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The Within-tree Variation in Wood Density and Mechanical Properties and Their Relationship in *Juniperus polycarpos*

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Abstract

The variations of wood density and mechanical properties of *Juniperus polycarpos* trees were studied in a natural forest in Iran. Sample disks were taken from each tree to examine wood density and mechanical properties (MOE and MOR) from pith to bark at breast height, 50%, and 75% of total tree height. The analysis of variance (ANOVA) indicated that radial position and height significantly affected all wood properties. The wood density, MOE and MOR were decreased along horizontal position from the pith to the bark and vertical direction from base upwards. Regression analysis showed that modulus of elasticity (MOE) and modulus of rupture (MOR) had a positive correlation with wood density.

Key Words: *Juniperus polycarpos*, density, modulus of elasticity, modulus of rupture

Introduction

Juniperus polycarpos known as Persian juniper is a dioecious tree up to 6-7 m tall or a low shrub with dense head (Emami et al. 2011). It is one of the dominant species of the Junipero- Pistacietea steppe forest in the interior basins of Iran (Liphschitz et al. 1979). It is also widely distributed in other areas such as south-east Arabia, Iran, Caucasus, Baluchistan, Afghanistan, north-west Himalaya (Townsend and Guest 1966), Armenia, India, Uzbekistan and Pakistan (Saderi et al. 2013).

In Iran, Persian juniper is distributed on the southern slopes of the high mountains of Alborz, in the northern parts of Khorassan and Arassbaran and also in some central mountains (Diavanshir 1974). However, juniper forests are mostly located in the north-east of Iran, at an elevation of 1500 to 2500 m above sea level (Fadaei et al. 2009) but have been seen as far south as Bandar Abbas close to the Persian Gulf. The significant role of the Persian juniper in soil protection and its ability to grow in very adverse climatic condition make it an important species in Iran. Its high resistance to frost enables it to grow in areas where the minimum temperature is -35°C (Saderi et al. 2013).

Wood density is an important wood property for both solid wood and fiber products in both conifers and hardwoods (Donaldson et al. 1995). Panshin and de Zeeuw (1980) reported that density is a general indicator of cell size and is a good predictor of strength, stiffness, ease of drying, machining, hardness and various paper making properties. Density within a tree varies from pith to bark and with height in the stem. Wood density varies from earlywood tissue to latewood tissue within each annual ring. Latewood tissue is composed of cells of relatively small radial diameter with a thick wall and a small lumen and there-

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fore, has a higher density than thin walled earlywood cells with a larger cell lumen (Haygreen and Bowyer 1996).

In a study carried out by Harvald and Olesen (1987) on the variation of basic density within the juvenile wood of Sitka spruce, it was found that basic density decreased with increasing height in the stem. Donaldson et al. (1995) reported a similar trend in Monterey pine grown in New Zealand. Simpson and Denne (1997) found that for comparable ring numbers, wood density was slightly greater at breast height than higher up in the tree. A similar pattern was noted by Harvald and Olesen (1987). Mitchell and Denne (1997) attributed this trend in density to the thicker tracheid walls that are found at breast height, than higher in the stem.

Most studies to date have focused on variation in wood properties (particularly density) throughout the tree (Zobel and Van Buijtenen 1989; Giménez and López 2002; Medina et al. 2013). However, fewer studies have analysed the variation in mechanical properties (Machado and Cruz 2005). In terms of mechanical properties, Machado and Cruz (2005) found a clear increase in MOR and MOE throughout the radial direction, from the pith to the bark. This increase is closely associated with the transition from juvenile to mature wood (Bao et al 2001; Beaulieu 2006). Pearson and Gilmore (1980) studied the variation in mechanical properties throughout the radial direction in P. taeda and found that the mean increase was more than 40% for trees aged 41 years and that the increase was greater the younger the tree was. In *Picea abies*, Kliger et al. (1998) observed an increase of more than 30% in MOE and MOR between wood near the pith and mature wood.

There is plenty of information on wood formation of *Juniperus polycarpos* (Saderi et al. 2013), while data on physical and mechanical properties are not available for the studied species. We reported some of the density and some of mechanical properties variation (MOE and MOR) along radial direction and axial position and the relationship between wood density and mechanical properties (MOE and MOR) for studied species.

