Radial Variation of Annual Ring Width and Fiber Dimensions from Natural and Plantation Trees of Alder (*Alnus glutinosa* L. Gaertner) Wood

Kamile TIRAK HIZAL[1*], Nurgün ERDİN[2]

Abstract

Due to the increasing demand and consumption of structural wood and the continuous development of forest industries, plantations of fast-growing trees became important for sustainability of industrial wood raw material. Black alder tree (*Alnus glutinosa* L. Gaertner) is naturally fast grown tree in North of Turkey. The aim of this research was to determine radial variation of annual ring width and fiber diamensions in planted and natural stands of black alder. The observations were made in young (28 years of age) and in mature trees (38-88 years of age). Three of planted trees were cut from Meryemana-Yeniköy, three of natural alder trees were cut from Maçka-Yüzüncüyıl in Trabzon. From the breast height a disc was taken and determined the South and North side of them. For fiber dimensions wood blocks were taken along the radial direction at three positions (near the pith, middle and periphery). The statistical analyses on the mean differences of the measured variables performed by ANOVA (analysis of variance) at %5 probability. The mean annual ring width was 4.08 mm for planted alder, 1.86 mm for nature alder. There was a significant difference between planted and mature alder wood annual ring width. The mean values of fiber length were 1115.1 and 1119.43 µm; fiber diameter were 27.27 and 26.46 µm; fiber lumen width were 18.68 and 17.32 µm while the mean values for fiber double cell wall thickness were 8.59 and 9.14 µm for natural and planted black alder wood respectively. There was significant difference between section of disc (inner, middle, outer) for fiber dimensions. Fiber length, fiber diameter and double cell wall thickness of fiber increased with age for natural and planted black alder wood; however fiber lumen diameter decreased with age for natural trees.The results of this study provide for understanding the differences between planted and natural tree annual ring and fiber properties and encourage to determine the other wood properties.

Key Words: Natural grown black alder, Planted black alder wood, Fiber, Radial variation.

Doğal ve Plantasyonda Yetişen Kızılağaç (*Alnus glutinosa* L. Gaertner) Odunlarının Yıllık Halka Genişliği ve Lif Boyutlarının Radyal Değişimi

Özet

Devam eden orman endüstri gelişiminin, yapısal odunun tüketiminin ve talebin artması nedeni ile hızlı büyüyen ağaçların plantasyonları endüstriyel odun hammaddesinin sürdürülebilirliği için önemli hale gelmektedir. Bu çalışmada, plantasyonda ve doğal yetişen kızılağaçlarda radyal yönde ki yıllık halka genişliği ve lif boyutlarındaki değişimi belirlemek amaçlanmıştır. Trabzon'dan Meryemana-Yeniköy bölgesinden üç adet plantasyon ağaçları, Maçka-Yüzüncüyıl bölgesinden üç adet doğal ağaçlar kesilmiştir. Göğüs yüksekliğinden bir adet disk çıkarılarak güney ve kuzey yönleri belirlenmiştir. Lif boyutları için odun blokları radyal yönde üç kısımdan (öze yakın, orta ve kabuğa yakın) alınmıştır. İstatistiksel değerlendirme % 5 güven aralığında ANOVA ile değerlendirilmiştir. Plantasyonda yetişen kızılağaçlarda ortalama yıllık halka genişliği 4.08 mm, doğal yetişenlerde. 1. 86 mm'dir. Plantasyonda ve doğal yetişen kızılağaçların yıllık halka genişlikleri arasında istatistikî olarak anlamlı fark görülmüştür. Lif boyutları açısından iç, orta ve dış kısımlar arasında anlamlı farklılık vardır. Doğal ve plantasyonda yetişen kızılağaç odunu için ortalama lif uzunluğu sırası ile; 1115.1 and 1119.43 µm; lif çapı 27.27 and 26.46 µm; lümen genişliği 18.68 and 17.32 µm ve çift çeper kalınlığı ise 8.59 and 9.14 µm'dir. Lif uzunluğu, lif çapı ve çift çeper kalınlığı doğal ve plantasyonda yetişen kızılağaç odunu için yaş ile birlikte artmış, bununla birlikte doğal yetişen kızılağaçlarda lif lümen çapı yaş ile birlikte düşmüştür. Bu çalışma sonucu plantasyonda ve doğal yetişen kızılağaçların yıllık halka genişlikleri ve lif özellikleri arasındaki farkı anlamayı sağlamış ve diğer odun özelliklerinin belirlenmesi teşvik edilmiştir.

Anahtar Kelimeler: Doğal yetişen kızılağaç, Plantasyonda yetişen kızılağaç, Lif, Radyal değişim.

[1]Düzce University, Forestry Faculty, Vocational School of Forestry kamiletirak@duzce.edu.tr
[2]İstanbul University, Forestry Faculty, Forest Industrial Engineering Department (retired)
[*]This study was prepared from a part of doctorate thesis in Istanbul Universiy, Institution of Science, Forest Industrial Engineering Department.

Introduction

Wood is one of the most important raw material used by man. Over millennia, most of the wood needs have come from the harvesting of natural forests, but the current and future wood demand of a growing human population cannot be covered by the natural forests of the world. It is the dilemma for the world harvest from natural forests. Plantation forests play an important role in the solution to this problem. To meet this deficit, wood production has to be increased in plantations by more growth per unit area with fast growing species.

Introduction of fast growing species to Turkey was started in 1880's with *Pinus pinaster* and in 1939 with *Eucalyptus camuldensis* as foreign species (Ayan and Sıvacıoğlu, 2006). About two decades ago, it was stated that the studies on fast growing species in Turkey should also be focused on native broadleaved species such as *Fraxinus* spp., *Alnus* spp., *Populus tremula*, *Ulmus* spp., etc. (Çiçek and Yılmaz, 2002). Common or black alder (*Alnus glutinosa* (L.) Gaertn.) belongs to the genus *Alnus* the family *Betulaceae* which comprises about 36 species is a broadleved tree native to most of Europe. Alder can be found over most of Europe from Scandinavia to the Mediterranean counties and parts of North Africa (Houston et al., 2016). Alder is adapted to wide range of temperature and is relatively frost-tolerant. It can grow well in continental climates but requires a high availability of water to thrive. It can be found on a wide range of soil types including poor soils and even coarse sands and gravels if the moisture is adequate, although it does not grow very well on calcareous soil (Mc vean, 1956; Funk, 1990; Anşin and Özkan, 1997; Savill, 2013).

