Short communication. Radial variations of wood different properties in *Diospyros lotus*

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Abstract

Aim of study: The aim of this study was to determine some of the physical, biometry and mechanical strength properties of *Diospyros lotu*s L. wood along radial direction from the pith to the bark and the relationship between wood various properties.

Area of study: The study area is located in north Iran in the province of Mazandarn.

Material and methods: Testing samples were taken at breast height of tree stem and three radial position of stem radius to determine physical (basic density), fiber biometry (fiber length, fiber diameter, cell-wall thickness) and mechanical properties (modulus of rupture and modulus of elasticity).

Main results: The results of ANOVA indicated that there are significant differences along radial direction in above mentioned properties for persimmon wood. Basic density, fiber length, fiber diameter, cell-wall thickness, modulus of elasticity and modulus of rupture increased along radial direction from pith toward the bark.

Research highlights: The persimmon wood isn't suitable for pulp and paper production due to the unfavorable flexibility and Runkel coefficients.

Key words: *Diospyros lotus;* basic density; fiber features; modulus of rupture; modulus of elasticity.

Introduction

*Diospyros lotu*s is one of diffuse-porous hardwood species that formes about 8.5 percent of area of the Iran's Northern Forests. This species is from Ebenaceae family, which grows naturally from Astara (Guilan province) to Gorgan (Golestan province) in Iran (Parsapajouh, 1998). Some of *Diospyros* genus (there are 500 species of *Diospyros* in the tropical to temperature region) is used in high-quality furniture, sculptures and musical instruments due to black heart wood, and their extractives have been investigated for medicinal uses (Node *et al*., 2002; Matsushitay *et al*., 2011; Jang *et al*., 2011).

Fiber dimensions are important indexes for pulp and paper production. These indexes have positive influence on the quality of pulp and paper (Wangaard and Woodson, 1973; Panshin and De Zeeuw, 1980) and wood mechanical strength properties (Bisset *et al.,* 1951). Modulus of rupture (MOR) and modulus of elasticity (MOE) are important characteristics for the use of wood as a structural application. MOR and MOE are indication of the wood bending strength and stiffness, respectively. The relationship between Modulus of rupture and modulus of elasticity with wood density is very strong for different hardwood and softwood species (Zhang, 1997). A study on the physical and chemical characteristics of the blackened portion of Japanese persimmon (*Diospyros kaki*) indicated that the specific gravity, modulus of elasticity (MOE) and modulus of rupture (MOR) in the blackened heartwood is higher, and the loss tangent is lower, than those in sapwood (Noda *et al.,* 2002).

The information about the effect of radial pattern on the wood different properties is not available for *Diospyros lotus* L. in Iran. Therefore, to use this material property and efficiently, it is requisite to know its different properties. This study sought to examine the variations of basic density, fiber dimensions (length, diameter and thickness) and mechanical strength properties (MOE and MOR) along radial direction, from pith toward the bark and to determine relationships between wood different properties in *Diospyros lotus* L.

Material and methods

Six samples persimmon trees (*Diospyros lotu*s L.) were collected from a stand located in the Noshahr region, north of Iran, 51° 27' 45" E and 36° 33' 15" N, at an altitude of 300 m. the age and height of trees were 25 years-old and 14.3 m respectively. The soil texture of this region was clay to clay-loam with a clay percentage of 30-35%. The annual rainfall and annual average temperature was 1,302 mm and 16°C, respectively. A log, 60 cm in thickness, was removed from each tree at breast height to evaluation the mechanical properties (MOE and MOR), fiber features (fiber length, fiber diameter, fiber cell wall thickness) and physical properties (basic density). Testing samples were taken along radial direction from pith to the bark (three radial positions of stem radius). The number of samples was 72 for wood basic density, fiber features and mechanical strength properties (6 trees × 4 geographical direction × 3 samples along radial position = 72 samples).

