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EFFECT OF SPACING ON SOME MECHANICAL PROPERTIES OF NARROW LEAVED ASH (*Fraxinus angustifolia*) WOOD

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ABSTRACT

In this study, conducted to test the effect of spacing on wood quality; the effect of four different spacing types, applied in Adapazarı Süleymaniye plantation (Region 1; 3x2 m; Region 2; 3x2,5 m; Region 3; 3,75x3,75 m; Region 4; 4x4 m), on some mechanical properties of narrow leaved ash (*Fraxinus angustifolia*) have been studied. In the present study, some mechanical properties such as the compression strength parallel to grain, tensile stress perpendicular to grain, bending strength, impact bending strength and modulus of elasticity were determined. As a result, the ash wood, grown in region 4 with a wide range of planting, has high mechanical properties. However, when analyzed in terms of wood quality characteristics, it has been found that spacing in region 1 (2x3 m) is more suitable for applications of ash plantations.

Keywords: Bending strength, compression parallel, density, mechanical properties, modulus of elasticity, wood quality.

INTRODUCTION

Geographical spread of ash begins from South East Europe, and reaches to Turkey, Iran and Turkestan. This species is more common in different forest regions in our country. Süleymaniye Forest at the stuffed areas at the mouth of Sakarya River near Adapazarı and Çilinkoz Forest near Demirköy are the most beautiful forests of this type. They have been formed from the 1940s to the present day as a plantation forest (Sahin 2013).

Spacing is a determinative and important issue for the quality of the forest to be grown. Additionally, it determines the cost of plant and which industry the tree material is used in. Spacing also determines the degree that trees benefit from the habitat. Different spacing types have an impact on density and strength characteristics. In wide-spaced planting, density in young-leaved trees with ring vessels is at the maximum level, consequently the resistance properties increase. Density decreases in coniferous trees when spacing is applied. The fact that annual rings are large in the first years increases the portion of young wood. As young wood is of low density, it will cause a decrease in density depending on its presence in the material (Haygreen and Bowyer 1996).

Since the narrow-leaved ash (*Fraxinus angustifolia*) is a fast-growing species, and because of the industrial value of its wood; the interest in this species especially in European countries has greatly increased. Lately, studies on especially this species have gained momentum (Fraxigen 2005).

The common presence of ash (*Fraxinus excelsior*), which has an important place in forest trees in Europe, is seen as a great opportunity (Kerr 1995). Many European countries are intensively breeding this species in order to produce high quality timber. So, the concern for silviculture, breeding and gene conservation activities of ash has recently increased in many countries (Kerr 1995, Pliura 1999, Eriksson 2001, Kerr 2003, Fraxigen 2005).

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Although narrow-leaved ash is common throughout Europe, it is mostly neglected and rarely studied (Piotto and Piccini 1998). In this context, the effects of different spacing and culture care methods on the development of narrow-leaved ash (*Fraxinus angustifolia*) have been investigated (Carus and Çiçek 2007).

On the other hand, many studies have been conducted on "the effect of spacing on narrow-leaved ash plantations, soil properties, stand structures and silvicultural measures" in Süleymaniye region, it is highlighted that ash trees with tight spacing form better quality and smooth body structures (Çiçek and Yilmaz 2002, Çiçek 2004, Çiçek 2010).

In this study; the effects of four different spacing (3x2 m in Region 1; 3x2,5 m in the Region 2; 3,75x3,75 m in the Region 3 and 4x4 m in the Region 4) applied in Adapazarı Süleymaniye plantations in Turkey on some mechanical properties of narrow-leaved ash (*Fraxinus angustifolia*) wood are investigated.

MATERIALS AND METHODS

Sample Tree Selection and Acquisition of the Sections

In the selection of the experiment field and experiment trees of narrow-leaved ash (*Fraxinus angustifolia* Vahl.), TS 4176 (1984) standard is used as a base. For the specified purpose, the spacing of 4x4 m; 3,70x3,70 m; 3x2,5 m; 3x2 m were determined in Adapazarı-Süleymaniye region, and 4 pieces of sample trees, corresponding to the average breast diameter that represents each group, having no cracks and showing no abnormal peak forms, have been cut with a chainsaw.

Preparation of Test Samples

Two cm wide strips were cut in North-South and East-West directions from the 15 cm sections taken from sample trees and cross-sectional samples were determined by drawing 2 cm lines on these strips. Air-dry density samples of 20 x 20 x 30 mm were prepared by determining in 30 mm sections parallel to the fibers. It was taken into consideration that the samples did not contain defects such as cracks, knots and so on. The defective samples were replaced with new ones.

