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RADIAL VARIATION OF FIBER DIMENSIONS, ANNUAL RING WIDTH, AND WOOD DENSITY FROM NATURAL AND PLANTATION TREES OF ALDER (*ALNUS GLUTINOSA*) WOOD

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ABSTRACT

The aim of this research was to determine radial variations of some wood properties from natural and plantation trees of *Alnus glutinosa*. Oven-dried wood density (WD), fiber cell features, and annual ring width (ARW) were determined in radial positions of stem at breast height of tree. The results showed that the cultivation methods had significant influence on the fiber length (FL), fiber diameter (FD) and ARW. The effect of interaction between radial position and cultivation methods on anatomical features was not significant, except for cell wall thickeness (CWT). Fiber cell features and WD increased with distance from pith for both cultivations trees. The ARW decreased with increasing the cambial age in both cultivation methods. The average of FL and ARW in plantation trees was higher than those in natural trees. Widest FD was found in natural forest. There were significant relationships between ARW-WD and WD-FD for natural forest and between ARW-WD, ARW-CWT and WD-FL for plantation forest. About 67 % of WD variation in natural and plantation trees were related to FD and ARW, respectively. Due to high FL and ARW, wood from planted trees could be suitable for paper production than wood from natural trees.

KEYWORDS: *Alnus glutinosa*, plantation forest, natural forest, wood properties.

INTRODUCTION

There are two alder trees species (*Alnus subcordata* and *Alnus glutinosa*) in Hyrcanian forest, Iran. The alder trees are species from Betulaceae, which constitutes about 9 % of the wood volume for Iranian Northern forests (Kiaei 2013). These species have high technological abilities. It is mostly used for box-making, furniture, plywood and veneer (Gartner et al. 1997).

Fiber dimensions and wood density are related to structural, physical and chemical properties of wood. It affects many wood-product properties in pulping process, wood behavior in the drying process, and chemical process (Kiaei et al. 2014). In pulping, fiber significantly influences the sheet properties including tensile, stretch, bursting and tearing strengths (Horn and Setterholm 1990; Smook 1994).

Growing factores influence on wood quality (Zobel and Van Buijtenen 1989; Saranpää 2013). Wood from trees growing in plantation has different properties from wood of natural forest (Butterfield et al. 1993; Moya et al. 2009). Butterfield et al. (1993) carried out a study on the radial variation from pith to bark of basic density, fiber length and vessel area in *Hyeronima alchorneoides* and *Vochysia guatemalensis*, comparing theses features in natural and plantation forests. González and Fisher (1998) studied the specific gravity, fiber length, vessel density, and vessel radial diameter from pith to bark in natural forests of *Vochysia guatemalensis* in Costa Rica. The results showed significant alteration among trees.

A research on the comparison of wood properties of planted big-leaf mahogany in Martinique Island with naturally grown mahogany from Brazil, Mexico and Peru indicated that wood density of plantation trees (young and old trees) was lower than that of natural forest trees. Although the wood density of natural forest was higher than that of plantation trees, the difference in some mechanical properties was not significant (Langbour et al. 2011).

To the best of our knowledge, there is no specific study to determine the variation of anatomical properties of the current species in the region except of measuring its growth ring width, ratio of cell wall, ration of lumen, and oven-dry wood density as: 2.61 cm, 33.44, 66.54 %, and 502 $g.cm^{-3}$ (Ors and Ay 1999).

There are no studies on annual ring width and fiber dimensions properties between plantation and natural forests for *Alnus glutinosa* species in Iran. Therefore, this study focused on *Alnus glutinosa* to examine radial changes of annual ring width, fiber dimensions and wood density from two different cultivation methods (natural and plantation forests) and the relationship between measured properties of wood.

