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Basic Density and Fiber Biometry Properties of Hornbeam Wood in Three Different Altitudes at Age 12

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Abstract: This study was carried to the influence of altitude above sea level on the wood density, fiber biometry and morphological properties of hornbeam wood (*Carpinus betulus L.*). A total of 15 normal hornbeam trees were sampled from three different altitudes include 300 m (low altitude), 750 m (intermediate altitude) and 1200 m (high altitude) in Mashelak forests (Noshahr province-north of Iran). Disks were taken at 25%, 50% and 75% of stem height. Results of ANOVA showed that the altitude and height of tree had effect on the wood density and fiber biometry properties of hornbeam. The interaction effects between altitude and height of tree on the wood density were not significant, but these effects on fiber properties were significant. With increase of altitude from sea level, the wood density, cell wall thickness and rankle ratio values were increased and the fiber length, fiber diameter, fiber lumen diameter, slenderness ratio and flexibility ratio values were decreased. In addition, the values of the wood density, fiber length, fiber diameter, cell wall thickness and rankle ratio were decreased with increasing of stem height. While the highest and lowest of fiber lumen diameter values were found in 75% and 50% of height tree, respectively.

Key words: Hornbeam · Altitude · Wood density · Fiber biometry properties

INTRODUCTION

Most of Iran's 7.3 million hectares of forests are found in the North, bordering the Caspian coastal plain and on the northern slopes of the Alborz mountain range. The Northern forest of Iran covered from Astara in northwestern of Guilan province to Golidagh in east of Golestan province. The length of these forests is 800 km and the width is 20 to 70 km. Three major provinces, Giulan, Mazandaran and Golestan are covered with dense forests, snow-covered mountains and impressive sea shores. The Caspian forests (Hyrcanian) comprise a little more than 2.1 million hectares of almost 100 percent hardwoods, primarily beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*). Other marketable species include maple (*Acer insigne*), oak (*Quercus castanefolia*), alder (*Alnus subcordata*), elm (*Ulmus glabra*), ash (*Fraxinus excelsior*) and iron wood (*Parrotia persica*). The small percentage of softwoods include cypress (*Cupresuss sempervirens*), juniper (*Juniperus polycarpos*) and yew (*Taxus bacata*) [1]. Hornbeam (*Carpinus betulus* L.) is a native diffuse porous hardwood species (covered about 30% of volume forest) in Caspian forests and grows in mixed stands with oak and beech and with iron wood in some areas. The species require a warm climate for good growth and occurs at elevations up to 1000 m above the sea level [2]. Mostly it is used for Tool handles, levers, parts for farm machinery, fuel wood, furniture and papermaking industrials. When treated with preservatives, hornbeam wood is suitable substitution for beech wood in railway ties productions [3].

Wood properties such as basic density, microfibril angle, spiral grain, compression wood, juvenile wood and large knots influence the properties, end-use and value of sawn wood [4, 5]. Wood density and fiber dimensions are related to many structural, physical and chemical properties in wood. It affects many wood-product manufacturing, like pulping process, behavior in the drying process and resistance to cutting and machining [6]. For the pulping industry it affects freight costs, pulp production for a given mill size, chemical and power consumption and paper quality [7-11]. Variations in wood density and fiber dimensions are also present in the tree, in the radial and longitudinal direction and within the annual rings [7]. The variation may be due to genetic, physiological or silvicultural treatments [12].

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Variations of the fiber length and wood density of hornbeam (*Carpinus betulus L.*) in Noshahr site indicated that the fiber length and wood density increased from the pith toward the bark and decreased from the base to the up of trees [13]. Although studied have shown the variability of the density and fiber dimensions in hornbeam wood (*Carpinus betulus* L.), haven't presented the effects of altitude on wood density and fiber biometry and its variability within the stem height in Iran. The objective of the present study was to determine the variation of basic density and fiber biometry properties of hornbeam wood (*Carpinus betulus L.)* in three different altitudes and longitudinal axis from the base to the up of tree.

MATERIALS AND METHODS

Material: A total of 15 hornbeam (*Carpinus betulus L.*) trees were sampled from three different altitudes above sea level include 300 m (low altitude), 750 m (intermediate altitude) and 1200 m (high altitude) in Mashelak forests (Noshahr province-north of Iran). All the trees were randomly selected, taking into account stem straightness and the absence of obvious decay. The sample disks were taken from different height levels (25%, 50% and 75%) of tree height (in sum, 45 disks). The age of all trees was 12 years-old and the annual average temperature was 16 °C for Noshar site. The soil texture of this region was clay to clay-loam with clay percentage 30-35%. The annual rainfall is 1345 mm for low altitude and 1300 mm for intermediate and high altitude. These trees were cut for the study in February 2005.