Determination of air dry density has been made by TS 2472 (1976). Of the mechanical properties; experiments of compression strength parallel to grain were conducted in accordance with TS 2595 (1977), bending strength in accordance with TS 2474 (1976) principles, modulus of elasticity on bending in accordance with TS 2478 (1978) principles, impact bending strength in accordance with TS 2477 (1976) principles, tensile strength perpendicular to grain in accordance with TS 2476 (1976) standard. Some mechanical strength test was given in Figure 1. Additionally, quality value of compression strength parallel to grain, bending quality and robustness and impact bending strength quality value were also calculated. Statistical evaluation was performed with SPSS software.

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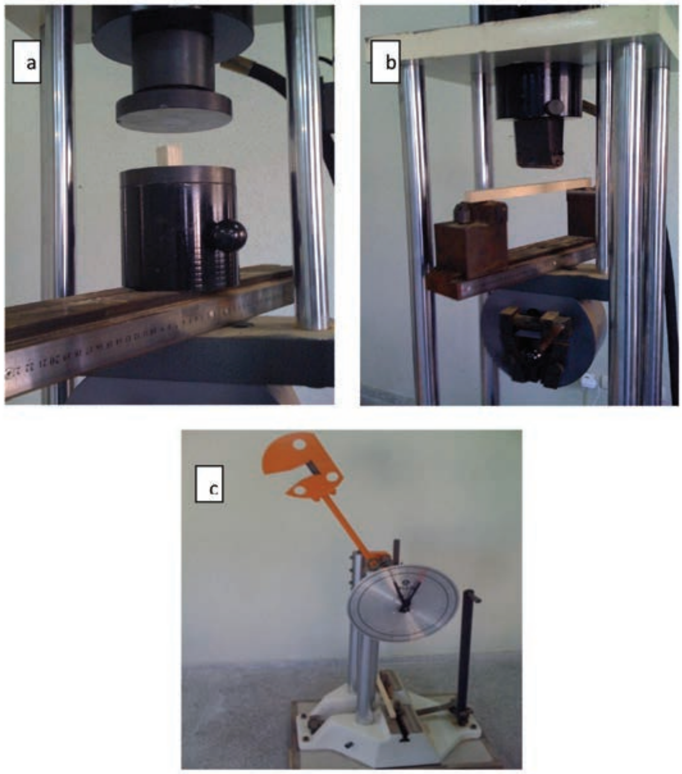

Figure 1. (a) Compression strength parallel to grain, (b) bending strength and (c) impact bending strength testing.

RESULTS AND DISCUSSION

Air-Dry Density

Air-dry density values were calculated on 374 samples from four experiment sites. Air-dry density values and statistical evaluation results calculated from narrow-leaved ash (*Fraxinus angustifolia*) samples taken from 4 different spacing are shown in Table 1. Differences in the arithmetic average were detected, in order to determine which factor caused this difference, a variance analysis was performed.

Table 1. Air-dry density values (kg/m^3).

Regions	N	X*	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value**
1	96	679 *b*	23	2,12	111	632	743		
2	88	691 *a*	35	4,35	152	635	787		
3	96	724 *a*	62	6,23	202	606	808	72,2	0,001
4	94	759 *c*	32	3,61	156	665	821		
Avg.	93,5	713	51	3,09	223	601	824		

* Means within each column followed by the same latter are not significantly different. ** p<0,05; Region 1; 3x2 m, 2; 3x2,5 m, 3; 3,7x3,7 m; 4; 4x4 m; N: Number of samples, X: Average value, S: Standard deviation, S^2: Variance, R: The difference between maximum value and minimum value, X_{min}: Minimum value, X_{max}: Maximum value, Avg: Overall average.

According to the results of variance analysis, differences between regions were statistically significant at 0,001 confidence level. Then, according to the Duncan test, given in Table 1, a significant different was not found between region 3 and region 2 in terms of air-dry density. The trees growing in regions 1 and 4 not only differ statistically from each other but also from those grown in regions 3 and 2.

Average air-dry density was found as 679 kg/m^3 in region 1 (3x2 m), 691 kg/m^3 in region 2 (3x2,5 m); 724 kg/m^3 in region 3 (3,7x3,7 m) and 759 kg/m^3 in region 4 (4x4 m). Region 4, with the largest spacing, belongs to the group of trees with having the highest air-dry density of all the other regions. The overall average was found to be 713 kg/m^3. These results are in agreement with those of previous studies using similar wood types (Yalcin and Sahin 2015, Govorcin *et al.* 2009, Forest Product Laboratory 2010). In wide-spacing, density is maximum in trees with ring vessels, thus, their resistance properties increase (Haygreen and Bowyer 1996, Bozkurt and Erdin 1997).

