Gazi University Journal of Science
GU J Sci
24(4):911-918 (2011)

Relationship Between Altitude Index and Wood Properties of *Pinus Eldarica Medw* (Case Study in North of Iran)

Majid KIAEI[1,♠], Ahmad SAMARIHA[2]

[1] *Department of Wood and Paper Science and Technology, Chalous Branch, Islamic Azad University (IAU), Chalous, Iran*
[2] *Young Researchers Club, Science and Research Branch, Islamic Azad University, Tehran, Iran*

Received: 27.11.2010 Revised:04.05.2011 Accepted: 10.05.2011

ABSTRACT

In the present study, the biometry (tracheid length and tracheid cell wall thickness), physical (oven dry density, basic density, volumetric shrinkage, and volumetric swelling), and mechanical properties (static bending (MOR), and compressive strength parallel to the grain) of eldar pine (*Pinus eldarica Medw)* was investigated as a function of altitude index. For this purpose, eighteen normal pine trees from three altitudes such as 500 (low altitude), 1200 (intermediate altitude), and 1400 meter (high altitude) that located in the forestry of Western Mazandran province (in north of Iran) was selected. Disks and logs of wood were sawn from the trunk 1-2 m height of trees. The results of statistical analyses showed that the altitude index was an important factor influencing on the biometry, physical and mechanical properties of eldar pine. The wood density, volume shrinkage, volume swelling, tracheid length, cell wall thickness, modulus of rupture, and compressive parallel to the grain in intermediate altitude is more than other altitudes classes.

Key words: Pinus eldarica Medw, altitude, wood biometry, wood physical, wood mechanical properties

1. INTRODUCTION

Due to increasing wood consumption and the development of pulp and paper production, plantations of fast-grown tree species managed with short rotations have a growing importance for the sustainability of industrial wood raw material. The softwoods, especially fast grown pine species, have a higher priority for plantation forestry due to their adaptation capability to wide ecological conditions and various usage areas (Sedjo 1999). Therefore, Parks and forestry officials have been imported approximately 48 foreign fast-grown softwoods species into Iran since 1956 and planted them in different ecological conditions (Zare 2001). *Pinus eldariaca Medw* (from Georgia) was one of the softwood species planted in many parts of Iran and has shown a good adaptation to environmental condition.

Wood density is a commonly used wood quality indicator that is related to other wood properties, such as timber strength and shrinkage, as well as pulp yield and properties (e.g. Panshin and de Zeeuw 1980; Zobel and Van Bujitenen 1989). Wood density is mainly influenced by genotype, ageing of the cambium, and growth rate (e.g. Olesen 1977; Blouin et al. 1994; Zhang 1995). In conifers, increased growth rate usually leads to a greater increase in earlywood (low density) than in latewood (high density) formation and also delays the transition from juvenile wood to mature wood (Zhang et al. 1996; Koga et al. 2002). The heartwood percentage, wood density, elastic dynamic module and moisture content depend on site location (Kokutse et al. 2004). The site index had an important factor influencing on the annual ring width, annual ring density, and latewood density of *Picea abies* (Raiskila et al. 2006), and also had effect on static bending (MOR), compressive, tensile strengths, and oven dry density of calabrian pine wood in Turkey (Bektas et al. 2003). A study on the relationship between altitude and wood properties of cypress wood indicated that the altitude major effects on wood density and mechanical in western of Mazandaran province in north of Iran. Also he stated that by increasing of altitude, wood density and some of mechanical properties increased (Bakhshi 2003).

The objective of the present study was to analyze the effects of altitude index on tracheid biometry, wood physical, and mechanical strength properties of *pinus eldarica medw* in western part of mazandran province in north of iran.

♠Corresponding author, e-mail: mjd_kia59@yahoo.com

2. MATERIALS AND METHODS

Study material originates from eighteen trees of *pinus eldarica medw* sampled from three altitude classes of the western mazandran province in north of Iran. These altitude classes are 500 meter (low altitude), 1200 meter (intermediate altitude), and 1400 meter (high altitude). *Pinus eldarica* was mixed with *pinus sylvestris* and *picea abies* in 1200 meter, and with *pinus sylvestris* and *cupressus sempervirens* in 500 and 1400 meters respectively. The characteristics of altitudes classes are recorded in table 1. These trees have been formed for 35 years in these altitudes classes. Disks and logs were taken from the trunk 1-2 m height to determine various wood properties.