Alder is another native fast growing species in Turkey and it is distributed mainly in North-East Anatolian Region covering 148 296 ha and 144 795 ha are in the Eastern Black Sea Region (Anonymous, 2013). Yield study of alder was carried out and an empirical yield table was constructed for its natural stands. It was found out that its mean annual increment (MAI) can reaches 21,0 m^3/ha/year at 20 years in good sites (Batu and Kapucu, 1995).

Alder wood is soft and diffuse porous, it has normally pale pinkish-brown colour, which darkens somewhat on exposure to light but durable if kept under water. Because of this property alder is used for jetties and underwater supports, bridge piles and small boats (parts of Venice were built on alder wood piles) (Knaggs and Xenopoulou, 2004; Housley et al., 2004; Klaassen and Creemers, 2012). Additionally it is used in sauna, benches and panels, turning and carving, plywood, flakeboard, MDF (medium density fiberwood), pulp and in the packaging industry but also more and more in furniture and different kinds of interiors and decorations as well as in various special products (Erdin and Bozkurt, 2013; Akyüz, 1998). Alder is not generally strong enough for heavy construction uses but good quality wood is sought after in joinery and wood veneer. It yields high quality charcoal and can be coppiced and provides material suitable for biomass production (Savill, 2013).

The changes in the growing condition and environment of a tree are closely associated with the growth of the tree and a rereflected morphologically and also anatomically. Wood properties vary from pith to bark, from tree base to the top and from the stem to the branches and roots (Gartner, 1995; Rupert et al., 2002). The primary structural block of wood is the tracheids or fiber cells. These cells vary from 16 - 42 micrometers in diameter and from 870 - 4000 micrometer long (Panshin and Zeeuw, 1980). The variations in wood properties are attributable to the different distribution patterns of its micro structures, its arrangement, size and dimension of components cells. Fibers are the principal element that is responsible for the strength of the wood (Panshin and Zeeuw, 1980; Desch and Dinwoodie, 1983) and fiber length is one of the quality parameters for pulpwood (Hudson et al., 1995; Sandercock et al., 1995; Jorge, 2000). It has been extensively studied in relation to tree age and within tree position (Hudson et al., 1995; Sandercock et al., 1995). During their formation, wood cells are affected by many factors such as site, ecological conditions, management, genetics, and age of the trees growing in plantation conditions (Zobel and Van Buijtenen, 1989).

Malan (1991) stated that fiber wall thickness, diameter and fiber length increase rapidly with increase distance from pith. The increases in fiber length from pith to bark are due to the increasing age of the tree with a resulting effect on cell wall development (Onilude, 2001). The patterns of radial variation are not the same for all wood characteristics. The radial pattern of variation for fiber length shows a marked transition from juvenile to mature wood. A similar conclusion was drawn in studies of other hardwoods (Dinwoodie, 1961; Bendtsen and Senft, 1986; Zobel and van Buijtenen, 1989; Peszlen, 1994).

Panshin and de Zeeuw (1980) conducted a literature review on longitudinal and radial variations in wood anatomical properties. They found three patterns of radial variation in tracheid and fiber length: 1- a rapid increase followed by constant length from pith to bark; 2- a smooth and continuous increase from pith to bark; and 3- an increase from from pith to bark up to a maximum, followed by a smooth decrease.

Radial variation in anatomical characteristics of five 13-year-old *Paraserianthes falcataria* planted in Indonesia was studied (Ishiguri et al., 2009). Significant differences among the five sample trees were reported in the cell diameter of wood fiber. Cell wall thickness of fibers showed an almost constant value up to 10 cm from pith and then increased towards bark. These results are also comparable to those found by other researchers on five Mississippi Delta hardwood, black willow, willow oak, sycamore, pecan and sugarberry (Taylor and Wooten, 1973), on *Eucalyptus grandis* (Malan and Gerischer, 1987) and on *E. camaldulensis* (Ohshima et al., 2003).

Radial variation of fiber morphology of five different poplar clones grown in the forest station in the suburb of Tiancchang city of Anhui Provenance, China, were selected as the materials to study the radial variation of fiber length, fiber width, lumen diameter, double cell wall thickness, the ratio of fiber length to width. Result showed that from pith outward, the fiber length, the fiber width and the ratio of fiber length to fiber width of five popular clones all increased with the increase of growth rings; reached a maximum in a certain year and then decrease or level off (Zha et al., 2005).

The radial variation patterns were determined for quebrancho blanco wood (*Aspidosperma quebranchoblanco*). Patterns of variation of fiber diameter, lumen diameter, and fiber cell wall thickness were examined using locations, trees and radial distances as sources of variation. Results showed that distance to the pith was the main source of variation for the traits studied. Fiber diameter and fiber cell wall thickness showed an increasing pattern along the radius. The diameter lumen fiber, fibers (%) and rays showed an indefinite pattern of radial change. Along the radius, the tissue proportion of fiber diameter and fiber cell wall thickness increased more rapidly up to a distance of 10.5 cm (Moglia and Lopez, 2001). Peszlen (1994) reported an increase in fiber area from pith to bark in poplar and Lei et al. (1996) found a similar variation pattern in white oak.

Significant differences among the properties and anatomical characteristics of wood have been recognised in radial direction. The variations in the structure of wood have a significant impact on the wood quality and yield of pulp and paper products, and on the strength and utility of solid wood products. Therefore differences in planted and natural trees wood properties is important. Radial variation directly influences wood homogeneity, and its study may provide a more rational use of material. Variation in anatomical features and, hence, in properties, is common during the increase in trunk diameter. Only limited information is avaliable about differences in the radial variation of black alder wood properties. In this study, we aimed to determine radial variations in fiber characteristics of black alder wood that had been grown in planted and natural stands. The present results provide useful information about planted wood properties for structural uses.