Materials and Methods

The study was carried out in a Juniper forest in the mountains of Hazarmasjed (altitude 3,123 m, type of climate is dry-cold), Dargaz, north-east Iran. In total, 4 *Juniperus polycarpos* trees (with stem height 6 m, age 35 years-old, and diameter at breast height 24 cm) were chosen in this region. All the trees were randomly selected, taking in to account stem straightness and the absence of obvious decay. The sample logs (50 cm) were taken from different height levels (breast height level, 50% and 75%) of total tree height. Testing samples (three samples) were taken along radial position from pith to the bark at each of stem height to determine wood density and some of mechanical properties.

Wood density

The samples were oven-dried at 103±2°C and afterwards the volume was defined using a Breuil volume meter. The oven-dry density was calculated according to ISO 3131 standard was based on the oven dry mass and volume:

$$p_0 = \frac{m_0}{V_0}$$

Where

p_0 is the oven-dry density (kg/m^3)

m_0 is the mass of the oven dried sample (kg)

V_0 is the volume of the oven dried samples (m^3)

MOE and MOR

According to the ASTMD143 standard (second method), the sample dimensions were 25x25x410 mm for static bending strength tests, such as modulus of rupture (MOR) and modulus of elasticity (MOE). The prepared samples were then conditioned in a room at a temperature of 20 °C and 65±5% relative humidity until the specimens reached an equilibrium moisture content of about 12%. The load was applied in the tangential direction. The modulus of rupture (MOR) and modulus of elasticity (MOE) were computed using the equations:

$$MOR = 3 \times P_{max} \times l/2 \times b \times h^2$$
$$MOE = P \times l^3/4 \times D \times b \times h^3$$

where P=load at the limit of proportionality (kN); P_{max}= maximum load (kN), l=span of the test specimen (mm), b=breadth of the test specimen (mm), h=depth of the test specimen (mm) and D=deflection at the limit of proportionality (mm).

Statistical analysis

In this research, the effect of radial direction and axial position on the density and some of mechanical properties (MOR and MOE) of Juniper wood were studied. Statistical analysis was conducted using the SPSS program in conjunction with analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to test statistical significance at the $\alpha = 0.05$ level. The simple linear regression model (REG procedure) was used to analyze the relationship between wood density and mechanical properties (MOE and MOR).

Results

The analysis of variance (ANOVA) indicated that the radial position and longitudinal direction had significant differences on the wood density, modulus of elasticity (MOE), and modulus of rupture (MOR). The interaction between radial and axial directions on the MOE and MOR was not significant except wood density (Table 1).

The pattern of variation in density, MOE and MOR, as a function of the stem height, is shown in Table 2. The density, MOE and MOR decreased along radial position with distance from the pith and along vertical direction from base to up of stem height. Within the samples, at the same height level wood density, MOE and MOR decreased from the pith to the bark (Table 3). The relationship between wood density with MOE and MOR were analyzed

Table 1. Results from ANOVA: F-value (in analysis of variance) of the results of wood properties in juniper trees growing in Iran

Wood properties	Density	MOE	MOR
Height (A)	2.770*	8.178**	51.610**
Radial position (B)	71.49**	29.630 **	14.797^{ns}
AxB	3.050^{s}	2.795^{ns}	1.619^{ns}

Ns, not significant; *significant at 0.05 level; **significant at 0.01 level.

Table 2. Average of wood properties according to the stem height

Height levels	Density (kg/m^3)	MOE (GPa)	MOR (MPa)
Breast height	453 a	4.8 a	55.73 a
50%	443 b	4.48 ab	42.11 a
75%	443 b	4.33 b	27.04 b

Table 3. Variation in wood properties according to stem height and distance from the pith to the bark

Height levels	Radial position from the pith to the bark		
	1	2	3
Breast height			
Density (kg/m^3)	500 (44)	460 (42)	400 (25)
MOE (GPa)	5.15 (0.27)	4.8 (0.16)	4.45 (0.35)
MOR (MPa)	63.65 (6.71)	54.55 (4.73)	49 (9.75)
50%			
Density (kg/m^3)	490 (49)	450 (29)	390 (19)
MOE (GPa)	4.61 (0.34)	4.55 (0.21)	4.3 (0.14)
MOR (MPa)	45.05 (1.06)	44.65 (3.18)	36.65 (4.59)
75%			
Density (kg/m^3)	490 (39)	410 (12)	400 (13)
MOE (GPa)	4.8 (0.14)	4.65 (0.17)	3.55 (0.35)
MOR (MPa)	40.1 (2.97)	24.01 (1.13)	17.3 (2.96)
Average			
Density (kg/m^3)	495 a	440 b	396 c
MOE (GPa)	4.85 a	4.66 a	4.10 b
MOR (MPa)	49.60 a	41.07 b	34.31 c

