberry (*Celtis australis* L.) growing naturally in Antalya-Kemer and Zonguldak-Devrek. Journal of the Bartın Faculty of Forestry 15: 1-15 (in Turkish with English abstract).

Sonderegger W, Mandallaz D, Niemz P (2008). An investigation of the influence of selected factors on the properties of spruce wood. Wood Sci Technol 42: 281-298.

Sopushynskyy I, Vintoniv I, Teischinger A, Michalak R (2005). The influence of site factors on wood density and moisture content of beech in the Ukrainian Carpathians. Wood Res-Slovakia 50: 43-49.

Topaloğlu E (2013). Doğu Kayını'nın (*Fagus orientalis* Lipsky.) odun özellikleri üzerine bazı yetişme ortamı koşullarının etkisi. PhD, Karadeniz Technical University, Trabzon, Turkey (in Turkish).

Wodzicki TJ (2001). Natural factors affecting wood structure. Wood Sci Technol 35: 5-26.

Yaman B (2008). Variation in quantitative vessel element features of *Juglans regia* wood in the western Black Sea Region of Turkey. Agrociencia 42: 357-365.

Yılmaz M, Serdar B, Altun L, Usta A (2008). Relationship between environmental variables and wood anatomy of *Quercus pontica* C. Koch (Fagaceae). Fresen Environ Bull 17: 902-910.