Physical properties (basic density)

In order to determine the wood basic density, samples with dimensions of 2 × 2 × 2 cm were prepared according to ISO-3131. The radial variation was also studied by preparing 3 samples, equal in size from the pith to the bark, in different geographical directions of each disk. The samples were soaked in distilled water for 72 h to ensure that their moisture content was above the fiber saturation point (FSP). Then the dimensions in all three principal directions were measured with a digital caliper to the nearest 0.001 mm. Finally, the samples were oven dried at $103 \pm 2°C$ to 0% moisture content. After cooling in desiccators, the oven-dry weights of the specimens were measured. The values of the wood basic density were determined using the following equations (D_b = basic density, p_0 = oven dried weight and v_s = saturated volume of specimen):

$$D_b = \frac{p_0}{v_s}$$

Fiber features

From Franklin (1964) method (hydrogen peroxide and glacial acetic in a 64°C oven for 24 hours) were used for fibers macerating, and these samples were washed by distilled water. The length, diameter and single-cell-wall thickness of 30 fibers of every sample were measured using the Leica Image Analysis System. From the fiber features data, fiber morphology values such as Runkel ratio (Runkel, 1949), slenderness ratio (Varghese *et al*., 1995) and flexibility ratio (Wangaard, 1962) were calculated according to the formulae (RR: Runkel ratio, CWT: cell wall thickness, FD: fiber diameter, FR: Flexibility ratio, LD: lumen diameter, FL: fiber length, SR: Slenderness ratio):

$$RR = \frac{2CWT}{LD}, \quad FR = \frac{LD}{FD} * 100, \quad SR = \frac{FL}{FD}$$

Mechanical properties (MOE and MOR)

According to the ASTMD143-94 standard (second method), the sample dimensions were $25 \times 25 \times 410$ mm for mechanical strength properties 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 $65 \pm 5\%$ relative humidity until the samples reached an equilibrium moisture content of about 12%. The load was applied in the tangential direction. The modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated using the following equation:

$$MOR = \frac{3P_{max}l}{2bh^2}$$

where P = load at the limit of proportionality (N); P_{max} = maximum load (N), 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

To determine the effect of radial direction on physical properties (wood basic density), fiber features (fiber length, fiber diameter and cell-wall thickness) and mechanical strength Properties (MOE and MOR), statistical analysis was conducted using the SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. Duncan's multiple range test (DMRT) was used to test the statistical significance at the $\alpha = 0.01$ levels. The linear regression mo-

del was used to analyze the relationship among the wood's various properties.

Results and discussion

The variations of wood different properties along radial position from the pith toward bark are shown in Fig. 1. According to this table, the wood basic density, fiber length, fiber diameter, cell wall thickness, modulus of elasticity and modulus of rupture along radial direction increased from the pith to the bark. The