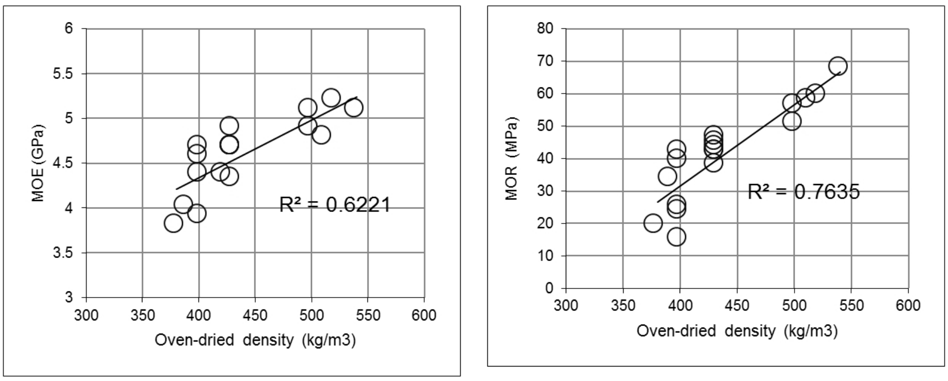

Fig. 1. the relationship between density and mechanical properties (MOE and MOR) of juniper wood.

by linear regression (y=ax+b). Positive correlations were found between wood density and MOR (R^2=0.764) and MOE (R^2=0.622). This relationship between wood density-MOR is stronger compared to the relationship between wood density-MOE (Fig. 1).

Discussion

Decreasing trend of wood density and mechanical properties (MOE and MOR) were found along axial direction from base to up of stem height. This finding may be attributable to variation of these properties throughout the stem being greatly influenced by the presence of juvenile wood (in up of stem height), as observed by Machado and Cruz (2005) in a study of *P. pinaster*. This is supported by the fact that the juvenile wood is usually known to be of a lower density than mature wood. It is well-known that wood density correlates significantly with mechanical properties (Donaldson et al. 1995; Zhang 1997).

Some researchers have reported that wood density and mechanical properties decreases with age or distance from pith due to existence of heartwood around the pith and it chemical structures. It is well-known that the extractives content in heart wood is higher than compared to sapwood. When lumber or other products are cut from the stem, the characteristics of these fibrous cells and their arrangement affect wood properties such as strength and shrinkage, as well as the grain pattern (Ayobi et al. 2011; Merela and Cufar 2013). The formation of heartwood is a natural aging process (Bosshard 1968); development of sapwood into heartwood takes place in a relatively narrow transition zone, perhaps only the width of one or two growth increments (Bamber and Fukazawa 1985). Sapwood is involved in the transport of water and minerals from the roots and due to their function sapwood cells contain more water and lack the deposits of darkly staining chemical substances commonly found in heartwood. Many of these differences between sapwood and heartwood are chemical; in some cases heartwood substances impregnate cell walls, in others they can also be found in the cell lumen. The amount of starch in parenchyma cells declines in older sapwood and is completely metabolized when sapwood is transformed to heartwood (Taylor et al. 2002). The death of parenchyma cells occurs as a consequence of the accumulation of toxic excretory products of metabolism (Zimmermann and Brown 1971). Such excretions are trans-located through parenchyma cells towards the center of the tree (pith), around which the cylinder of heartwood is formed and gradually expanded (Tsoumis 1991).

There are positive correlations between wood density and mechanical properties (MOR and MOE) in this study. Coefficient correlation between wood density and MOR is stronger than other relationship. The existence of a linear relationship between wood density and strength has been demonstrated by several investigators (Cave and Walker 1994; Zhang 1997). Similarly, it has been found that within the range of density found in most species, an approximately linear relationship exists between strength and wood density. Thus, Mitchell (1963) reported that a 0.02 change in specific gravity represents a change of 70 kg cm-2 in the modulus of rupture of clear wood. Density was a poor indicator of modulus of elasticity (Cave and Walker 1994).

Conclusion

In this study, density and mechanical properties of juniper wood along horizontal and vertical axes were studied. The remarks of this research could be concluded as follow:

There are significant differences between vertical and horizontal position with density, MOR and MOE in juniper wood. The wood density, MOE and MOR were decreased along radial position from the pith to the bark. The wood density, MOE and MOR were decreased along axial position from base to up of stem height. There are strong relationship between wood density and mechanical properties in juniper wood.

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