Table 1.The environmental factors of the test areas and trees

Altitude (m)	500	1200	1400
Slope (%)	10	10	10
Exposure	North	North	North
Age	35	35	35
Soil type	clay	clay	clay
Latitude	N 36° 27'	N 36° 29'	N 36° 30'
Longitude	E 51° 18'	E 51° 10'	E 51° 14'
Annual rainfall (mm)	350	430	430
annual average temperature (°C)	13	10	10
Tree height (m)	13.7	15.7	11.5
Diameter (cm)	28.9	29.5	28

3. BIOMETRY PROPERTIES

A 5-cm-thick disc was collected from these logs for evaluation of biometry properties. Wood maceration tracheid length and tracheid wall thickness was performed with franklin's reagent (franklin 1945). The tracheid length of late wood of the every second was determined by Olympus microscope with image analyzer (measuring a minimum 50 tracheid in one specimen).

4. PHYSICAL PROPERTIES

A 5-cm-thick disc was collected from these logs for evaluation of physical properties such as oven dry density, basic density, volumetric shrinkage, and volumetric swelling. In order to determine the physical properties samples with dimensions of 2 × 2 × 2 cm were prepared according to astm-d143. The radial variation was also studied by preparing 3-5 samples equal in size from the pith to the bark in different geographical directions of each disc. on the other hand, samples were continuously taken along radial axis from the pith to the bark. Number of samples depends to diameter of trees in each of altitudes classes. The physical properties of the specimens were calculated by the following equations:

$D_0 = P_0 / V_0$

$D_b = P_0 / Vs$

$\beta v = (V_s - V_o) / V_s$

$\alpha_v = (V_s - v_0) / V_0$

where D_0 is oven-dry density (g cm^{-3}), D_b is basic density (g cm^{-3}), βv is volumetric shrinkage (%), α_v is volumetric swelling (%), V_s is volume in state of saturate (cm^{-3}), V_o is volume in state of oven-dry (cm^{-3}), P_0 is weight in state of oven dry (g), and P_s is weight in state of saturate.

Fiber saturation point (FSP)

Fiber saturation point (fsp) was calculated by the following equation (bozkurt and goker 1987).

$FSP = \beta v / D_b$

where βv is the volumetric shrinkage (%) and db is the basic density (g/cm^3).

5. MECHANICAL STRENGTH PROPERTIES

One 50 cm log and one 15 cm log was removed for evaluation of mechanical properties. The first log was used for the static bending tests (to calculate the modulus of rupture) and the other second log was use for the compressive strength parallel to the grain. The specimens were taken from mature wood. The age demarcation point between juvenile and mature wood was estimated at around 25 years (Clark and Saucier 1989). According to the ASTM D143-94 standard (second method), the sample dimensions were 25 × 25 × 410 mm for modulus of rupture (MOR) and were 25 × 25 × 100 mm for compressive parallel to the grain. 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.

$MOR = 3 P_{max} l / 2 b h^2$, $\sigma cpl = P_{max} / F$

where MOR = modulus of rupture (kg m^{-2}), P_{max} = maximum load at break point (kg), l = length of span (m), b = width of specimen (m), h = thickness of specimen (m), σcpl = compressive strength (kg m^{-2}), F = area of cross section of specimen on which force was applied (m^2).

6. STATIC QUALITY VALUE

Static quality (ratio of compression strength parallel to the grain and 100 × density at 12 % moisture content) were calculated for evaluating the properties and use of pine wood.

7. STATISTICAL ANALYSIS

In order to determine the relationship between the experimental variable (altitude index parameters) and wood properties, all the data measured were subjected to an analysis of variance and Duncan's mean separation test.

8. RESULTS

a. Biometry Properties

Tracheid length

Table 2 shows the results of an analysis of variance and Duncan's mean separation test for the tracheid length of eldar pine wood. The tracheid from high altitude has a low length, and the tracheid from intermediate altitude has a high fiber length. The analysis of variance indicates that altitude index factor has a highly significant effect on the tracheid length at the 95 percent confidence level (F = 10.272, Sig = 0.001). The Duncan's mean separation test indicates that there is a significant difference in the tracheid length between low and high altitude and between intermediate and high altitudes. The tracheid length values varied between the altitudes from 2.54 ± 0.595 to 2.80 ± 0.890 mm.

Table 2. The results of variance analysis and Duncan's mean separation test for the biometry properties of the Eldar pine wood.

