

Formation of Juvenile/Mature Wood in *Pinus eldarica medw* and Related Wood Properties

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Abstract: The aims of this study were: a) to investigate anatomical properties (tracheid length and annual ring width) and to examine the age of transition from juvenile to mature wood, b) to examine physical properties (oven dry density and volumetric shrinkage) in juvenile and mature wood, c) to determine the relationship among the wood various properties in juvenile/mature wood. Results showed that with increasing cambial age (ring from pith), the values of tracheid length and annual ring width increased and decreased, respectively. The duration of juvenile wood was 24 year. The wood density and volume shrinkage content are higher in the mature wood while tracheid length is taller. After determining the age of transition (24 yr), the relationship between tracheid length and ring width and also between the wood density and volume shrinkage were investigated in the juvenile and mature wood by linear regression. According to this correlation, there was a negative relationship between tracheid length and ring width, but this relation in juvenile wood was stronger than mature wood. In addition, the correlation between the wood density and volumetric shrinkage in juvenile wood was weaker than mature wood.

Key words: *Pinus eldarica Medw* • Juvenile/mature wood • Wood density • Tracheid length • Annual ring width

INTRODUCTION

Juvenile wood is one of the most important sources of between-tree and inter-tree wood variation, particularly in conifers [1]. Because of the impacts of juvenile wood characteristics on the end products, it is necessary to have an accurate estimation of the proportion and size of juvenile wood core in a tree or sawlog. This allows the separation of juvenile from mature wood materials, thus minimizing the negative influence on end products [2]. The concept of juvenile wood and its formation is discussed in numerous publications [3, 4]. Juvenile wood forms a central core around the pith from the base up to the top of the tree [5, 6] following the crown as it grows. Juvenile wood is found in softwoods and hardwoods and is usually of lower quality, especially in conifers, than mature wood. Typically, properties of juvenile wood make a gradual transition toward those of mature wood. For example in conifers higher ring width, longitudinal shrinkage and grain angle, lower specific gravity, cell length and modulus of elasticity is found wood in juvenile wood in tree is mainly influenced by genetic factors, tree species, size of growth rings up to a distinct cambial age and the active live grown. For Douglas-fir and Norway spruce the size and length of the active live crown seems

to regulate the quantity and quality of juvenile wood [7].

For one reason some species show indistinct juvenile-mature transition zone as spruce (*Picea spp.*), fir (*Abies spp.*) and cypress (*Cupressus spp.*), some show clear transition from juvenile to mature wood as Scots pine, Spruce, Douglas-fir and most hard pines [2]. Furthermore the boundary of this zone depends upon the property measured [8]. Variables that have been taken mostly into account are tracheid length, fibril angle, longitudinal shrinkage, lignin/cellulose ratio and wood density. Based on tracheid length, Yang and Hazenberg (1994) [9] determined that the transition between juvenile wood and mature wood occurred between ring 11 and ring 21 in black spruce (*Picea mariana*).

It is necessary that we develop large-scale plantations to meet the increased wood demand that is expected in the future. The wood quality that will be supplied by these plantations is important. Properties of wood and wood-based products are closely connected with anatomical structure [6, 10]. Cell length increases rapidly outward from the pith during the juvenile period of the tree. After this early increase, cell length fluctuates in the outer rings. It has been proposed that the cell length of mature wood is related to growth rate, but conflicting results have been reported about this relationship.

An inverse relationship between cell length and ring width has been observed in conifers by Chalk (1930) [11], Bisset *et al.* (1951) [12], Strickland and Goddard (1966) [13], Ahmad (1970) [14], Dutilleul *et al.* (1998) [15] and in hardwoods by Liese and Ammer (1958) [16]. A positive relationship between cell length and ring width has been observed in conifers by Echols (1958) [17] and in hardwoods by Kennedy (1957) [18]. Echols (1955) [19] and Marton *et al.* (1968) [20] reported no relationship between the cell length and ring width in conifers and hardwoods, respectively. With regard to the relationship between ring width and tracheid length, Bannan's investigations of conifers showed that the maximum cell length was associated with a ring width of 1 mm and cell length decreased in both wide and narrow rings [21, 22, 23].

The objectives of the present study were about *Pinus eldarica* Medw species: a) to investigate anatomical properties (tracheid length and annual ring width) and to examine the age of transition from juvenile to mature wood, b) to examine physical properties in juvenile and mature wood, c) to determine the relationship among the wood various properties in juvenile/mature wood.

MATERIALS AND METHODS

In this research, 3 normal *Pinus eldarica* Medw trees were randomly selected from a plantation at the Garagpas-Kelardashat site, which is located in the western part of the Mazandran province in the north of Iran. These trees have been formed for 35 yr in the above site. The annual rainfall and annual average of temperature (1976~2008) was 434.9 mm and 9.6°C, respectively. October and November are high-rain months and June and July are low-rain months. The temperature in June, July and August reaches to its maximum level. *Pinus eldarica* Medw is mixed with *Pinus sylvestris*, *Pinus nigra* and *Picea abies* at the Kelardashat site. The *Pinus eldarica* trees were cut for this study in January 2009. Table 1 shows the characteristics of the trees and the district from which the samples were taken.