Material and Method

Black alder trees were felled from Eastern Blacksea Region of Turkey. Natural stand was belong to Maçka region in Trabzon (40º43’22” / 39º41’50”), and plantation stand was belong to Meryemana region in Trabzon (40 º42’04” /39º44’12”). Black alder trees were planted in 3x2m spacing. The location and details of the sites and sampled trees are given in Table 1. Sample tree was selected from each study site for destructive sampling, representing the mean diameter class, and avoiding extreme cases such as excessively knotty and crooked trees. A total of 6 trees were identified and numbered and measured at the breast height (1.3 m from height from the tree base) diameter (DBH) before felling. DBH was determined as the mean of two cross diameter. Each tree was felled and the tree height was measured.

Table 1. The location and details of two sites and sampled trees.

Trabzon	Planted Stand			Natural Stand		
	T1	T2	T3	T4	T5	T6
Region name/No	Meryemana			Yüzüncü yıl/396		
Slope	Kuzey- batı			Kuzey- batı		
Aspect (%)	40			45		
Altitude (m)	1221			1214		
Coordination	40 º42’04” /39º44’12”			40º43’22” / 39º41’50”		
Precipitation (mm yr^{-1})	971			902		
Mean temperature (°C)	12			8.4		
DBH diameter (cm)	21	20	19	32	24	25
Tree height (m)	13.9	14	12.5	16.3	15	11
Number of rings at DBH	28	28	28	88	68	38

A 5 cm long disk was taken at breast height from the stems. From each disk 2 cm wide strips were cut from north to south side. Transverse surfaces of each strip were polished with sandpaper. For fiber analysis, annual ring was selected for measuring from inner part (first 5. annual ring), middle part and outer part (periphery) in North and South side of strip at three height level. We used totally 6 strips and 18 cubes (Figure 1).

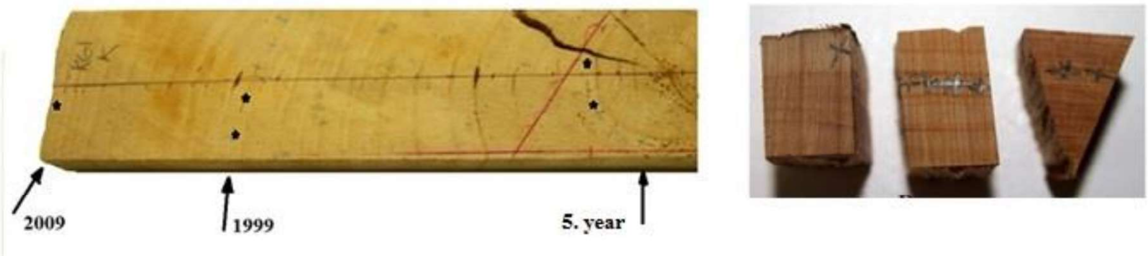

Figure 1. Selected annual rings and used wood cubes

All cubes were cut small wood chips about 1-2 cm long. Wood chips for fiber dimension measuremnts were macerated in %10 nitric acid and %10 cromic acid according to Jeffrey method for 24 hours (Bozkurt and Erdin, 2011). Then rinsed in distilled water and placed in glycerin (Figure 2). 25 whole fibers per sample were measured at different magnification (4x, 10x, 100x). From the macerated samples, fiber length, fiber diameter and double cell wall thickness of fiber were identified. Olympus BX 51 microscope connected to Olympus DP 71 camera was used to acquire images using the image analysis software ANALYSIS FIVE. All measuremnts were made according to *International Association of Wood Anatomists* (IAWA)(IAWA Committee, 1989).

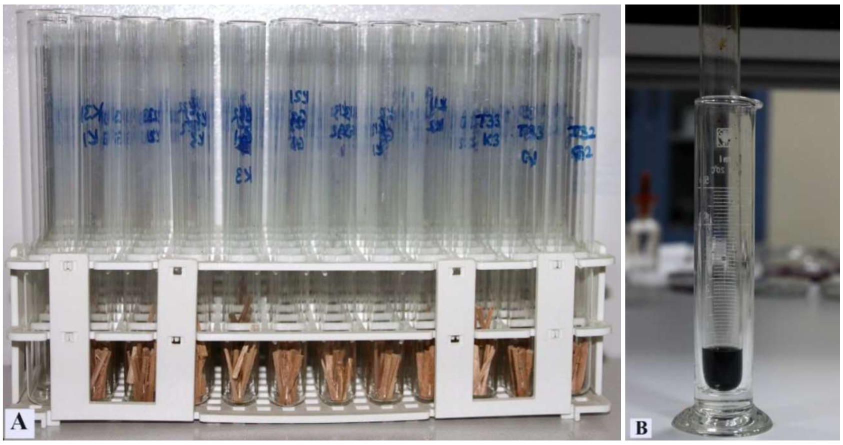

Figure 2. Maceration sapmples; A- Wood chips, B- Jeffrey solution

The overall means were calculated from the means of individual samples and an ANOVA procedure was formed using SPSS 17.0 software and for each sites were analyzed on the basis of the 95% confidence interval.

Result and Discussion

The data recorded on annual ring width, fiber length, fiber diameter, fiber lumen diameter, double cell wall thickness of both natural and plantation grown trees in three sections from pith to periphery (inner, middle and outer) are presented hereunder.

Annual Ring Width

Tree radial growth measured at breast height diameter showed the variation in wood diameters for individual trees. All measured annual ring width was evaluated and showed in Table 2.