Altitude	Tracheid length (mm)	cell walls thickness (μm)
500 m	2.75 ± 0.781 a	5.51 ± 2.48 a
1200 m	2.80 ± 0.890 a	5.99 ± 2.85 a
1400 m	2.54 ± 0.595 b	4.61 ± 1.68 b
N	270	270
Mean	2.69	5.37
Stdev	0.772	2.44
F	10.272**	30.009**
Sig	0.001	0.001

** Significantly difference at 95% confident level, means with the same capital letter are not significantly different,

Tracheid cell wall thickness

Table 2 shows the results of an analysis of variance and Duncan's mean separation test for the tracheid wall thickness of eldar pine wood. The tracheid from high altitude has a low cell wall thickness, and the tracheid from intermediate altitude has a high cell wall thickness. The analysis of variance indicates that altitude index factor has a highly significant effect on the tracheid cell wall thickness at the 95 percent confidence level (F = 30.009, Sig = 0.001). The Duncan's mean separation test shows that there is a significant difference in the tracheid cell thickness low and high altitude and between intermediate and high altitudes. The tracheid length values varied between the altitudes from 4.61 ± 1.68 to 5.99 ± 2.85 μm.

b. Physical Properties

Oven dry density

Table 3 shows the results of an analysis of variance and Duncan's mean separation test for the oven dry density of eldar pine wood. The wood from high altitude has a low oven dry density, and the wood from intermediate altitude has a high oven dry density. The analysis of variance indicates that the altitude index factor has a highly significant effect on the oven dry density at the 95 percent confidence level (F = 32.312, Sig = 0.001). 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. Wood density values varied between the altitudes from 0.397 ± 0.044 to 0.478 ± 0.065 g cm^{-3}.

Table 3. The results of variance analysis and Duncan's mean separation test for the physical properties of the Eldar pine wood [g].

Altitude	D_0 [a]	D_b [b]	[c] β_v	[d] α_v
500 m	0.462 ± 0.042a	0.409 ± 0.032 a	11.70 ± 1.90 a	13.31 ± 2.42 a
1200 m	0.478 ± 0.065 a	0.431 ± 0.058 b	12.42 ± 2.27 a	14.26 ± 2.99 a
1400 m	0.397 ± 0.044b	0.347 ± 0.036 c	9.68 ± 1.61 b	10.75 ± 1.97 b
N [e]	150	150	150	150
Mean	0.450	0.399	11.21	12.70
Stdev [f]	0.062	0.056	2.25	2.87
F	32.312**	44.652**	27.77**	27.523**
Sig	0.001	0.001	0.001	0.001

** Significantly difference at 95% confident level, [a] oven dry density (gr cm^{-3}), [b] wood basic density (gr cm^{-3}), [c] volumetric shrinkage (%), [d] volumetric swelling (%), [e] number of specimens, [f] standard deviation, [g] both tests (the analysis of variance and Duncan's mean separation test) are non-significant between trees.

Wood basic density

Table 3 shows the results of an analysis of variance and Duncan's mean separation test for the wood basic density of eldar pine wood. The wood from high altitude has a low wood basic density, and the wood from intermediate altitude has a high wood basic density. The analysis of variance indicates that the altitude index factor has a highly significant effect on the wood basic density at the 95 percent confidence level (F = 44.652, Sig = 0.001). Significant differences among all the types of altitude indexes studied were found for wood basic density. The wood basic density values varied between the altitudes classes from 0.347 ± 0.036 to 0.431 ± 0.058 g cm^{-3}.

Volumetric shrinkage

Table 3 shows the results of an analysis of variance and Duncan's mean separation test for the volumetric shrinkage of eldar pine wood. The wood from class high altitude has a low volumetric shrinkage, and wood from intermediate altitude has a high volumetric shrinkage. The analysis of variance indicates that the altitude index factor has a highly significant effect on the volumetric shrinkage at the 95 percent confidence level (F = 27.77, Sig = 0.001). The Duncan's mean separation test shows that there is a significant difference in the volumetric shrinkage between low and high altitudes and between intermediate and high altitudes. The volumetric shrinkage values varied between the altitudes from 9.68 ± 1.61 to 12.42 ± 2.27%.

Volumetric swelling

Table 3 shows the results of an analysis of variance and Duncan's mean separation test for the volumetric swelling of eldar pine wood. The wood from high altitude has a low volumetric swelling, and wood from intermediate altitude has a high volumetric swelling. The analysis of variance indicates that the altitude index factor has a highly significant effect on the volumetric swelling at the 95 percent confidence level (F = 27.523, Sig = 0.001). The Duncan's mean separation test shows that there is a significant difference in the volumetric swelling between low and high altitude and between intermediate and high altitudes. The volumetric swelling values varied between the altitudes from 10.75 ± 1.97 to 14.26 ± 2.99%.