Wood Basic Density: The samples testing were randomly prepared from these discs to evaluation wood basic density according to the ASTM-D143 standard (in sum, 217 samples from three different altitudes). Oven-dry measurements were taken after the specimens were dried to constant weight in an oven at 103 ± 2°C. The dimensions were measured in both green and dry conditions by a slide caliper and mass measured on an electric balance to an accuracy of 0.01 g. Wood basic density was determined from green volume (using the water displacement method) and oven-dry mass. If the specimen developed collapse during oven drying, it was replaced with a new sample.

Fiber Biometry Properties: From each of disks, the numbers of four samples were prepared from near the bark (about 10-12 rings) for evaluation fiber biometry properties such as fiber length, fiber diameter, single wall thickness, fiber lumen diameter (in sum, 180 samples from three different altitudes). For macerating them with Jeffrey's solution (10% nitric acid: 10% chromic acid: water, 1:1:18), the length of 45 fibers of samples was measured using the Leica Image Analysis System. From these data, the averages of fiber dimensions were calculated and then the following derived indexes (morphological properties) were determined:

$$\text{Slenderness ratio} = (\text{Length of fiber}/\text{Diameter of fiber})$$

$$\text{Flexibility ratio} = (\text{Lumen width of fiber}/\text{Diameter of fiber}) \times 100$$

$$\text{Rankle ratio} = (2 \times \text{Wall thickness})/(\text{Lumen width}) \times 100$$

An ANOVA test was done to determine the effect of altitudes indexes and stem height on the wood density and fiber biometry properties, followed by a post-hoc (Duncan's test) test if the ANOVA showed significant differences.

RESULTS AND DISCUSSION

Wood Basic Density: The results of ANOVA indicate that the altitude and stem height of tree had significant effects on the wood basic density, but the interaction effect between altitude and height of tree on the wood basic density was not significant. The pattern of variation of the wood basic density as a function of altitude and height are shown in Tables 1 and 2. The Duncan's mean separation test indicates that there is a significant difference in the wood density between low and high altitude and between intermediate and high altitudes. By increase altitude from sea level, the amount of wood basic density was increased. In each altitude from sea level, the value of wood basic density along longitudinal position from the base to up of tree was decreased [13, 14]. The increasing in the wood density was due to the increase in cell wall thickness and the variation in dimension, structure and distribution of woody cells [7]. Because there is a close relationship between the wood density and cell wall thickness and is negative relationship between wood density and vessel [7, 15].

Wood basic density is used to estimate carbon stored in the woody stems of trees [16] and has an appreciable influence on many solid wood properties and conversion processes, including cutting, gluing, finishing, rate of drying and paper making. It provides a good but not always direct indication of the strength, stiffness and toughness of timber [17]. In the present study, the mean wood basic density of hornbeam wood in three different altitudes were 0.672 g cm^{-3}, which these values are lower than Veysar-Mazandaran site [18] and Golestan site [19].

Table 1: The mean of wood basic density in three different altitudes levels and stem height

	Properties	Wood basic density (g cm^{-3})
Altitude (m)	300 m	0.662 ± 0.046 a
	750 m	0.673 ± 0.049 a
	1200 m	0.681 ± 0.049 b
Longitudinal position	25%	0.684 ± 0.054 b
	50 %	0.674 ± 0.036 b
	75 %	0.657 ± 0.049 a

Table 2: Average of wood basic density of hornbeam wood in longitudinal direction from each of altitudes

	Height of tree		
Altitude	25%	50 %	75 %
300 m (low altitude)	0.684 ± 0.045	0.667 ± 0.027	0.634 ± 0.049
750 m (intermediate altitude)	0.679 ± 0.046	0.673 ± 0.047	0.668 ± 0.054
1200 m (high altitude)	0.694 ± 0.070	0.681 ± 0.032	0.669 ± 0.035

Table 3: The mean of fiber dimensions in three different altitudes levels and stem height