Table 2. Descriptive ARW values for planted and natural black alder trees (mm)

Stand	Tree	$\overline{x}$	S	X_{min}	X_{max}
Plantation	T 1	4.36	2.08	1.63	8.85
	T 2	3.91	2.35	1.62	10
	T3	3.69	2.09	0.52	8.01
	Mean	4.08	2.16	0.52	10.28
Natural	T3	1.96	1.06	0.78	5.77
	T4	1.83	1.39	0.46	6.17
	T5	3.71	0.96	2.19	5.59
	Mean	1.86	1.19	0.40	6.57

There is a significant difference between planted and natural black alder tree ring width. Wider annual rings were seen on planted black alder trees. In current study, annual ring width of natural black alder trees values were lower, annual ring width of plantation black alder trees values were higher than the literature. The mean annual ring width of natural black alder was found 2.61 mm (Örs and Ay, 1999), 3.67 mm from 1400 altitude (Güller and Ay, 2001), 3.25 mm (Yaman, 2009), 2.98 mm in Arhavi region, 2.64 mm in Akçaabat region and, 2.10 mm in Espiye region (Usta et al., 2014).

Annual ring width is often considered as a useful predictor of some wood properties (e.g. density, mechanical strength). The patterns of annual ring width variation with age of planted and natural black alder trees are shown in Fig. 3.

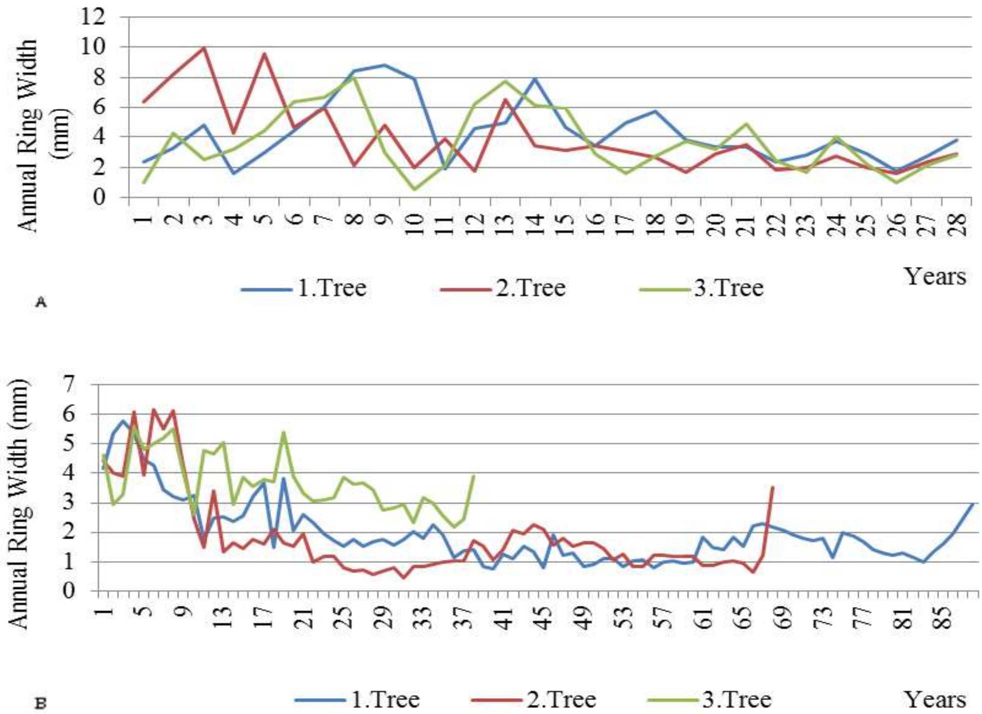

Figure 3. Annual ring width; A- Planted black alder trees, B- Natural black alder trees

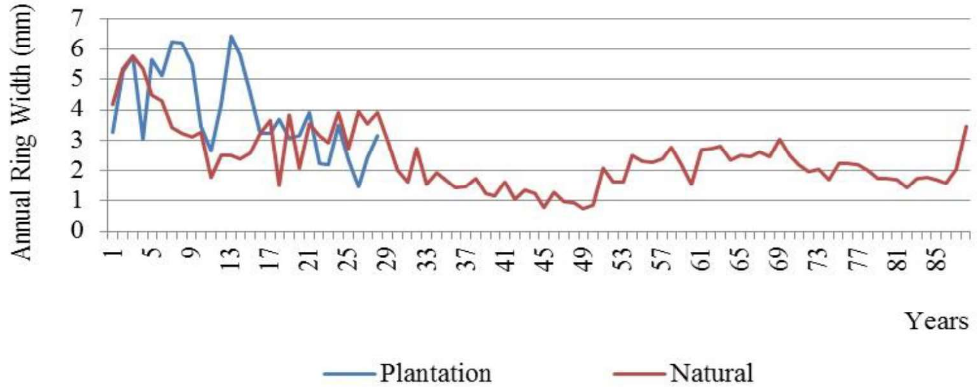

Figure 4. The mean annual ring width of planted and natural black alder trees

Highest annual ring width was presented in the initial years; afterward annual ring width began to decline rapidly with increasing the age for planted and natural black alder trees (Fig 4). In natural black alder trees there was no uniformity in annual ring width for individual trees. Uniformity of growth rate has an effect on wood structure and density variation both within and between annua rings. Larson (1967, 1969) indicated that lack of uniformity represents one of the greatest wood quality problems facing all wood-using industries. Uniform wood is desirable not only for manufacture of fiber products but for solid wood products as well. Within-ring density variation often presents a problem when painted and exposed to the elements. Such wood is also difficult to machine to a smooth condition or to peel on a veneer lathe because of differing hardness between earlywood and latewood bands (Schulsky and Jones, 2011).

In general, annual ring width decreased with cambial age for planted and natural black alder trees. The mean annual ring width of planted trees was higher (4.08 mm) than natural trees (1.86 mm).