According to Bozkurt and Erdin (1990), classification of air-dry density is listed as; very light trees <290 kg/m^3, light trees 300-490 kg/m^3, medium weight trees 500-690 kg/m^3, heavy trees 700-990 kg/m^3 and very heavy trees >1000 kg/m^3. Air-dry density values and classes are shown in table 2 of according to spacing. The overall average of narrow-leaved ash belongs to the group of ‘’heavy’’ trees.

Table 2. Air-dry density values and classes according to spacing.

Species	Regions	D_{12} (kg/m^3)	Class of air-dry density
F. angustifolia Vahl.	1	679	medium
	2	691	medium
	3	724	heavy
	4	759	heavy
	Avg.	713	heavy

D_{12}: Air-dry density (kg/m^3).

Compression Strength Parallel to Grain

Descriptive data on compression strength parallel to grain (MPa) is given in Table 3. Furthermore, whether there was a significant difference between regions was tested by analysis of variance; in the event of a difference, which group or groups it arose from was determined by the Duncan test. The statistical evaluation results for these are given in Table 3.

Table 3. Values of compression strength parallel to grain (MPa).

Regions	N	X	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value*
1	60	58,6 *a*	5,43	29,57	30,7	42,7	73,5	11,3	0,001
2	60	57,4 *a*	3,97	15,76	19,2	48,1	67,3		
3	60	56,5 *a*	8,02	64,31	37,7	38,2	75,9		
4	54	62,7 *b*	6,11	37,28	27,2	47,2	74,4		
Avg.	58,5	58,8	5,88	36,73	28,7	44,0	72,8		

*p<0,05.

According to the results of the Duncan test given in Table 3, there is not a statistically significant difference between region 1, region 2 and region 3 in terms of compression strength parallel to grain, while there is no statistically significant difference between regions 2 and 3, however, it was found different from these three groups in region 4. In terms of spacing of compression strength parallel to grain values, they are 58,643; 57,41; 56,53; 62,7 MPa respectively. Compression strength was found maximum (62,7 MPa) in region 4 (4x4 m), and minimum (56,53 MPa) in region 3 (3,7x3,7 m). In wide spacing of trees with ring vessels; high resistance properties are considered normal and the resistance properties increase as a result of density increase (Haygreen and Bowyer 1996, Bozkurt and Erdin 1997).

According to Bozkurt and Erdin (1990); classes of compression strength parallel to grain are listed as < 20 MPa very small, 20-35 MPa small, medium 35-55 MPa, 55-85 MPa high and > 85 MPa very high. Average compression strength among the regions was found to be 58,8 MPa. According to this, narrow leaved ash belongs to the group of trees with a high compression strength parallel to grain (55–85 MPa). Region 4, with the largest spacing, belongs to the group of trees with "high" compression strength having the highest compression strength of all the other regions. Compression strength parallel to grain and its classification is given in Table 4.

Table 4. Values of compression strength parallel to grain and its classes for some species of trees.

Tree species	Compression strength parallel to grain (MPa)	Classes of compression strength	Literature
Ash	48,6	medium	Govorcin *et al.* 2009
White ash (*F. americana*)	51,1	medium	Forest Product Laboratory 2010
Pine (*Pinus eldarica*)	52,2	medium	Kiaei 2011
Eastern beech (*Fagus orientalis*)	60,6	high	Bektas *et al.* 2002
Eucalyptus grandis	60	high	Bal and Bektas 2013
Common ash (*F. excelsior*)	63,6		Mozina 1969

The overall average of compression strength of narrow leaved ash is 58,8 MPa. With this value; its compression strength parallel to grain is higher than white ash, pine and ash but lower than those of common ash, beech and eucalyptus.

Values of Compression Strength Parallel to Grain

Static quality values of compression strength parallel to grain are given in Figure 2. Static quality values found by values of compression strength parallel to grain and air-dry density are 8,6 in region 1; 8,3 in region 2; 7,86 in region 3 and 8,25 in region 4 respectively. Bozkurt and Erdin (1997) states that when the static quality value for hardwood is <6, it has a "low" quality, when it is between 6,5-7,5; it has a "medium" quality, and when it is > 7,5; it has a "good" quality.

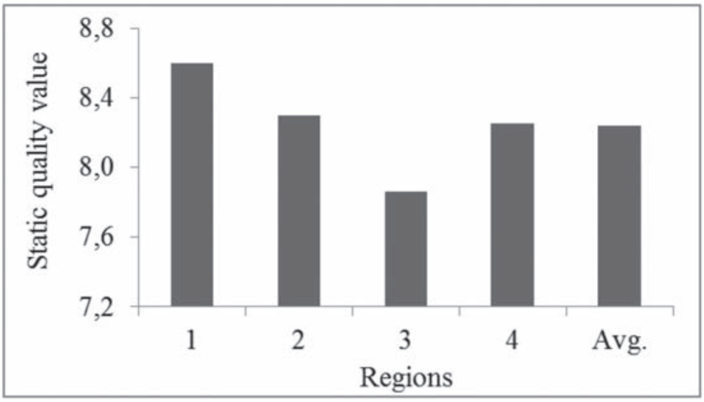

Figure 2. Compression strength static quality values for Fraxinus angustifolia.