analysis of variance (ANOVA) indicated that there are significant differences among samples of radial position in wood different properties. The reason of this phenomenon is because of juvenile cambium cells activities in the first years of growing (juvenile wood periods). The juvenile wood is explained by short fiber length, low wood density and low mechanical strength properties than mature wood. These results have reported by several researchers (Heräjärvi, 2004; Alteyrac *et al.,* 2006; Kord *et al*., 2010; Izekor and Fuwape, 2011; Ferreira *et al*., 2011; Naji *et al.,* 2012).
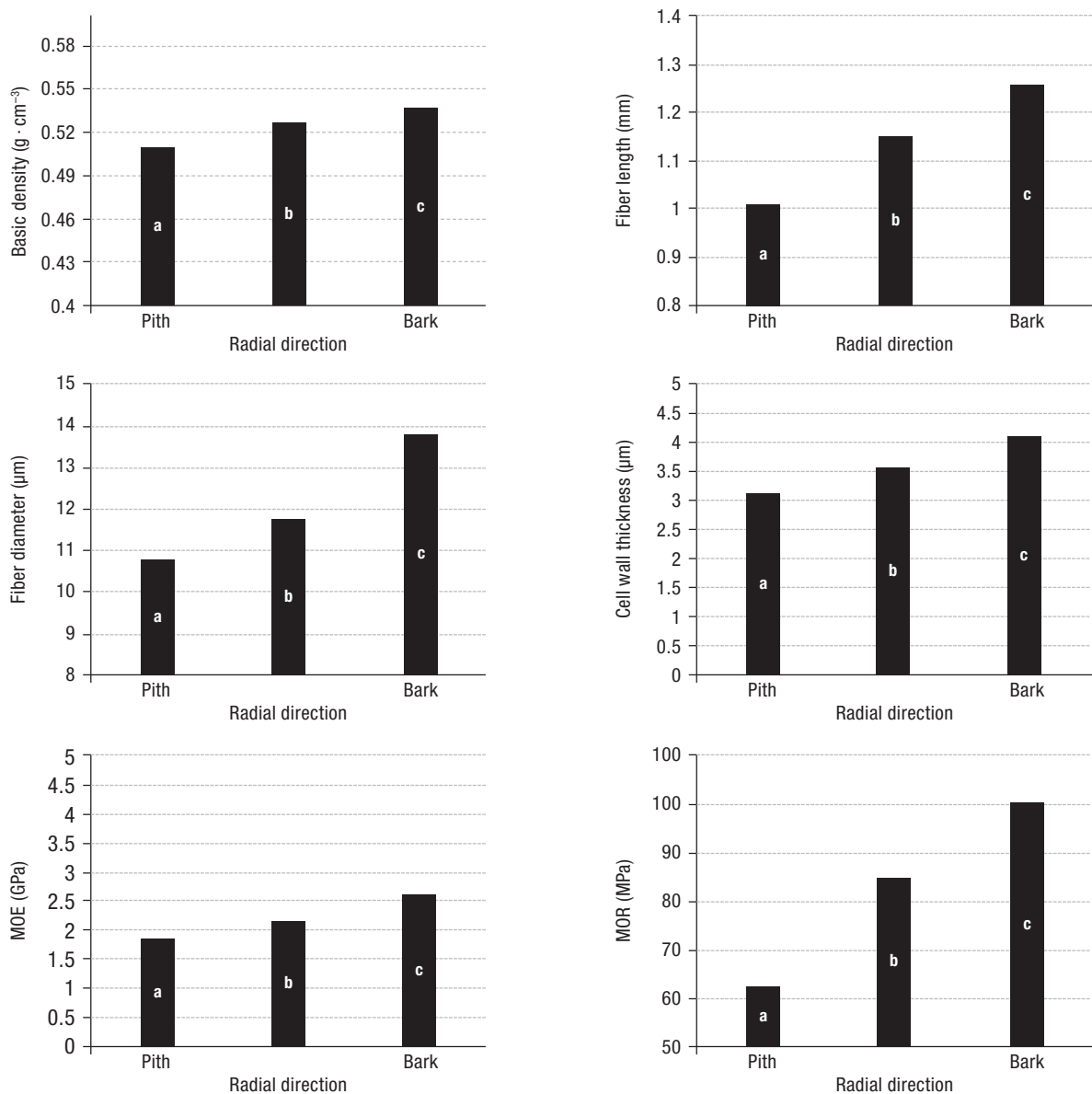

Figure 1. The radial variations of wood different properties in persimmon wood.

There are positive relationships between fiber length and burst strength (Casey 1952; Miyake 1968; El-Hosseiny and Anderson 1999; Ona *et al*. 2001), tensile strength (Casey 1952, Miyake 1968), tear strength (Casey 1952; Haygreen and Bowyer 1996) and folding endurance (Dinwoodie 1965; Ona *et al*. 2001). The fiber length of persimmon wood (1.13 mm) is lower than that of other hardwood such as *Populus euramricana* (Bektas *et al*. 1999), plane wood (Bektas *et al*. 1999), and hornbeam wood (Tank 1978) and is higher than robinia wood (Liao *et al*. 1981), and Eucalyptus (13-14 years; Hus *et al*. 1975). The fibers of hardwoods are categorized in three groups (Hosseini and Naghdi 2004) such as short fibers (< 900 μm), middle fibers (900-1,600 μm), and long (> 1,600 μm), which the studied species categorized in middle fibers. Generally, Wood species with long fibers are suitable for paper production, which this trait wasn't found in persimmon wood.

The results of mechanical strength properties of persimmon wood indicated that the values of modulus of elasticity (MOE) and modulus of rupture (MOR) were very lower than that of *Diospyros kaki* in USA (Alden, 1995). The values of MOE, MOR and wood oven-dry density of American persimmon wood were 13.859 GPa, 122.042 MPa and 0.78 g cm^{-3}, respectively.