Anatomical Properties: A 5-cm-thick disc was removed from each tree at breast height level to study the anatomical (annual ring width and tracheid length) properties. Width of every 3rd annual ring was measured using a Normal Binocular and Lintab 5 ring width measuring system (Rinnteech Company, Germany). The tracheid length of the latewood of every 3rd ring from the pith was measured for each of the tree sample disks.

Table 1: The characteristics of the test areas and trees

Tree No	1	2	3
Elevation (m)	1256	1276	1238
Slope (%)	15	15	15
Exposure	North	North	North
Age	35	35	35
Soil type	Clay	Clay	Clay
Latitude	51°10'29"E	51°10'29"E	51°10'37"E
Longitude	36°29'48"N	36°29'46"N	36°29'50"N
Annual rainfall (mm)	434.9	434.9	434.9
annual average temperature (°C)	9.6	9.6	9.6
Tree diameter (mm)	306	302	300
Tree height (m)	17.6	17.5	17.8

After macerating with Jeffrey's solution (10% nitric acid: 10% chromic acid: water, 1: 1: 18), the length of 20 tracheids per growth ring were measured a using Leica Image Analysis System.

Physical Properties: A 5-cm-thick disc was removed from each tree at breast height level to study the physical properties. Sample dimensions to determine the physical properties (oven dry density and volume shrinkage) were 2 cm in the longitudinal, radial and tangential direction based on ASTM 143-94. After determining the age of transition by tracheid length, the samples were taken from juvenile wood and mature wood.

Statistical Analysis: To determine the effect of cambial age (ring from pith) on the anatomical properties (annual ring width, tracheid length), the statistical analysis was conducted using SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. Duncan multiply range test (DMRT) was used to test the statistical significance at $\alpha = 0.05$ levels. T-test statistical method was used for comparing the anatomical and physical properties between juvenile and mature wood. The linear regression model was used to analyze the relationship between the ring width and tracheid length and also for wood density with volumetric shrinkage in juvenile and mature wood.

RESULTS

Table 2 shows the results of the descriptive statistics of Eladr pine wood in terms of their anatomical properties (tracheid length and ring width). Differences between cambial age (rings from pith) were tested at the level $p < 0.05$ and significant distinctions were marked with letters a, b, c, d, e, f. tracheids are shorter in juvenile wood than

Table 2: Average and descriptive statistics of anatomical properties of Eldar pine

Cambial age (yr)	Tracheid length (mm)	Annual ring width (mm)
3	1.79 a	4.64 de
6	1.94 ab	6.24 f
9	2.1 b	5.34 ef
12	2.36 c	5.57 ef
15	2.59 d	4.60 de
18	2.68 d	3.47 cd
21	3.02 e	3.68 cd
24	3.23 f	3.35 bcd
27	3.23 f	2.31 abc
30	3.24 f	1.95 ab
33	3.29 f	1.70 a
35	3.38 f	1.36 a

Results with different letters are significantly different (Duncan test)

Table 3: Average and descriptive statistics of the anatomical properties of Eldar pine

Properties	Tracheid length (mm)		Ring width (mm)	
	Juvenile wood	Mature wood	Juvenile wood	Mature wood
N	21	15	21	15
Mean	2.32	3.40	4.79	2.13
Max	3.97	4.61	6.50	4.42
Min	1.21	2.14	2.45	1.29
Standard deviation	0.590	0.55	1.19	0.90

Table 4: Average and descriptive statistics of the physical properties of Eldar pine

Properties	Oven dry density (gr cm^{-3})		Volumetric shrinkage (%)	
	Juvenile wood	Mature wood	Juvenile wood	Mature wood
N	36	16	36	16
Mean	0.44	0.49	11.24	12.40
Max	0.51	0.56	14.03	15.51
Min	0.36	0.43	7.80	6.33
Standard deviation	0.034	0.040	1.69	2.49

in mature wood (Table 3) so that there are significant different between mature wood and juvenile wood in tracheid length. A rapid increase of tracheid length was observed from the pith to about 3rd~24th growth ring. Changes of tracheid length in the mature wood zone were very small. On the other hand, the age of transition from juvenile wood to mature wood was 24 yr (rings from pith). Because the Duncan's table categorizes the average of tracheid length at 24~35 rings from pith in only 1 group (f group).

The mean annual ring width has been found to increase rapidly from the 1st up to the 12th annual ring and then it decreases up to the 21st growth ring from pith remaining more or less constant in the mature wood.

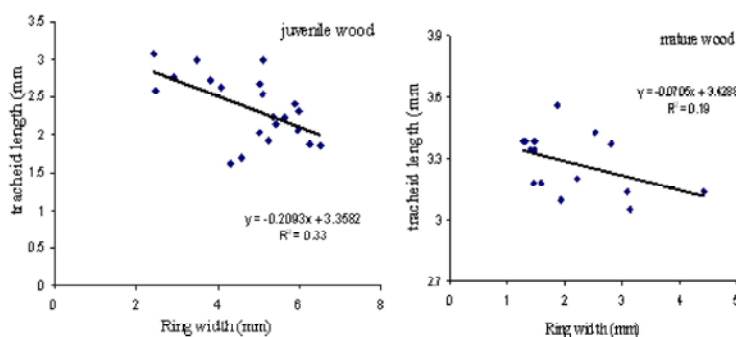


Fig. 1: The relationship between ring width and tracheid length in juvenile wood and mature wood.