Overall average of compression strength static quality value of narrow leaved ash was found to be 8,24. According to this classification; the overall average for narrow-leaved ash and the entire region belong to the "good" quality group. Static quality values are given for some species of trees in table 5.

Table 5. Static quality values of some tree species.

Tree species	St.	Literature
Narrow leaved ash (*F. oxycarpa*)	7,6	Bozkurt and Göker 1996
Maple (*Acer trautvetteri*)	7,93	Büyüksarı 2006
Taurus cedar (*Cedrus libani*)	8,6	Bozkurt and Göker 1996
Alder	8,78	Güller and Ay 2001
Common ash (*F. excelsior*)	8,9	Gürsu 1971
Oriental beech (*Fagus orientalis*)	11,5	Bozkurt and Göker 1996

According to the general average; the quality value of narrow-leaved ash was found 8,24. Based on these results; the static quality value of beech-bodied maple is higher than that of sharp fruity ashen, but lower than those of Taurus cedar, common ash and Eastern beech.

Bending Strength

Descriptive statistics of values of bending strength are given in Table 6. There is no statistically significant difference between regions 2 and 3, however, average bending strength was found 117,1 MPa in region 1; 109,6 MPa in region 2; 105,7 MPa in region 3 and 130,3 MPa in region 4. Bending strength is maximum (130,3 MPa) in region 4 and minimum (105,7 MPa) in region 3. The overall average of narrow leaved ash samples is 115,7 MPa. Reason for obtaining a high resistance in the region 4 is the fact that wide spacing increase density in trees with ring vessels.

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Table 6. Bending strength values (MPa).

Regions	N	X	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value*
1	35	117,1 *b*	10,5	110	43,6	88,4	132	33,3	0,001
2	35	109,6 *a*	10,4	107	44,6	81,4	126		
3	35	105,7 *a*	12,6	158	47,1	82,8	130		
4	35	130,3 *c*	10,9	120	44,9	108	153		
Avg.	35	115,7	11,1	124	45,1	90,3	135		

*p<0,05.

According to Bozkurt and Erdin (1990); classes of bending strength are listed as <50 MPa "very small", 50-85 MPa "small", 85-120 MPa "medium" , 120-175 MPa "high" and > 175 MPa "very high". The overall average of bending strength of narrow-leaved ash samples is 115,7 MPa. According to this, in terms of the overall average of bending strength of narrow-leaved ash; there is no statistically significant difference between regions 2 and 3, however, belongs to the group of trees with "medium" values (85–120 MPa). Of these regions, region 4 is placed under the group with "high" bending strength with a value of 130,3 MPa. Bending strengths and their classes are given for some tree species in Table 7.

Table 7. Bending strengths and their classes of some tree species.

Tree species	Bending strength (MPa)	Classes of bending strength	Literature
Eucalyptus grandis	100	medium	Bal and Bektas 2013
Yunnan Pine	100,8	medium	Zhang 1997
Ash	103,7	medium	Govorcin *et al.* 2009
White ash (*F. oxycarpa*)	103	medium	Forest Product Laboratory 2010
Common Ash (*F. excelsior*)	116	medium	Niemz *et al*. 2014
Eastern beech	120,4	medium	Bektas *et al.* 2002
Ash	135,1	high	Tankut *et al.* 2014

The overall average of bending strength of narrow-leaved ash samples is 115,66 MPa. According to this result, the bending strength of narrow-leaved ash is higher than those of eucalyptus, pine, white ash and ash; but lower than those of ash, beech and common ash. It is understood that the wood of narrow-leaved ash, having a "medium" general bending strength can be used in furniture, sports equipment, bridges and joists.

Quality and Strength in Bending

Values of bending quality and quality results are given in Figure 3. Average quality in bending was found 17,2 in region 1; 15,9 in region 2; 14,6 in region 3 and 17,1 in region 4. According to Bozkurt and Erdin (1990); classes of bending quality are listed as 10-15 "low", 15-20 "medium", 20-25 "high".