Fiber saturation point (FSP)

The values of fiber saturation point in low altitude were 28.60 %, in intermediate altitude were 28.81%, and in high altitude were 27.89 %. As be saw, the FSP values in intermediate altitude is more than other altitudes (low and high altitude).

c. Mechanical Properties

Density at 12 % moisture content

Table 4 shows the results of an analysis of variance and Duncan's mean separation test for the density at 12 % moisture content of eldar pine wood. The analysis of variance indicates that the altitude index factor has a highly significant effect on the oven dry density at the 95 percent confidence level (F = 27.903, sig = 0.001). The Duncan's mean separation test shows that there is a significant difference in the wood density between low and high altitude and between intermediate and high altitudes. The wood from high altitude has a low oven dry density, and the wood from intermediate altitude has high wood density. These values density values varied between the altitudes from 0.487 ± 0.029 to 0.573 ± 0.043 g cm^{-3}.

Table 4. The results of variance analysis and Duncan's mean separation test for the mechanical properties of the Eldar pine wood.

Altitude (m)	density at 12 % moisture content ($g\ cm^{3}$)	MOR ($Kg\ m^{-2}$)	Compressive strength ($Kg\ m^{-2}$)
500 m	0.565 ± 0.067 a	730.50 ± 70.88 a	436.58 (113.87) a
1200 m	0.573 ± 0.043 a	754 ± 115.29 a	521.85 (95.20) b
1400 m	0.487 ± 0.029 b	624.53 ± 94.92 b	370.05 (103.08) c
N	90	90	90
Mean	0.541	703.01	439.70
Stdev	0.062	110.05	120.26
Min	0.44	501	220
Max	0.70	986	689
F	27.903 **	15.666**	18.191**
Sig	0.001	0.001	0.001

** Significantly difference at 95% confident level, ± Standard deviation

Modulus of rupture (MOR)

Table 4 shows the results of an analysis of variance and Duncan's mean separation test for the modulus of rupture of eldar pine wood. The wood from high altitude has a low modulus of rupture, and the wood from intermediate altitude has a high modulus of rupture. The analysis of variance shows that the altitude index factor has a highly significant effect on the MOR at the 95 percent confidence level (F = 15.666, Sig = 0.001). The Duncan's mean separation test indicates that there is a significant difference in the modulus of rupture between low and high altitude and between intermediate and high altitudes. The MOR values varied between the altitudes from 624.53 ± 94.92 to 730.50 ± 70.88 kg m^{-2}.

Compressive strength parallel to the grain

Table 4 shows the results of an analysis of variance and Duncan's mean separation test for the Compressive strength parallel to the grain of eldar pine wood. The wood from high altitude has a low compressive parallel to the grain, and wood from intermediate altitude has a high compressive mechanical strength. The analysis of variance indicates that the altitude index factor has a highly significant effect on the compressive strength at the 95 percent confidence level (F = 18.191, Sig = 0.001). The Duncan's mean separation test shows that significant differences exist among the altitudes index. The compressive strength properties values varied between the altitudes from 370.05 ± 103.08 to 521.85 ± 95.20 kg m^{-2}.

Static quality value

The static quality value in Intermediate altitude (9.09) is more than low altitude (7.71) and high altitude (7.56).

Relationship between wood density and static bending (MOR)

Relationship between wood density and static bending (MOR) are shown in figure 1 (a, b, and c) for each of altitudes classes. There are positive correlations between wood density and static bending. But correlation coefficients between these properties in intermediate altitude are more than other altitudes.