MATERIAL AND METHODS

Wood sampling

Six alder trees (*Alnus glutinosa*) from two natural and plantation forests were collected in North of Iran, eastern part of Mazandaran (36° 11' 40'' N to 36° 17' 40'' N; 52° 53' 10'' E to 52°

57' 20'' E). All sample trees from both cultivations were at age of about 20 years. A disc was cut at breast height of each tree. Selected trees had straight trunks, normal branching and no signs of any diseases or pest symptoms. The average air temperature of the region was 11.2 °C and the average annual precipitation was recorded at 386 mm/year. Both forests were located near to each other; therefore the ecological conditions were almost similar. The soil of the region was similar for both planting sites as silt-clay to clay- loam.

Wood properties

A 5-cm disc in thickness was collected from each sample tree at diameter of breast height (dbh) for evaluation of annual ring width (ARW), fiber properties and wood density (WD). The width of the every annual growth ring was measured using a normal binocular and the LINTAB 5 ring-width measuring system (Rinntech Company in Germany).

For the WD, the some blocks with the preciese dimensions of 2 x 2 x 2 cm were taken along radial position from pith to the bark based on the ISO-3131 (2001) standard. The samples were then oven-dried at 103 ± 2°C to reach 0 % moisture content. After cooling down in a desiccator, the oven-dry weights of the specimens were measured with accuracy of 0.01. The values of the oven-dry wood density were calculated using the following equation:

$$D_0 = \frac{p_0}{v_0}$$

where: D_0 - oven-dry density,
p_0 - dried weight,
v_0 - dried volume.

For fiber dimensions, wood blocks were taken along the radial direction at three positions (near the pith, middle, and near the bark) for both cultivation methods to determine fiber features includings: Fiber length (FL, mm), fiber diameter (FD, μm), and cell wall thickness (CWT, μm). The blocks were then macerated in a mixture of 30 % hydrogen peroxide and glacial acid (1:1) in oven at 64°C for 24 hours. After maceration, the samples were gentely twice washed with distilled water. The dimensions were determined by Leica Image Analysis System (Nikon microscopic, Eclipse 50i, Japan).

Statistics analysis

The statistical analyses on the average differences of the measured variables in the radial direction at both culivation methods were performed by ANOVA (analysis of variance) and Duncan Multiple Range Test (DMRT) for statistics analysis at 5 % probability. The relationships between wood various properties were determined by Pearson correlation matrix and forward stepwise regression.

RESULTS

Annual ring width (ARW)

The variation of annual ring width along radial direction from the pith to the bark for both cultivation methods is shown in Fig. 1. Analysis of variance indicated that the effect of cultivation methods (*F= 4.081, sig = 0.047,* $P<0.05$) and cambial age (*F= 14.248, sig= 0.001,* $P<0.01$) on the annual ring width were significant, while their interaction effects (*F= 0.780, sig= 0.723*) had no significant differences for ARW. The ARW in tree diameter was related to the age. Highest ARW was presented in the initial years; afterward ARW began to decline rapidly with increasing the age for natural and plantation forests. The average ARW in plantation alder forest was higher (6.87 mm) compared to natural alder forest (6.41 mm).

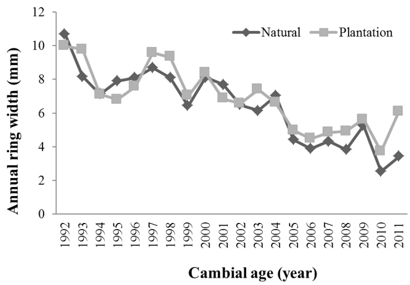

Fig. 1: Annual ring width variation along cambial age from natural and plantation forests.

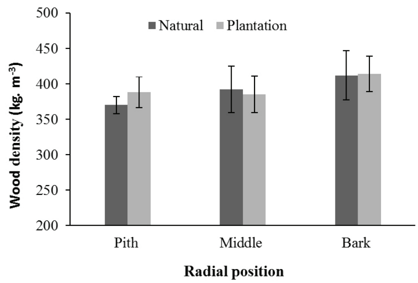

Fig. 2: Variation of wood density along radial position in both cultivation methods.