From the fiber dimensions features, derived values (morphology properties) were calculated, such as Runkel ratio, flexibility ratio, slenderness ratio. The mean of flexibility ratio was 40.59%, slenderness ratio was 93.75 and Runkel coefficient was 1.47 for persimmon wood. Standard value of Runkel coefficient is 1. Favorable pulp strength properties are usually obtained when value of Runkel ratio is below the standard value (Xu *et al*., 2006; Ashori and Nourbakhsh, 2009). The average of Runkel coefficient was 1.47 so it isn't suitable for paper production. The Runkel ratio of persimmon wood (1.47) is more than that of other hardwood species such as plane (Bektas *et al*. 1999), eucalyptus (Hus *et al*. 1975), *Carpinus orientalis* (Tank 1978) Paulownia wood (Ashori and Nourbakhsh, 2009). There are four groups according to the flexibility ratio (Bektas *et al*.,1999): 1- high elastic fiber (having flexibility ratio greater than 75), 2- elastic fiber (flexibility coefficient between 50-75), 3- rigid fiber (flexibility ratio between 30-50), and 4- high rigid fibers (flexibility coefficient less than 30). As a result observed fibers of persimmon wood classify in rigid fibers group. The rigid fibers don't have efficient elasticity and they aren't suitable for paper production. Other calculated fiber properties is the slenderness ratio. The

acceptable values for slenderness ratio of papermaking are more than 33 (Xu *et al*., 2006; Enayati *et al*., 2009), which this status was found in the studied species. In general, there is a positive relationship between slenderness ratio and folding endurance (Dinwoodie, 1965; Ona *et al*., 2001), and between flexibility coefficient and burst (Ona *et al*., 2001), and breaking length and tear resistance (Mabilangan and Estudillo, 1996).

The relationships between fiber features and basic density were determined by linear regression analyses (Fig. 2). It was found that there are positive relationships between basic density and fiber features in the per-
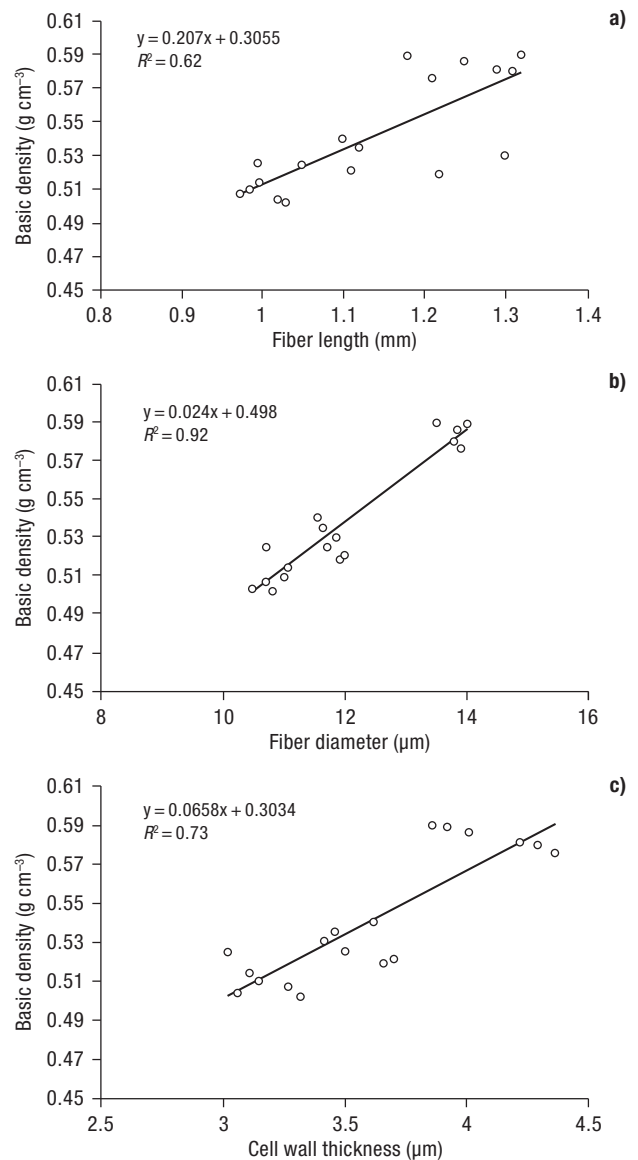

Figure 2. The relationship between basic density with fiber length (a), fiber diameter (b), and cell wall thickness (c) in persimmon wood.

simmon wood. The correlation coefficients between fiber diameter-basic density ($R^2 = 0.92$) are stronger that the relationship fiber length-basic density ($R^2 = 0.62$) and cell wall thickness-basic density ($R^2 = 0.73$).