Fiber Characteristics

The mean fiber length values were 1115.1 and 1199.43 µm, the mean fiber diameter values were 27.27 and 26.46 µm, the mean fiber lumen diameter values were 18.68 and 17.32 µm, double cell wall thickness of fiber values were 8.59 and 9.14 µm for natural and planted black alder wood respectively. Statistical analyses revealed significant differences between planted and natural trees in fiber length, fiber diameter, fiber lumen diameter and double cell wall thickness of fiber. The mean of fiber length and double cell wall thickness of fiber in planted trees was higher than the natural trees. Fiber diameter and fiber lumen diameter values in planted trees were lower than that of natural trees. Analysis of variance carried out at 5% probability level showed that the variations in fiber length, fiber diameter, fiber lumen diameter, and double cell wall thickness of fiber for different radial position were significant for natural black alder trees. Fiber length, fiber lumen diameter and double cell wall thickness of fiber were significant; fiber diameter was not significant for planted black alder trees.

In innerwood, fiber length was lower than in middle and outerwood; fiber diameter was higher in outerwood than in inner and middlewood, fiber lumen diameter was higher in innerwood than in middle and outerwood, double cell wall thickness of fiber was lower in innerwood than in middle and outerwood for natural black alder wood. Fiber length was lower in innerwood than in middle and outerwood; fiber diameter was similar, fiber lumen diameter was higher in innerwood than in middle and outerwood, double cell wall thickness of fiber was lower in innerwood than in middle and outerwood for planted black alder wood. Fiber length, fiber lumen diameter, double cell wall thickness of fiber values has significant difference in inner and outerwood between planted and natural black alder wood, except fiber diameter. For all fiber dimension values were nonsignificant in middlewood (Table 3). Significant difference was seen on innerwood and outerwood between planted and natural black alder wood.

Table 3. Fiber dimensions of planted and natural black alder trees

Property	Position	Planted				Natural				p<0.05
		Mean	Min.	Max.	SD	Mean	Min.	Max.	SD	
Fiber length (µm)	Inner	1093.80^{a}	640.54	1802.47	168.93	945.81^{a}	468.71	1637.01	184.24	*
	Middle	1229^{b}	760.94	1573.44	160.08	1192.08^{b}	750.38	1680.56	176.57	ns
	Outer	1275.51^{c}	807.1	1957.49	191	1207.39^{b}	691.88	1660.27	219.33	*
	Mean	1199.43	640.54	1957.49	189.82	1115.1	468.71	1680.56	227.97	*
Fibre diameter (µm)	Inner	25.79^{a}	17.86	36.77	3.96	26.59^{ab}	16.77	36.94	4.18	ns
	Middle	26.82^{a}	11.62	39.94	4.81	27.51^{b}	16.92	42.05	4.9	ns
	Outer	27.79^{a}	16.75	37.95	4.55	27.70b^{c}	18.73	44.48	4.31	ns
	Mean	26.46	11.62	39.94	4.47	27.27	16.77	44.48	4.49	*
Fiber lumen diameter (µm)	Inner	17.97^{bc}	11.03	27.7	3.59	19.19b^{c}	11.18	29.1	3.64	*
	Middle	17.42^{b}	4.27	27.63	4.14	18.21^{ab}	10.91	33.72	4.06	ns
	Outer	16.58^{a}	7.41	30.15	4.81	18.65^{b}	10.05	34.25	3.74	*
	Mean	17.32	4.27	30.15	4.24	18.68	10.05	34.25	3.83	*
Double cell wall thickness (µm)	Inner	7.82^{a}	3.79	13.80	1.64	7.40^{a}	4.31	12.44	1.45	*
	Middle	9.40^{b}	4.36	16.67	2.28	9.30^{b}	4.83	20.56	2.33	ns
	Outer	10.21c	3.55	21.20	3	9.05^{b}	5.43	15.96	1.86	*
	Mean	9.14	3.55	21.20	2.57	8.59	4.31	50.56	2.09	*

-Letters show significant differences between positions. -* Significant difference between planted and natural trees.
– ns non significant.

Analysis of variance carried out at 5% probability level showed that the variations in wood fiber length and double cell wall thickness of fiber for different stand (planted/natural) and radial position were significant but the variations in wood fiber diameter and fiber lumen diameter for different position were not significant.

Fiber length increased with increase in age both planted and natural black alder wood, generally an increase from innerwood to outerwood (Figure 5). Similar results had been reported in the wood of planted *Eucalyptus globulus* (Jorge et al., 2000) and *Tectona grandis*

(Izekor and Fuwape, 2011). In literature, there is a general increase of fiber length due to the length increase of cambial initials with increasing cambial age for teak wood (Izekor and Fuwape, 2011; Lima et al., 2011; Ridoutt and Sands, 1993; Cardoso et al., 2015; Kiaei et al., 2016).

Fiber diameter and double cell wall thickness of fiber increased with age, it also increased from innerwood to outerwood. The observed increase in fiber diameter associated with the increasing age of the tree may be due to many molecular and physiological changes that ocur in the vascular cambium as well as the increase in the wood cell wall thickness during tthe tree ageing process (Plomion et al., 2001; Roger et. al., 2007). Fiber lumen width decreased with age and also from innerwood to outerwood for planted black alder wood. Fiber lumen diameter first decreased to middlewood then increased to periphery for natural black alder wood. This showed that fiber lumen width decreases with age, which may be attributed to the increase in the length of fiber initials associated with increasing age of the cambium (Jorge et al., 2000). The observed differences in lumen width with increasing age of the tree may also be due to increase in cell size and physiological development of the wood as the tree grows in girth. Roger et al. (2007) reported positive relationship between variations in lumen width and age of the cambium.