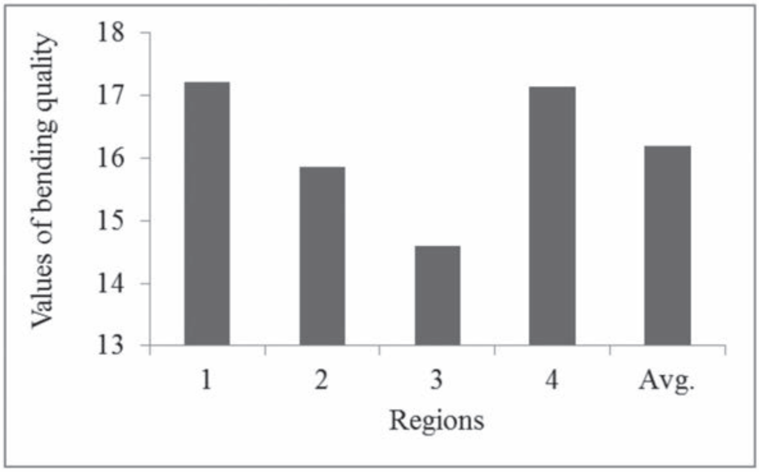

Figure 3. Values of bending quality and results for *Fraxinus angustifolia.*

Quality in bending was maximum in region 1 and minimum in region 3. The overall average quality in bending was found 16,2. Value of quality in bending was found "medium" (15-20) in all regions and for the overall average.

Classes of bending strength values are listed as <2 "low", 2-3 "medium", 3-4 "very high" (Bozkurt 1986). Bending strength values and classification of samples are given in Table 8.

Table 8. Bending strength values and their classes.

Regions	Values of bending strength	Classes of bending strength
1	2,00	medium
2	1,90	low
3	1,86	low
4	2,07	medium
Avg.	1,95	low

Overall average of bending strength is 1,95; and it belongs to the class of "low" (1-2) strength. Strength in bending was highest in region 4 and lowest in region 3. Region 4, with a bending strength of 2,07; is in the "medium" (2-3) strength group. In addition to this, region 1, with a bending strength of 2,00 is both higher than the average and in the "middle" class.

Modulus of Elasticity

Descriptive statistics of modulus of elasticity are shown in Table 9. According to the results of the Duncan test, there is not a statistically significant difference between region 1, region 2 and region 3 in terms of modulus of elasticity, while there is no statistically significant difference between regions 2 and 3, however, it was found different from these three groups in region 4.

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Table 9. Modulus of elasticity values (MPa).

Regions	N	X	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value*
1	35	9601 *a*	1746	3046918	5113	6838	11952	15,9	0,001
2	35	9556 *a*	1390	1932463	4866	7093	11958		
3	35	8847 *a*	1224	1498161	4819	7038	11857		
4	35	11502 *b*	2224	4945260	8531	7798	16329		
Avg.	35	9877	1646	2855701	5832	7192	13024		

*p<0,05.

Overall average of modulus of elasticity was 9601 MPa in region 1; 9556 MPa in region 2; 8847 MPa in region 3 and 11502 MPa in region 4. Modulus of elasticity was highest in region 4 (11502 MPa) and lowest in region 3 (8847 MPa).

According to Bozkurt and Erdin (1990); classes of modulus of elasticity are defined as <6000 MPa “very small”, 6000–10000 MPa “small”, 10000–13000 MPa “medium”, 13000–16000 MPa “high” and >16000 MPa “very high”. The overall average of modulus of elasticity of narrow leaved ash was found 9877 MPa. Narrow leaved ash belongs to group of trees with a “small” overall average of modulus of elasticity (6000–10000 MPa). The sample results of the modulus of elasticity taken from region 4, whose spacing is larger than those of others, are the highest and belongs to the group of “medium” degree trees. Modulus of elasticity and their classification for some tree species were shown in Table 10.

Table 10. Modulus of elasticity and its classes for some tree species.

Tree species	Modulus of elasticity (MPa)	Classes of modulus of elasticity	Literature
Alder	8781	small	Güller and Ay 2001
Maple	9400	small	Bozkurt and Erdin 1997
Eucalyptus grandis	10074	medium	Bal and Bektas 2013
Maple (*Acer trautvetteri*)	10850	medium	Büyüksarı 2006
White ash	12000	medium	Forest Product Laboratory 2010
Common ash (*F. excelsior*)	12623	medium	Niemz *et al*. 2014
Ash	15656	high	Tankut *et al.* 2014

Overall average modulus of elasticity in bending (9877 MPa); is higher than those of maple and alder, but lower than those of beech-bodied maple, eucalyptus, ash, white and common ash.

Impact Bending Strength

Descriptive statistics of impact bending strength are shown in Table 11. According to Duncan test results given in Table 11, in terms of impact bending strength; There is no statistically significant difference between regions 2 and 3, however, overall average impact bending strength was 91,8 J/m in region 1; 72,7 J/m in region 2; 64,9 J/m in region 3; and 133,1 J/m in region 4.

Table 11. Values of impact bending strength (J/m).