The relationships between fiber features and mechanical strength properties (MOE, MOR) were determined by linear regression (Fig. 3). It was found that there are positive relationships between wood fiber properties and mechanical properties for *Diospyros lotus*. The relationships between fiber features (length, diameter, and thickness of fibers) and MOR is stronger than the relationship between fiber features and MOE in persimmon wood. These results were pre-

viously reported some researchers for other species (Clark, 1962; Zobel and Van Buijtenen, 1989). Although these relationships between fiber dimension (length, diameter and cell wall thickness) and wood basic density were strong, but other factors such as anatomical indexes can have major effect on the variation of wood basic density (Gominho *et al.,* 2001; Quilho *et al.*, 2006).

The relationships between wood basic density and mechanical strength properties (MOE, MOR) were determined by linear regression (Fig. 4). It was found that there are positive relationships between wood basic density with MOE and MOR for *Diospyros lotus*.
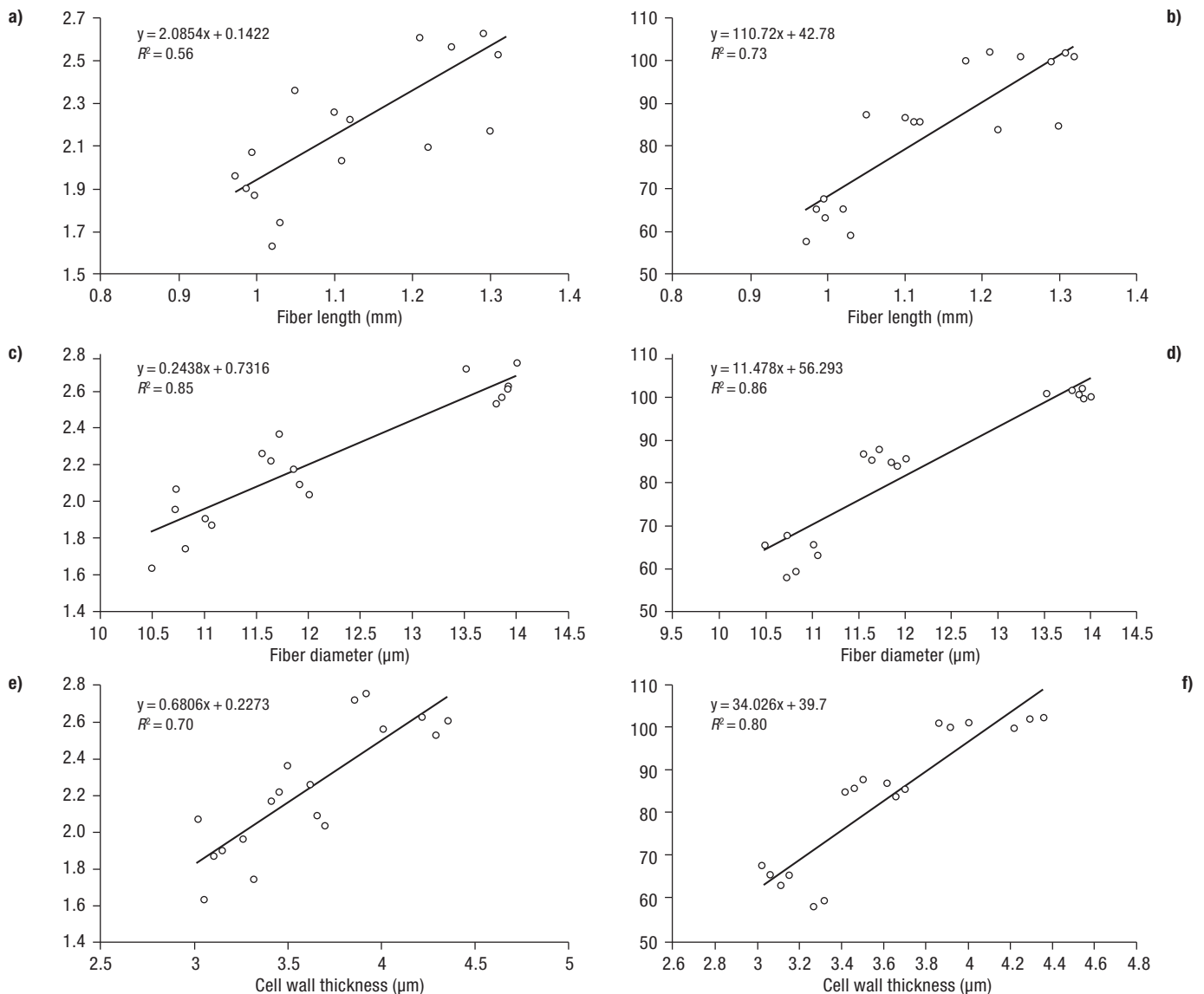