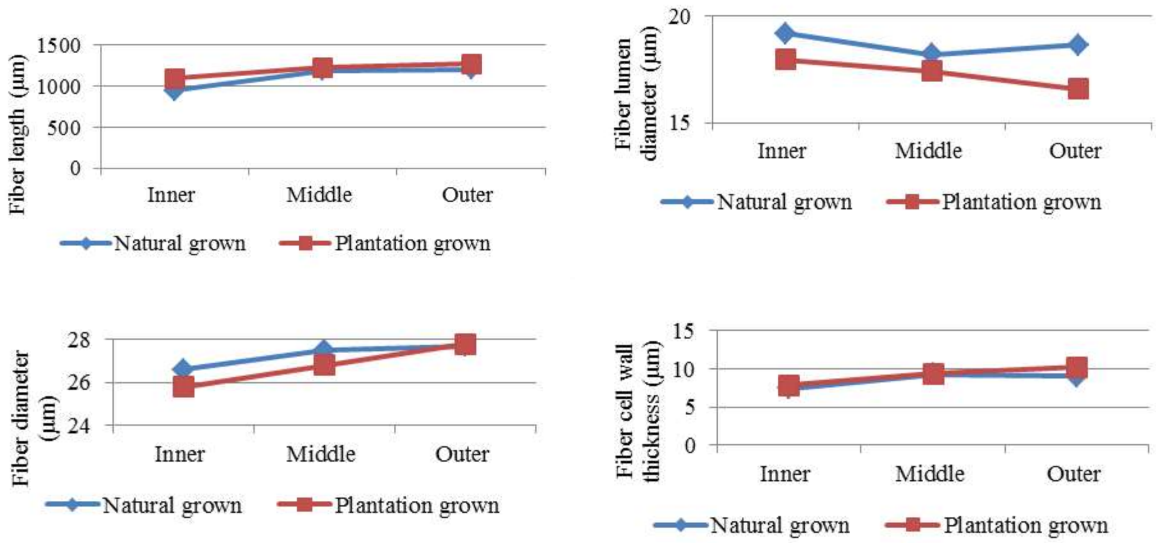

Figure 5. Radial variations of fiber dimensions

For natural black alder wood, fiber lumen diameter was decreased towards pith to periphery but for planted black alder wood it was increased. This may be related to age classes. While natural trees were 38-88 years old, planted trees were 28 years old. Zobel and van Buijtenen (1989) concluded that faster growing trees usually showed shorter fiber length but an inverse relationship between fiber length and annual ring width was observed in some conifers and hardwood species (Dutilleul et al., 1998; Fujiwara and Yang, 2000; Adamopoulus et al., 2010; Moya and Tomazello, 2007).

Radial variation of *Paraserianthes falcataria* from plantation stands were studied and as a result significant differences in fiber length were observed between core and outerwood (Ishiguri et al., 2007). Variation within tree of wood anatomical properties of I-214 poplar in Beijing area were examined by (Jiang et al., 2003). Their results indicated an initial rapid and then gentle increase in fiber length and width, double cell wall thickness of fiber from pith to outwards as in current paper.

Fiber dimensions of *Melia dubia* was evaluated as fast grown and slow grown wood. The fast grown wood showed higher numerical values for fiber length, fiber diameter, fiber lumen diameter and double wall thickness of fiber when compared to slow grown wood. The intra variation revealed that in slow grown wood middle portion of the wood had higher values while in fast grown wood outer region had higher values (Swaminathan et al., 2012). In the current paper, fiber length, fiber diameter and double cell wall thickness of fiber values were heigher in outerwood than inner and middlewood of both planted and natural black alder wood.

The fibers of natural black alder wood were shorter than the plantation growing, which could affect the finishing quality. When planning the wood, shorter fibers are torn more easily than longer fibers which would cause uneven surfaces and raised fibers, thereby reducing the quality of the finish (Silva et al., 2005). Fiber length has an effect on a number of pulp and paper properties, including tear resistance and tensile, fold and burst strength. In most cases long lengths are desirable. Thick cell walled fibers result in paper with low burst and tensile strengths but with high tear resistance. Paper made primarily of thick-walled cells also tends to have very low folding endurance (Shmulsky and Jones, 2011).

According to IAWA (1989) fiber length classification, short fibers are <900 µm, medium length is 900-1600 µm and long fibers are 1600 µm. The classes for fiber wall thickness are based on the ratio of lumen to wall thickness. Fibers are very thin-walled; fiber lumen 3 or more times wider than the double wall thickness, fibers are thin- to thick walled; fiber lumen less than 3 times the double wall thickness and distinctly open, fibers are very thick-walled; fiber lumen almost completely closed. In current study, all fibers were in medium length and fiber cell wall was thin- to thick walled. There is no difference in classification of fiber dimensions.

Conclusion

The results of this study can be summarized as follows:

- The mean annual ring width was 4.08 mm for plantation growing, and 1.86 mm for natural black alder trees. The mean annual ring width was found to differ significantly among planted and natural black alder trees.
- With increasing of cambial age the annual ring width were decreased for all black alder trees.
- Statistical analyses revealed significant differences between planted and natural black alder trees in fiber length, fiber diameter, fiber lumen diameter and double cell wall thickness of fiber. The mean of fiber length, fiber diameter, double cell wall thickness of fiber in planted black alder trees was higher than the natural black alder trees.
- The radial differences in fiber length, fiber diameter, and double cell wall thickness of fiber of planted and natural black alder wood were discovered significant ($p<0.05$). Fiber length, fiber diameter, and double cell wall thickness of fiber increases with age for both planted and natural, however fiber lumen diameter decreases with age for natural trees.
- Fiber length, fiber lumen diameter, double cell wall thickness of fiber values has significant difference in inner and outerwood between planted and natural black alder wood, except fiber diameter.

Acknowledgment

This study was prepared by Kamile TIRAK HIZAL and a part of doctorate thesis which name is “Comparison of Structural Properties of Ash and Alder Wood Species Grown in Natural and Planted stands” in İstanbul University, Institute of Science, Forest Industry Engineering Department. Thanks for Istanbul University and Forest Industry Engeneering Department, Prof. Dr. Yılmaz BOZKURT Wood Anatomy Laboratory.

References

Adamopoulos, S., Chavenetidou, M., Passialis, C. and Voulgaridis, E. 2010. Effect of cambium age and ring width on density and fiber length of black locust and chestnut wood. *Wood Research*, 55(3):25-36.