Regions	N	X	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value*
1	40	91,8 *b*	20,2	47	108,7	32,3	141	78,2	0,001
2	40	72,7 *a*	14,4	25	64,9	33,1	98		
3	40	64,9 *a*	20,7	46	81,5	28,5	110		
4	40	133,1 *c*	31,5	98	150,7	45,3	196		
Avg.	40	90,6	21,6	51	100,1	35,9	136		

*$p<0,05$.

According to the results obtained, impact bending strength was highest in region 4 with a value of 133,1 J/m; and lowest in region 3 with a value of 64,9 J/m.

According to Bozkurt and Erdin (1990); classes of impact bending strength are listed as <30 J/m "very small", 30–45 J/m "small", 45–60 J/m "medium", 60–90 J/m "high" and >90 J/m "very high".

Narrow- leaved ash belongs to group of trees with a "very high" degree with a impact bending strength value of 90,6 J/m. Of all the regions, the highest impact bending strength was found in region 4 with the highest value of 133 J/m. Impact bending strength of regions 4 and 1 belongs to group of trees with "very high" degrees. Impact bending strengths and their classes are given for some tree species in Table 12.

Table 12. Impact bending strengths and their classes for some tree species.

Tree species	Impact bending Strength (J/m)	Classes of impact bending Strengths	Literature
Alder	58	medium	Güller and Ay 2001
Narrow leaved ash (*F. oxycarpa*)	64	high	Gürsu 1971
Common ash (*F. excelsior*)	65	high	As *et al.* 2001
Eastern beech	85	high	Bektas *et al.* 2002
Beech	95	very high	As *et al.* 2001
Common ash (*F. excelsior*)	96	very high	Mozina 1969

Narrow leaved ash belongs to group of trees with a "very high" degree with a impact bending strength value of 90,6 J/m. Based on this result; its impact bending strength is higher than those of sharp fruity ash, eastern beech, alder and common ash, but lower than those of common ash and beech.

Dynamic Quality Values of Impact Bending Strength

Dynamic quality values calculated by the values of impact bending strength and air-dry density are 1,997 in region 1; 1,529 in region 2; 1,244 in region 3 and 2,325 in region 4. Overall average dynamic quality value was calculated as 1,774. The highest quality value of all the regions was in region 4 with a value of 2,325. According to Bozkurt and Erdin (1997), quality of wood material and quality factor is listed as; brittle (easily broken) <0,8; medium 0,8-1,2; flexible (hard to break) >1,2.

Overall dynamic quality value of narrow-leaved ash wood belongs to the group of "flexible" (hard to break; quality value >1,2) trees with a value of 1,774 Region 4, with the highest value, is in the group of "flexible" trees. Quality values of some tree species in shock strength are given in Table 13.

Table 13. Quality values of some tree species in shock strength.

Tree species	Quality factor	Literature
Narrow leaved ash (*F. oxycarpa*)	1,40	Gürsu 1971
Common ash	1,43	Bozkurt and Erdin 1997
Oak	1,54	Büyüksarı 2006
Maple (*Acer trautvetteri*)	1,71	Büyüksarı 2006
Cedar	1,90	Bozkurt and Erdin 1997
Alder	2,49	Güller and Ay 2001

Dynamic quality value of narrow-leaved ash wood is 1,774. Its dynamic quality value is higher than those of sharp-fruited ash, common ash, oak, and beech-bodied maple, but lower than that of cedar.

Tensile Strength Perpendicular to Grain

Descriptive statistics of tensile strength perpendicular to grain are given in Table 14. According to the results of the Duncan test given in table 14, there is no statistically significant difference between region 1 and region 2 in terms of tensile strength perpendicular to grain. There is no statistically significant difference between region 3 and region 4, either.

Table 14. Values of tensile strength perpendicular to grain (MPa).

Regions	N	X	S	S^2	R	X_{min}	X_{max}	*F*-value	*P*-value*
1	62	4,43 *a*	1,12	1,25	6,45	1,05	7,50	21,3	0,001
2	62	4,51 *a*	1,44	2,07	6,15	1,41	7,56		
3	62	5,98 *b*	2,20	4,84	8,39	1,98	10,37		
4	62	6,15 *b*	1,34	1,79	8,06	1,20	9,26		
Avg.	62	5,27	1,52	2,49	7,26	1,41	8,67		

*$p<0,05$.

Average tensile strength perpendicular to grain is 4,43 MPa in region 1; 4,51 MPa in region 2; 5,98 MPa in region 3 and 6,15 MPa in region 4. The highest result of tensile strength perpendicular to grain was in region 4 with a value of 6,15 MPa. Spacing is thought to affect the amount of the cellulose. The tensile strength perpendicular to grain is closely related to the amount of cellulose. The increased amount of cellulose increases the tensile strength perpendicular to grain. Values of tensile strength perpendicular to grain for some tree species are given in Table 15.

Oliver and Larson (1996) examines the anatomy, annual ring width, timber quality, physical and mechanical resistance properties of *Fraxinus excelsior* in wide spacing, states that it has more diameter increments in wide spacing.