	Properties	Fiber length (mm)	Fiber diameter (μm)	Cell wall thickness (μm)	Lumen diameter (μm)
	300 m	1.62 ± 0.248 c	28.53 ± 4.68 c	4.60 ± 1.34 a	19.33 ± 4.80 c
	750 m	1.45 ± 0.284 b	26.34 ± 2.61 b	5.42 ± 1.04 b	15.50 ± 2.43 b
Altitude (m)	1200 m	0.989 ± 0.236 a	22.20 ± 2.61 a	6.67 ± 1.53 c	8.85 ± 2.64 a
Longitudinal position	25 %	1.48 ± 0.330 c	27.97 ± 4.79 c	6.70 ± 1.62 c	14.56 ±6.94 b
	50 %	1.35 ± 0.347 b	25.29 ±3.41 b	5.46 ± 1.25 b	14.37 ±4.93 a
	75 %	1.22 ± 0.391 a	23.81 ± 3.56 a	4.53 ± 0.92 a	14.75 ±4.41 c

Table 4: Average (± standard deviation) of fiber dimensions of hornbeam wood in longitudinal direction from each of altitudes

	Height of tree		
Altitude	25%	50 %	75 %
300 m (low altitude)			
Fiber length (mm)	1.77 ± 0.200	1.61 ± 0.214	1.50 ± 0.249
Fiber width (μm)	32.29 ± 5.35	27.38 ± 3.52	25.92 ± 1.61
Single wall thickness (μm)	5.50 ± 1.37	4.41 ± 1.22	3.83 ± 0.82
Fiber lumen diameter (μm)	21.28 ± 6.38	18.55 ± 4.57	18.15 ± 1.32
750 m (intermediate altitude)			
Fiber length (mm)	1.51 ± 0.280	1.46 ± 0.267	1.38 ± 0.287
Fiber width (μm)	27.27 ± 1.66c	26.39 ± 2.33	25.36 ± 3.22
Single wall thickness (μm)	6.24 ± 0.55	5.48 ± 0.88	4.53 ± 0.84
Fiber lumen diameter (μm)	14.77 ± 0.978	15.43 ± 1.72	16.30 ± 3.57
1200 m (high altitude)			
Fiber length (mm)	1.17 ± 0.178	0.984 ± 0.160	0.807 ± 0.203
Fiber width (μm)	24.36 ± 2.32	22.12 ± 1.22	20.14 ± 2.16
Single wall thickness (μm)	8.36 ± 1.15	6.49 ± 0.53	5.17 ± 0.58
Fiber lumen diameter (μm)	7.36 ± 3.13	9.14 ± 1.77	9.79 ± 2.35

Table 5: The mean of morphology properties in three different altitudes levels and stem height

	Properties	Slenderness ratio	Flexibility ratio (%)	Runkel ratio (%)
Altitude (m)	300 m	57.74 ± 8.89 c	67.30 ± 10.34 c	53.68 ± 34.71 a
	750 m	55.52 ± 11.10 b	58.82 ± 7.22 b	72.65 ± 22.39 b
	1200 m	44.28 ± 8.27 a	40.03 ± 10.73 a	171.61 ± 87.80c
Longitudinal position	25%	53.25 ± 8.64 b	49.96 ± 16.86 a	133.21 ±104.81c
	50 %	53.41 ± 11.72 c	55.53 ±13.51 b	92.56 ±55.01b
	75 %	50.88 ±12.59 a	60.66 ± 11.80 c	72.16 ± 38.64a

Table 6: Average (± standard deviation) of morphology properties of hornbeam wood in longitudinal direction from each of altitudes

	Height of tree		
Altitude	25%	50 %	75 %
300 m (low altitude)			
Slenderness ratio	55.80 ± 8.56	59.84 ± 10.49	57.58 ± 6.75
Flexibility ratio (%)	64.83 ± 11.73	66.89 ± 11.72	70.19 ± 5.59
Runkel ratio (%)	61.98 ± 44.66	55.77 ± 36.47	43.29 ± 10.52
750 m (intermediate altitude)			
Slenderness ratio	55.38 ± 7.89	56.07 ± 11.74	55.12 ± 13.01
Flexibility ratio (%)	54.21 ± 2.41	58.59 ± 5.17	63.65 ± 8.91
Runkel ratio (%)	84.80 ± 7.78	71.94 ± 14.82	61.21 ± 30.76
1200 m (high altitude)			
Slenderness ratio	48.57 ± 7.46 c	44.34 ± 5.79	39.94 ± 8.88
Flexibility ratio (%)	30.84 ± 10.27	41.10 ± 6.16	48.15 ± 7.13
Runkel ratio (%)	252.84 ± 95.79	149.99 ± 49.53	112.01 ± 29.72

These differences may be explained by different factors, such as growth conditions and ecological factors. In particular, age of trees, exposure, altitude, soil and climate conditions can affect the wood density. Sample size and properties (e.g. ring orientation) and the test procedure can also affect the test results.