Figure 3. The relationships between fiber length with MOE (a) and MOR (b); The relationships between fiber diameter with MOE (c) and MOR (d); The relationships between cell wall thickness with MOE (e) and MOR (f).
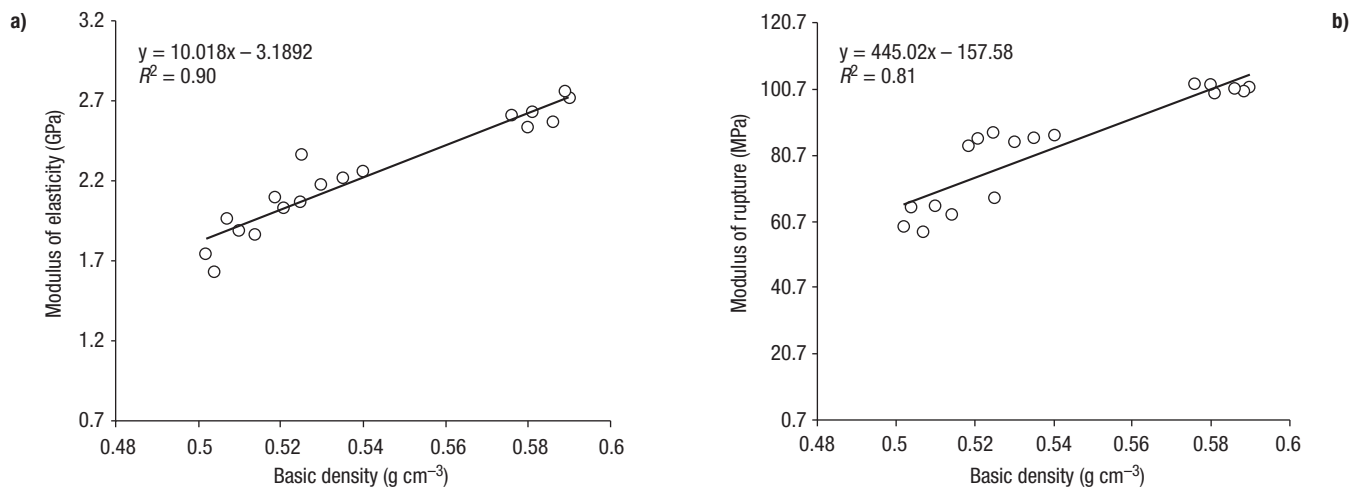
a)

$y = 10.018x − 3.1892$
$R^2 = 0.90$

Modulus of elasticity (GPa)

Basic density (g cm^{-3})

b)

$y = 445.02x − 157.58$
$R^2 = 0.81$

Modulus of rupture (MPa)

Basic density (g cm^{-3})

Figure 4. The relationship between basic density with MOE (a) and MOR (b) for persimmon wood.

The relationship between wood density and modulus of elasticity ($R^2 = 0.90$) is stronger than the relationship between wood density and modulus of rupture ($R^2 = 0.81$). The dependences of MOE and MOR on to wood density were previously reported by several researchers (Zhang, 1997; Heräjärvi, 2004; Kiaei, 2011) for some of softwood and hardwood species. The correlation coefficients between wood basic density with MOE and MOR for Iranian persimmon wood were determined 0.90 and 0.81, respectively.

Conclusion

1. The wood of *Diospyros lotus* trees is not suitable for pulp and papermaking due to unfavorable flexibility and Runkel coefficients and the length of middle fibers, and they can be used in fiber plate and cardboard production.

2. The wood of near the bark due to its high density and mechanical strength properties can be utilized in more structural applications than wood from near the pith.

3. Significant positive relationships have been found between fiber dimensions (length, diameter and thickness of fibers) with wood basic density and mechanical properties, and also basic density-mechanical strength properties, in the persimmon wood.

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