Akyüz, M. 1998. Wood properties and applications of Black Alder (*Alnus glutinosa* subsp. *barbata* (C.A. Mey. Yalt)), Karadeniz Technical University Faculty of Forestry and General Directorate of Forestry, *Symposium on Forest Ownership Issues Proceedings*, 467-471.

Anonymous, 2010. Turkey Forest Inventory General Directorate of Forestry (Unpublished].

Anşin, R. and Özkan, Z.C. *Spermatophyta*, Karadeniz Technical University, Faculty of Forestry, No: 167, Trabzon. (in Turkish), 1997.

Ayan, S. and Sıvacıoğlu, A. 2006. Review of the Fast Growing Tree Species in Turkey, *Boletin del CIDEU*, Vol.2, 57-71, 2006.

Batu, F. and Kapucu F. 1995. Doğu Karadeniz Bölgesi kızılagac mescerelerinde bonitet endeks ve hasilat tablosunun duzenlenmesi, *I. Ulusal Ormancilik Karadeniz Kongresi,* s.348-363, Trabzon, Turkey.

Bendtsen, B. A. and Senft, J. 1986. Mechanical and anatomical properties in individual growth rings of plantation-growth eastern cottonwood and loblolly pine, *Wood and fiber Science*, 18 (1): 23-38.

Bozkurt, Y. and Erdin, N.2011. *Ağaç teknolojisi*, İstanbul Üniversitesi, Orman Fakültesi, İ.Ü. Yayın No: 5029, O.F. Yayın No: 445, ISBN 978-975-404-900-8, 2011.

Cardoso, S., Sousa, V. B., Quilho, T. and Pereira, H. 2015. Anatomical Variation of Teakwood from Unmanaged Mature Plantations in East Timor, *J Wood Sci*., DOI 10.1007/s10086-015-1474-y.

Çiçek, E. and Yılmaz, M. 2002. The importance of *Fraxinus angustifolia* subsp. *oxycarpa* as a fast growing tree for Turkey, In: Management of fast growing plantations, *Proceedings of a meeting of IUFRO*, p.192-202.

Desch, H. E. and Dinwoodie, J. M. 1983. *Timber, Its structure, Properties and Utilization*, 6th Edition. Published by Macmillan Education Limited. 410pp.

Dinwoodie, J. M. 1961. Tracheid and fiber-length in timber- a reviw of literatüre, *Forestry,* 34:125-144.

Dutilleul, P., Herman, M. and Avella-Shaw, T. 1998. Growth rate effects on correlations among ring width, wood density, and mean tracheid length in Norway spruce, *Can. J. for. Res*, 28:56-68.

Erdin, N. and Bozkurt, Y. 2013. *Odun anatomisi*, İstanbul Üniversitesi, Orman Fakültesi, İ.Ü. Yayın No: 5145, O.F. Yayın No: 506, ISBN. 978-975-404-932-9, İstanbul.

Fujiwara, S. and Yang, K.C. 2000. The relationship between cell length and ring width and circumferential growth rate in five Canadian species, *IAWA J*., 21(3):335-345.

Funk, D. T. 1990. *Alnus glutinosa* (L.) Gaertn. European Alder, *Agriculture Handbook 654* (U.S. Department of Agriculture, Forest Service, Washington, DC.,), pp. 239–256.

Gartner B.L. 1995. Patterns of xylem variation within a tree and their hydraulic and mechanical consequences. In: Gartner B.L. (Ed.), *Plant stems: physiology and functional morphology*, Academic Press, San Diego.

Güller, B. ve Ay, N. 2001. Artvin yöresi sakallı kızılağaç (*Alnus glutinosa* subsp. *barbata* (C. A. Mey.) Yalt.) odununun bazı mekanik özellikleri, *Turk. J. Agric. Forestry*, No.25, S. 129-138.

Housley, R. A., Ammerman, A. J. and McClennen C. E. 2004. That Sinking Feeling Wetland Investigations of the Origins of Venice, *Journal of Wetland Archaeology ,* 4: 139-153.

Houston Durrant, T., de Rigo, D., Caudullo, G. 2016. *Alnus glutinosa* in Europe: distribution, habitat, usage and threats, *European Atlas of Forest Tree Species*, ISBN 978-92-79-36740-3, Publication Office of the European Union, p.64-65, Belgium.

Hudson,I., Wilson, L; Sandercock, C. and Sands, R. 1995. Within ring variability of Wood microstructure in *Eucalyptus nitens*. In: B.M. Potts, N.M.G. Borralho, J.B. Reid, R.N. Cromer, W.N. Tibbits and C.A. Raymond (eds), *Eucalyptus plantation: Improving fibre yield and quality: CRC for temperate Hardwood Forestry*. Hobart, 110-115pp.

IAWA Committee, 1989. IAWA list of microscopic features for hardwood identification, *IAWA Bull*. n.s. 10: 219–332.

Ishiguri. F., Hiraiwa, T., Iizuka, K., Yokota, S., Priadi, D., Sumiasri N. and Yoshizawa N. 2009. Radial variation of anatomical characteristics in *Paraserianthesis falcataria* in Indonesia, *IAWA Journal*, 30 (3):343-352.

Ishiguri, F., Eizawa, J., Saito, Y., Iizuka, K., Yokota, S., Priadi, D., Sumiasri, N. and Yoshizawa, N. 2007. Variation in the wood properties of *Paraserianthes falcataria* planted in Indonesia, *IAWA J.*, 28(3):339-348, 2007.

Izekor , D. N. and Fuwape, J. A. 2011. Variations in the Anatomical characteristics of plantation grown *Tectona grandis* Wood in Edo State, Nigeria, *Applied Science Research*, 3(1):83-90.

Jiang, X. M., Yin, Y. F. and Urakami, H. 2003. Variation within tree of wood anatomical properties and basic density of I-214 Poplar in Beijing area and their relationship modelling equations, *Scientia Silvae Sinicae*, 39 (6): 115-121.

Jorge, F; Quilho,T. and Pereira, H. 2000. Variability Of Fibre Length in Wood And Bark in *Eucalyptus globulus*, *IAWA Journal*, 21 (1): 41-48.