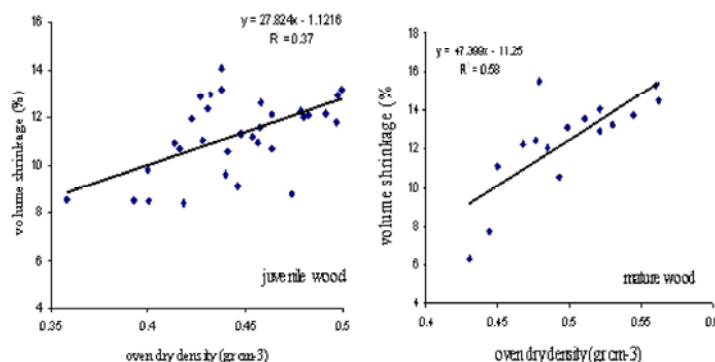


Fig. 2: The relationship between oven dry density and volume shrinkage in juvenile wood and mature wood

Juvenile wood had wider annual ring width compared to the mature wood (Table 3) so that the difference in the annual ring width between juvenile and mature wood was significant at the level mentioned above. After determining the age of transition by tracheid length, the relationship between tracheid length and ring width in juvenile and mature wood were investigated. The correlation results showed that there is a negative relationship between the ring width and tracheid length, but this relationship in mature wood ($R^2 = 0.19$) had lower than juvenile wood ($R^2 = 0.33$, Fig. 1).

Table 4 shows the results of the descriptive statistics of the physical properties of Eldar pine wood. The wood density and volumetric shrinkage of mature wood was found to be higher compared to the juvenile wood so that the difference in the physical trait between juvenile and mature wood was significant. The correlation results showed that there is a positive relationship between the wood density and volumetric shrinkage so that this correlation in mature wood ($R^2 = 0.58$) is stronger than juvenile wood ($R^2 = 0.37$) (Fig. 2).

DISCUSSION

In the present research, wood properties of juvenile and mature wood were studied. Tracheid length increased rapidly with cambial age up to about 24 year and then increased gradually thereafter but annual ring width content decreased. Koizumi *et al.* (2003) determined the transition between juvenile wood and mature wood occurred ring 20 in *larix sibirica* [24].

Tracheid length, wood density and volume shrinkage content were higher in the mature wood while ring width was lower. In this direction, Evans *et al.* (2000) and Guler *et al.* (2007) studied the effect of juvenile wood on the mechanical and physical properties of red alder (*Alnus rubra*) and *Pinus nigra*, respectively [25, 26]. They found that tree growth in the 1st 10~20 yr reduced the mechanical strength properties of the tree species [25]. In addition, juvenile wood is characterized by a lower density, shorter tracheids or fibers, lower latewood percentage, thinner cell walls, smaller tangential cell dimensions, more ring width, lower cellulose content, lower strength, higher longitudinal shrinkage, higher microfibrill angle, larger cell lumen, more reaction wood, more spiral grain, higher lignin, lower holocellulose, lower extractive content and a higher degree of knottiness than mature wood [1, 26, 27]. Mature wood in softwoods is defined by a relatively constant tracheid length, whereas juvenile wood is characterized by an increasing tracheid

length [9]. Densities of juvenile woods are lower because they contain relatively few latewood cells. Earlywood cells found in a high proportion in juvenile wood have a thin wall layer that is one of the reasons for lower density [6].

The correlation results showed that the relationship between the wood densities with volume shrinkage in mature wood had stronger than juvenile wood. The volumetric shrinkage and swelling properties are affected by several wood factors such as heartwood-sapwood ratio, fibrillar angle on S_2 layer, etc [28]. But the most important parameter affecting wood shrinkage is the wood density [26]. Also this correlation between ring width and tracheid length was negative so that this correlation in juvenile wood was higher than mature wood which reported by Fujiwara and Yang (2000) [29]. They stated that there was a negative relationship between the cell length and ring width in jack pine ($R^2 = 0.508$).

CONCLUSION

The following results were obtained in the present study:

- ANOVA indicates that significant difference in tracheid length and ring width existed between annual rings from pith. The transition between juvenile and mature wood occurred ring 24 yr in pine wood.
- Statistical results indicated that significant differences in the anatomical and physical properties existed between mature wood and juvenile wood so that the physical properties and tracheid length in mature wood was more than juvenile wood. In addition, ring width in juvenile wood was wider than mature wood. Juvenile wood reduce the physical and mechanical strength properties of pine wood.
- There was a positive correlation between wood density and volumetric shrinkage, while this correlation in mature wood was stronger than juvenile wood. Negative relationship existed between tracheid length and annual ring width so that this relation in juvenile wood was higher than mature wood.

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