Fiber Biometry Properties: The results of ANOVA indicate that the altitude, height and the interaction effects between altitude and height had significant effects on the fiber properties. The pattern of variation of the fiber properties as a function of altitude and height are shown in Tables 4 and 5. The Duncan's mean separation test indicates significant differences among all the types of altitude indexes studied were found for the fiber biometry properties. The fiber length, fiber diameter and fiber lumen diameter values were decreased by increasing altitude above sea level, but the fiber thickness wall values were increased. In each altitude from sea level, the fiber length, fiber diameter, fiber wall thickness values were decreased in longitudinal direction from the base to the up of tree. While the highest of fiber lumen diameter values were found in 75% stem height and the lowest of this parameter were found in 50% stem height.

The cell size and relative cell dimensions have a major influence on the quality of pulp and paper products and on solid wood products [20]. The fiber length and width, wall thickness and lumen size have an effect on the bulk, burst, tear, fold and tensile strengths of paper [21]. For pulp and paper production, species with higher lengths are preferred since a better fiber length net is achieved, resulting in a higher resistance of the paper. These characteristics were found in low altitude (300 m).

Morphology Properties: The results of ANOVA indicate that the altitude, height and the interaction effects between altitude and height had significant effects on the morphology properties. The pattern of variation of the morphology properties as a function of altitude and height are shown in Tables 5 and 6. The Runkle ratio values were decreased by increasing altitude above sea level, but the slenderness and flexibility ratio values were increased. Also, the mean of flexibility ratio and Runkel ratio values in longitudinal direction from the base to the up of tree were increased and decreased, respectively. While the highest of slenderness ratio were found in disk 50 % of stem height and the lowest of this properties were found in 75% of stem height (in sum three altitudes). The Duncan's mean separation test indicates significant differences among all the types of altitude indexes studied were found for the fiber morphology properties.

When the slenderness ratio is higher, the quality of the manufacture paper would be better [21]. Therefore, with attention to these terms, it would be expected that the paper made from the low altitude would have better quality. Generally, the acceptable vale for slenderness ratio of papermaking fibers are more than 33 [22] which these characteristics were found in three altitudes above sea level. These values varied between altitudes from 44.28 (low altitude) to 57.74 (intermediate altitude).

According to flexibility ratio, there are 4 groups of fibers [21, 23]: 1-High elastic fibers having elasticity coefficient greater than 75. 2-Elastic fibers having elasticity ratio between “50-75”. 3-Rigid fibers having elasticity ratio between “30-50”. 4-High rigid fibers having elasticity ratio less than 30. According to this, flexibility coefficient in low altitude (300 m) and intermediate altitude (750 m) are 67.30 % and 58.82 %, respectively.

Thus, they can be considered as elastic fibers group. But the flexibility ratio values in high altitude are 40.03%, which these values were considered as rigid fibers. Rigid fibers don't have efficient elasticity, they aren't suitable for paper production and they are used more on fiber plate, rigid cardboard and cardboard production.

When rankle proportion is greater than 1, it is assessed as fiber having thick wall and cellulous obtained from this type fibers is least suitable for paper production; when it is equal to 1, cell wall have medium thickness and cellulose obtained from this type fibers is suitable for paper production, when the rate is less than 1, cell wall is thin and cellulose obtained from these fibers is most suitable for production of paper [21, 22, 24]. According to this, rankle value in the high altitude (1200 m) is 171.61% (1.71) and it is included in thick wall fibers group and the rankle values in intermediate altitude and low altitude are 72.65% (0.72) and 53.68% (0.53), respectively and it is classification in thin cell wall fibers group.

CONCLUSIONS

- The results of ANOVA indicated that the altitude above sea level and height of tree had effect on wood density and fiber properties, so that by increasing altitude above sea level, the mean of wood density and cell wall thickness were increased and the length and diameter of fibers and lumen diameter were decreased. In addition, the interaction effects between attitude and height of tree on wood density were not significant, but these interactions effects on fiber biometry properties were significant.
- Pattern of the wood basic density and fiber properties along longitudinal direction showed that the highest of wood density, fiber length, fiber width, fiber cell wall thickness were found in 25% of stem height, while the lowest of lumen diameter values were found in the 50% of stem height.
- The values of slenderness and flexibility ratios were decreased by increasing altitude above sea level, but the Runkel amount were increased. In addition, the values of flexibility ratio and Runkel ratio along longitudinal direction from base to the up of tree were increased and decreased, respectively. But the highest values of slenderness ratio were found in 50% tree height.
- The results for morphological properties indicated that low altitude due to increasing in fiber length, flexibility ratio, slenderness ratio and also with having a good density is suitable for paper production.

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