Kiaei, M., Naji, H.R., Abdul-Hamid, H. and Farsi, M. 2016. Radial variation of fiber dimensions, annual ring width, and wood density from natural and plantation trees of alder (*Alnus glutinosa*) wood, *Wood Research*, 61(1):55-64.

Knaggs G. and Xenopoulou S. 2004. *Guide to Irish Hardwoods*, ISBN 1 902696 31 X, COFORD, Dublin.

Klaassen R. K. W. M. and Creemers, J. G. M. 2012. Wooden foundation piles and its underestimated relevance for cultural heritage, *Journal of Cultural Heritage*, 13S, S123-S128.

Lei, H., Milota, M. R., and Gartner, B. L. 1996. Between and within-tree variation in the anatomy and specific gravity of wood in Oregon white oak (*Quercus garryana* Dougl.), *IAWA J.,* 17(4): 445-461.

Lima, I.L, Garcia R, Longui, E.L. and Florsheim, S.M.B. 2011. Anatomical dimensions of the wood of *Tectona grandis* Linn. in relation to spacing and radial position in the trunk, *Sci For*., 39:61–68.

Malan, F. S. and Gerischer, G. F. R. 1987. Wood properties differences in South African grown Eucalyptus grandis trees of different growth stress intensity, *Holzforschung,* 41: 331-335.

Malan, F. S. 1991. Eucalyptus improvement for lumber production, *Anais do Seminário Internacional de Utilização da Madeira de Eucalipto para Serraria*.

Mc vean, D. E. 1956. Ecology of *Alnus glutinosa* (L) Gaertn. III. Seedling establishment, *Ecology*, 44: 195 – 218.

Moglia, J. G. and Lopez, C. R. 2001. Radial variation trend in the wood of Aspidosperma quebracho blanco, *Investigacion Agraria; Sistemasty Recursos Forestales*, 10 (1): 69-80.

Moya, R. and Tomazello, M. T. 2007. Wood density and fiber dimensions of *Gmelina arborea* in fast growth trees in Costa Rica: relation to the growth rate, *Investigaciones Agrarias: Sistema de Recursos Forestales*, 16(3):267-276.

Ohshima, J., Yokota, S., Yoshizawa, N. and Ona, T. 2003. Within-tree variation of detailed fiber morphology and the position representing the whole-tree value in *Eucalyptus camaldulensis* and *E. Globules, Appita J.*, 56: 476-482.

Onilude, M.A. 2001. Variation in the relationship of fibre length with age of plantation-grown afara (*Terminalia superba* Eng. And Diels), *Journal of Tropical Forest Resources*, 17(1) :154-159.

Örs, Y. ve Ay, N. 1999. Rize-Çayeli bölgesi kızılağaç (*Alnus glutinosa* subsps. *barbata* (C. A. Mey.) Yalt.) odunlarının bazı fiziksel özellikleri, *Turk. J. Agric. Forestry*, No.23, Ek Sayı.4, s. 803-808.

Panshin, A.J. and de Zeeuw, C. 1980. *Text book of Wood Technology*, Structure, Identification, Properties and Uses of the commercial wood of the United States and Canada, McGraw Hill Book Company, New York. 722 pp.

Peszlen, I. 1994. Influence of age on selected anatomical properties of Populus clones, *IAWA J*, 15(3): 311-321.

Ridoutt, B.G. and Sands, R. 1993. Within-tree variation in cambial anatomy and xylem cell differentiation in *Eucalyptus globulus, Trees* 8:18–22.

Rupert W., Geoffrey M.D. and Robert E. 2002. High-resolution analysis of radial growth and wood density in Eucalyptus nitens grown under different irrigation regimes, *Ann. For. Sci*. 59:519–524.

Sandercock, C.F; Sands, R;Rideoutt, B.G; Wilson, L.F. and Hudson, I. 1995. Factors Determining wood microstructure in Eucalyptus. In: B.M. Potts, N.M.G. Borralho J.B. Reid, R.N Cromer, W.N. Tibbits and C.A.Raymond (eds), *Eucalyptus Plantations: Improving fibre yield and quality*: CRC FOR Temperate Hardwood Forestry. Hobart. 5-9 pp.

Savill, P. S. 2013. *The silviculture of trees used in British forestry*, CABI, ISBN 9781780640266.

Silva J. R.M., Muniz, G.I., Lima, J.T. and Bonduelle, A.E. 2005. Influencia da morfologia das fibras na usinabilidade da madeira de *Eucalyptus grandis* Hill ex. Maiden, *Revista Arvore, Viçosa*, 29(3): 479-487, 2005.

Swaminathan, C., Vijendra Rao, R. and Shashikala, S. 2012. Preliminary evaluation of variations in anatomical properties of *Melia dubia* Cav. Wood, *International Research Journal of Biological Sciences*, 1(4):1-6, 2012.

Taylor, F. W. and Wooten, T. E. 1973. Wood properties variation of Mississippi Delta hardwoods, *Wood Fiber*, 5: 2-13.

Usta, A., Yılmaz, M., Kahveci, E., Yılmaz, S. and Öztürk, H. 2014. Effects of different site conditions on some of the wood properties of black alder (*Alnus glutinosa* (L.) Gaertner subsbarbata (C. A. Meyer) Yalt), *Fresenius Environmental Bulletin*, 23(8), 1840-1851.

Yaman, B. 2009. Wood anatomy of ivy-hosting black alder (*Alnus glutinosa* Gaertn.), *Dendrobiology*, Vol:62, 41-45.

Zha, C. S., Fang, Y., Shengquan L. and Wang. B. 2005. Radial variation of fiber morphology of different poplar clones, *Journal of Anhui Agricultural University*, 32 (2): 192-197.

Zobel, B. J. and van Buijtenen, J. P. 1989. *Wood variation: its causes and control*. Springer-Verlag, Berlin, ISBN-13: 978-3-642-74071-8, 363 pp.