Wood density (WD)

Radial variation of WD for plantation and natural forests is shown in Fig. 2. The analysis of variance (ANOVA) indicated that planting methods ($F = 0.169$, $sig = 0.685$), and the interaction between planting methods and radial position ($F = 0.488$, $sig = 0.620$) did not significantly affect the WD. The WD increased along radial direction from the pith to the bark for both planting methods. The WD showed significant difference in radial direction ($F = 4.253$, $sig = 0.026$). The average WD in the plantation forest was slightly higher than that in the natural forest. The average WD in plantation and natural alder trees were close to each other as 396 and 391 $kg.m^{-3}$, respectively.

Fiber length (FL)

The statistical analysis indicated that the cultivation methods ($F=9.187$, $sig=0.003$, $P<0.01$) and radial position ($F= 11.252$, $sig = 0.001$, $P<0.01$) had significant effect on the FL with no significant effect of their interaction ($F=0.121$, $sig = 0.886$). The value of the FL in plantation forest was higher than that in natural forest (1.45 mm vs. 1.34 mm). The FL was meaninfully related to the cambial age. Highest and lowest FL were found near the bark and near the pith, respectively. The FL increased along radial direction from pith to the bark in both planting methods (Fig. 3a).

Fiber diameter (FD)

Concerning to the FD, the results showed that the cultivation methods (sig=0.026, $P<0.05$) and radial position (sig = 0.001, $P<0.01$) had significant influence on the FD, while their interaction effect (sig = 0.355) was not significant. The value of FD in plantation forest is lower than that in natural forest (28.91 µm vs 31.43 µm). Highest and lowest of FD were found near the bark and near the pith, respectively. The FD was increased along radial direction from pith to the bark in both planting methods (Fig. 3b).

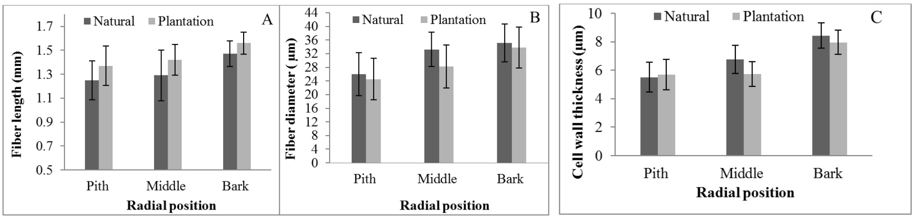

Fig. 3: Radial variation in mean fiber dimensions properties of Alnus glutinosa wood from natural and plantation forests.

Cell wall thickness

The analysis of variance (ANOVA) indicated that the cultivation methods (*F=0.539, sig=0.465*) had not significant effects on the CWT, while radial position (*F= 3.311, sig = 0.040, P<0.05*) and their interaction effect (*sig = 0.028, P<0.05*) were significant. The value of CWT in natural forest is slightly higher than that in plantation forest (6.87 vs 6.48 µm). Highest and lowest of CWT were found near the bark and near the pith, respectively. The CWT was increased along radial position from pith towards the bark in both planting methods (Fig. 3c).

Relationship between wood various properties

The relationship between wood various properties in both planting methods were determined by Pearson correlation matrix (Tab. 1). There is a significant correlation between ARW and WD in both methods. The magnitude of relationship in plantation forest was stronger (r = -0.823) than the natural forest (r = - 0.671). In natural forest, FD had negative correlation (r = -0.822) with WD, while in plantation, FL had positive relationship with WD (r = 0.672). A negative correlation was observed between ARW and CWT in plantation trees (r =-0.821). There were no significant relationships between other wood properties in both cultivation methods.

Tab. 1: Relationship between various properties of Alnus glutinosa wood from natural and plantation forests.