Table 15. Tensile strength perpendicular to grain for some tree species.

Tree species	Tensile strength perpendicular to grain (MPa)	Literature
Narrow leaved ash (*F. oxycarpa* W.)	3,55	Gürsu 1971
Maple (*Acer trautvetteri* Medw.)	6,28	Büyüksarı 2006
Oak	9,0	Berkel 1970
Common ash	11,2	Berkel 1970

In the experiments conducted, the overall average tensile strength perpendicular to grain of narrow-leaved ash was found as 5,27 MPa. Based on these results; its tensile strength perpendicular to grain is higher than those of sharp-fruited ash, but beech-bodied maple, common ash and oak.

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CONCLUSIONS

We determined the effects of spacing on some mechanical properties of narrow-leaved ash (*Fraxinus angustifolia*) wood in accordance with the purposes. The major findings were as follows:

It has been determined that wide spacing increases density in narrow-leaved ash, and also boost the resistance properties in a positive way. According to these results, materials with the best mechanical properties are obtained from region 4, having the widest spacing (Table 1).

The mechanical properties of narrow-leaved ash wood capable to give the highest value in region 4, with the highest spacing; the increased diameter and number of knots together with the formation of the tapered body depending on the widened spacing, and also the reduced resistance quality value represent an obstacle to suggest the region 4, with the widest spacing, as the plantation spacing.

The spacing type in region 1 (2x3 m), which is in the highest quality group according to timber quality classes and allows formation of the cylindrical body, is considered to be more suitable for narrow-leaved ash plantations and is recommended. It has been instrumental in the creation of this opinion that the resistance and quality values of the wood samples taken from region 1 are close to the average value of four plantations.

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REFERENCES

As, N.; Koç, H.; Doğu, D.; Atik, C.; Aksu, B.; Erdinler, S. 2001. Anatomical, physical, mechanical and chemical properties of industrial trees grown in Turkey. *Journal of the Faculty of Forestry Istanbul University Series B* 51(1):71-88.

Bal, B.C.; Bektas, I. 2013. The mechanical properties of heartwood and sapwood of flooded gum (*Eucalyptus grandis*) Grown in Karabucak, Turkey. *Düzce University Journal of Forestry* 9(1):71-76.

Bektas, I.; Guler, C.; Basturk, M.A. 2002. Principal mechanical properties of Eastern beech wood (*Fagus orientalis* Lipsky) naturally grown in Andırın Northeastern Mediterranean region of Turkey. *Turkish Journal of Agriculture and Forestry* 26:147-154.

Berkel, A. 1970. *Wood material technology (Volume 1)*. Istanbul University Publication No: 1448, Faculty of Forestry Pablication No: 147, Kurtulmuş Press, İstanbul.

Bozkurt, Y. 1986. *Wood technology.* Istanbul University Publication No: 3403, Faculty of Forestry Pablication No: 380, İstanbul.

Bozkurt, A.Y.; Erdin, N. 1990. Physical and mechanical properties of wood used in trade. *Journal of the Faculty of Forestry Istanbul University Series B* 40(1):6-24.

Bozkurt, A.Y.; Erdin, N. 1997. *Wood material technology.* Istanbul University Publication No: 3998, Faculty of Forestry Pablication No: 445,ISBN 975–404–449-X.

Bozkurt, A.Y.; Göker, Y. 1996. *The physical and mechanical wood technology.* Istanbul University Publication No: 3944, Faculty of Forestry Pablication No: 436. ISBN 975-404-420-1.

Büyüksarı, U. 2006. Effect of growth regions on some technological properties of maple (*Acer trautvetteri* Medw.) wood. Abant İzzet Baysal Üniversity, Institute of Natural Sciences, Master Thesis, Düzce, Turkey.

Carus, S.; Çiçek, E. 2007. A diameter increment model for individual trees of ash (*Fraxinus angustifolia* Vahl.) plantations in Adapazarı-Süleymaniye region. *Suleyman Demirel Universty Faculty of Forestry Journal Series* A 1: 34-48.

Çiçek, E. 2004. Characteristics of forested wetlands and forested wetlands in Turkey. *Journal of the Faculty of Forestry Istanbul University Series B* 52(2):107-114.

Çiçek, E.; Yılmaz, M. 2002. The importance of *Fraxinus angustifolia* subsp. *oxycarpa* as a fast growing tree for Turkey. In: IUFRO Meeting on Management of Fast Growing Plantations, September 11-13, Izmit, Turkey.

Çiçek, E. 2010. Aralamanın dar yapraklı dişbudak (*Fraxinus angustifolia* Vahl.) plantasyonlarında büyüme ve bazı toprak özelliklerine etkisi, TÜBİAK Projesi, Proje No: 1050519, Türkiye

Eriksson, G. 2001. Conservation of noble hardwoods in Europe. *Canadian Journal of Forest Research* 31:577-587.