Cultivation methods	Properties	ARW	FL	FD	CWT	WD
Natural alder forest	ARW	1				
	FL	-0.174	1			
	FD	0.615	0.132	1		
	CWT	0.001	-0.140	-0.018-	1	
	WD	-0.671*	0.314	0.822**	-0.308	1
Plantation alder forest	ARW	1				
	FL	0.566	1			
	FD	-0.465	0.174	1		
	CWT	-0.821**	-0.390	0.775*	1	
	WD	-0.823**	0.672*	0.023	0.511	1

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level ARW: annual ring width, WD: wood density, FL: fiber length, FD: fiber diameter, 175 CWT: cell wall thickness.

The effects of FL, FD, CWT and ARW on the WD in both cultivation methods were determined by forward stepwise regression (Tab. 2). WD was influenced by two variables in both cultivation methods. In natural forest, FD explained up to 67 % of the WD, complemented by the FL representing 18 % of total variation. In plantation forest, variations in WD were accounted for by the effect of ARW (67 %) and FD (16 %).

Tab. 2: Multiple stepwise correlation analyses for the relationship between wood density and wood properties from natural and plantation forests.

Cultivation methods	Wood parameters	Statistical parameters	1st parameter	2nd parameter
Natural	WD R=0.926	Variable	FD**	FL**
		R2 ap.	0.676	0.182
		R2 mul.	0.676	0.858
Plantaion	WD R=0.917	Variable	ARW**	FD**
		R2 ap.	0.677	0.165
		R2 mul.	0.677	0.842

** Statistically significant at 99 % confidence; R^2ap: Contribution of the parameter to the 187 coefficient of determination; R2mul: Multiple coefficient of determination. ARW: annual ring width, 188 WD: wood density, FL: fiber length, FD: fiber diameter, CWT: cell wall thickness.

In order to visualizing the behavior of the two main variables (FL and FD) on the WD for both cultivation methods, the Figs. 4a and 4b clearly presents the response serface for the two variables. In natural forest, the highest WD was obtained when FL was higher than 1.52 mm and FD is lower than 28 µm (Fig. 4a). For plantation forest, the highest of WD was seen when ARW and FD was lower than 6 mm and 28 µm, respectively (Fig. 4b). In general, the FD had more effect on WD in both cultivation methods as shared variable.

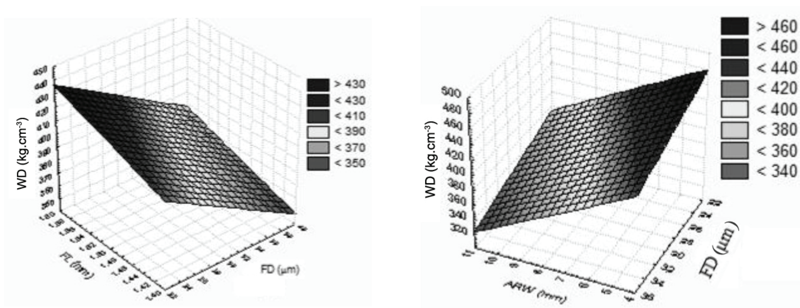

Fig. 4: Response surfaces for the most significant variable correlations between WD and wood characteristics in natural a) and plantation b) alder forests.

DISCUSSION

Cell dimensions and WD that are related to the cambium age and growth rate are main factors affecting wood properties. The patterns of WD variation and cell dimensions with age are associated with the process of cambium maturity and the assessment of the tree growth and development (Zobel and Van Buijtenen 1989; Adamopoulos et al. 2010). Our study indicated that the fiber dimensions and WD were increased with cambial age or distance from the pith, while ARW decreased in both cultivation methods. Increasing the WD, FL, FD and CWT and decreasing the ARW along radial direction was due to existence of great amount of juvenile wood around the pith during the early years of tree growth. This is supported by the fact that juvenile wood is usually known to have lower WD, wider ARW, shorter fibers, lower latewood percentage, thinner cell walls, lower mechanical properties, higher microfibril angles, and larger cell lumen than mature wood (Pinto et al. 2004; Moya and Tomazello 2007).