Forest Product Laboratory 2010. *Wood handbook-Wood as an engineering material.* General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, 508 p.

Fraxigen, 2005. Ash species in Europa: biological characteristics and practical guidelinis for sustainable use, a summary of findings from the fraxigen. Project EU Project EVK-CT–00108, Oxford Forestry Institute, University of Oxford, UK.

Govorcin, S.; Sinkovic, T.; Hrcka, R. 2009. Some physical and mechanical properties of recent and heat treated ash (*Fraxinus excelsior* L.). *Journal of Forestry Society of Croatia* 133(3-4):185-191.

Güller, B.; Ay, N. 2001. Some mechanical properties of alder [*Alnus glutinosa subsp. barbata* (C. A. Mey.) Yalt.] wood obtained from Artvin region. *Turkish Journal of Agriculture and Forestry* 25:129-138.

Gürsu, İ. 1971. Süleymaniye ormanı sivri meyveli dişbudakları (*Fraxinus oxycarpa* Willd.) odununun bazı fiziksel ve mekanik özellikleri ve değerlendirme imkânları hakkında araştırmalar. Ormancılık Araştırma Enstitüsü Yayınları, Teknik Bülten Seri No: 47, Ankara.

Haygreen, J.G.; Bowyer, J.L. 1996. *Forest products and wood science*. Third Edition, IOWA State University Press.

Kerr, G. 1995. Silviculture of ash (*Fraxinus excelsior* L.) in Southern England. *Forestry* 68(1):63-71.

Kerr, G. 2003. Effects of spacing on the early growth of planted *Fraxinus excelsior* L. *Canadian Journal of Forest Research* 33:1196-1207.

Kiaei, M. 2011. Anatomical, physical, and mechanical properties of eldar pine (*Pinus eldarica* Medw.) grown in the Kelardasht region. *Turkish Journal of Agriculture and Forestry* 35:31-42.

Mozina, I. 1969. Unter suchungen des holzes der gemeinen esche (*Fraxinus excelsior* L.). Research repports 7. İnstitut for Forest and Wood Economy, Ljubljana.

Niemz, P.; Clauss, S. Michel, F.; Hansch, D.; Hansel, A. 2014. Physical and mechanical properties of common ash (*Fraxinus excelsior* L.). *Wood Research* 59(4):671-682.

Oliver, C.D.; Larson, B.C. 1996. *Forest stand dynamics*. John Wiley and Sons, New York.

Pliura, A. 1999. *Fraxinus* spp. conservation strategy. In: Noble harwood network, Reporth of the 3rd Meeting, 13-16 June 1999, Sagadi, Estonia, Edited by J. Turok, J. Jensen, C. Palmberg-lerche, M. Rusanen, K. Rusell, -S. Devries, and E., Lipman, International Plant Genetic Resources Institute, Rome, Italy.

Piotto, B.; Piccini, C. 1998. Influence of pretreatment and temperature on the germination of *Fraxinus angustifolia* seeds. Seed *Science* and *Technology* 26:799-812.

Sahin, H.İ. 2013. Effect of heat treatment on some technological properties of ash (*Fraxinus angustifolia* Vahl.) wood grown in natural and plantation forests. Ph.D. Thesis, Duzce University, Duzce.

Tankut, N.; Tankut, A.N.; Zor, M. 2014. Mechanical properties of heat-treated wooden material utilized in the construction of outdoor sitting furniture. *Turkish Journal of Agriculture and Forestry* 38:148-158.

TS 2472, 1976. Wood-determination of density for physical and mechanical tests. Ankara, Turkey.

TS 2474, 1976. Wood-determination of ultimate strength in static bending. Ankara, Turkey.

TS 2476, 1976. Wood-determination of ultimate tensile stress perpendicular to grain. Ankara, Turkey.

TS 2477, 1976. Wood-determination of impact bending strength. Ankara, Turkey.

TS 2478, 1978. Wood-determination of modulus of elasticity in static bending. Ankara, Turkey.

TS 2595, 1977. Wood-determination of ultimate stress in compression parallel to grain. Ankara, Turkey.

TS 4176, 1984. Wood-sampling sample trees and long for determination of physical and mechanical properties of wood in homogeneous stands. Ankara, Turkey.

Yalcin, M.; Sahin, H.I. 2015. Changes in the chemical structure and decay resistance of heat-treated narrow-leaved ash wood. *Maderas.Ciencia y tecnología* 17(2): 435-436.

Zhang, S.Y. 1997. Wood specific gravity-mechanical property relationship at species level. *Wood Science and Techology* 31:181-191.