Many researches suggested that trees growing in plantations produce wood of the lowest properties (Zobel 1984; Zobel and Sprague 1998). For example, *Swietenia macrophylla* trees from natural forests had higher density than mahogany plantation trees (Langbour et al. 2011). *Alnus glutinosa* tress from natural forests in Turkey (Ors and Ay 1999) had higher WD to those from the plantation (396 kg.m^{-3}) and natural forests (391 kg.m^{-3}) evaluated in the present study.

In plantation trees, FL and ARW were significantly different from those of natural forest trees. The FL and ARW of plantation forest trees were 8 and 7 % respectively higher than those of natural forest trees, while FD in natural forest tress is higher compared to plantation forest for about 9 %. These change in wood properties reflects different growing conditions in two sites. The growing conditions in plantations are generally more favorable compared with those in natural forest that wood properties show different quality (Zobel 1984). In plantation, growth rates and fiber dimensions are higher (Zobel and Van Buijtenen 1989). These results was in line with other studies shown that trees from plantation-grown produce wood with different properties compared to the trees grown in the natural forest (Butterfield et al. 1993; Bauch and Dunish 2000).

Zobel and Van Buijtenen (1989) summarized the relationship between FL with growth rate in hardwoods. They concluded that faster growing trees usually showed shorter fibers length. An inverse relationship between FL and ARW was observed in some conifers and hardwood species (Ahmad 1970; Dutilleul et al. 1998; Fujiwara and Yang 2000; Adamopoulos et al. 2010; and Moya and Tomazello 2007). A positive relationship between FL and ARW was stated in trembling aspen by Fujiwara and Yang (2000). In balsam fir, the FL tended to level off below 1 mm ring width, but decreased as ARW increased above 1 mm (Fujiwara and Yang 2000). Although, our study indicated that the relationship between FL and ARW was not significant in both cultivation methods for alder wood, positive relation between ARW and FL was found in plantation alder forest, which agreed with results about aspen (Fujiwara and Yang 2000). However, negative correlation of ARW with FL for natural forest was in agreement with several studied for *Gmelina arborea*, black locust and chestnut (Moya and Tomazello 2007; Adamopoulos et al. 2010).

No relationship between ARW-CWT was found in natural forest tress, while there was a negative correlation between ARW and CWT in plantation trees ($r = -0.821$). This was supported by Lei et al. (1997) on *Alnus rubra* wood, Moya and Tomazello (2007) on Melina wood and Naji et al. (2015) on maple wood.

There are different reports about relationship between ARW and WD in hardwoods species. Negative correlation, positive correlation and no relationship between ARW-WD were stated by Adamopoulos et al. (2010), Moya and Tomazello (2007) and Naji et al. (2015). The present study indicated that the WD had negative correlation with ARW in both cultivation methods. These relationships between WD and ARW in plantation forest were stronger than that of natural forest.

Strong correlations between fiber dimensions and WD was reported for both hardwoods and softwoods (Zobel and Van Buijtenen 1989), which was in agreement with results of forward stepwise regression in this present research. Therefore, FD and FL in natural forest trees and ARW and FD in plantation forest tress had important effect on variation of WD. It can be seen that FD is an important variable affecting on WD from samples of both natural and plantation trees.

CONCLUSIONS

Statistical analyses revealed significant differences between natural forest tress and plantation forest trees in FL, FD and ARW. The mean of FL and ARW in plantation forest trees was higher than the natural forest trees. The FD value in plantation forest trees was lower than that of natural forest.

Radial position had significant effect on the FL, FD, CWT, WD and ARW. The average of fiber dimensions and WD were increased with distance from pith. With increasing of cambial age, the ARW were decreased.

There was negative relationship between WD and ARW in natural forest trees. Other relationships between wood various properties were not significant. In forward stepwise regression, FD and FL had important effect on the variation of WD than other variables.

In plantation forest, there were significant and negative relationships between CWT and WD with ARW. Positive correlation was observed between WD and FL in plantation trees. Other relationships between wood various properties were not significant. In forward stepwise regression, ARW and FD had great effect on the variation of WD than other variables.

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