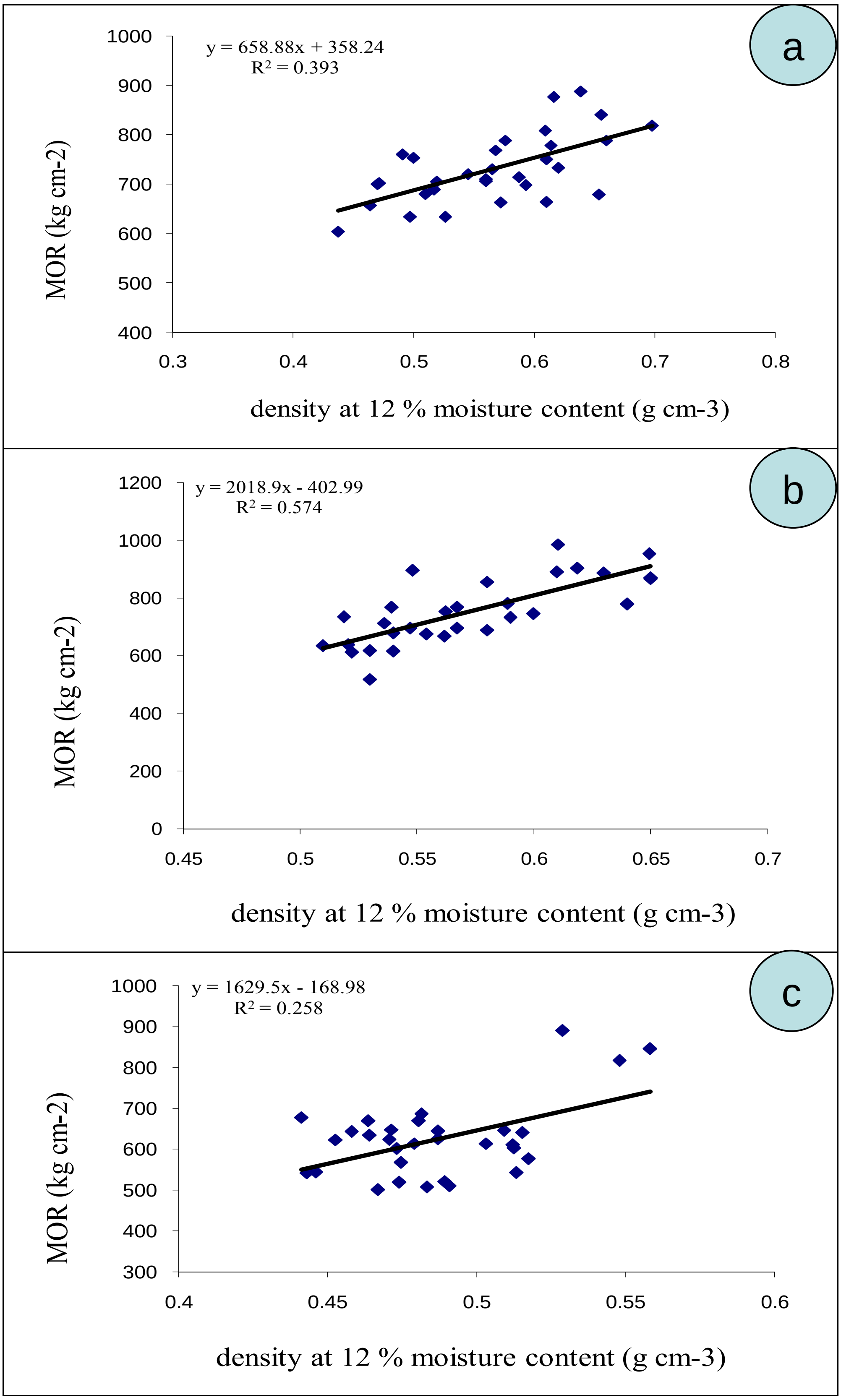

Figure 1. Relationship between wood density and MOR in low altitude (a), intermediate altitude (b), and high altitude (c)

9. DISCUSSION

This study examined the effect of altitude variation on wood biometry, physical and mechanical strength properties of eldar pine in north of Iran. The results of wood properties showed that the altitude index had a significant influence on biometry, physical, and mechanical strength properties. These differences in tracheid characteristics, wood density, volumetric shrinkage, volumetric swelling, and mechanical properties might to be attributed to ecological factors such as altitude index that can affect the wood properties. These differences for wood properties have been reported by Bakhshi (2003) and Bektas et al. (2003).

The wood density, volumetric shrinkage, and volumetric swelling values in intermediate altitude were higher than other altitudes classes (low and high altitudes). This can be ascribed to the tracheid cell wall thickness measured for each altitude index. Because the tracheid length value in intermediate altitude is more than other altitudes indexes. In general, wood density is a complex feature influenced by cell wall thickness, the proportion of the different kind of tissues, and the percentages of lignin, cellulose and extractives (Valente et al. 1992). As such, in the wood of coniferous trees, the wood density properties are inversely proportional to the width of the annual rings (Zhang et al. 1996; Saranpää 2003). Additionally, the volumetric shrinkage and swelling properties are affected by several wood factors such as heartwood-sapwood ratio, fibrillar angle on S_2 layer, and etc (Bektas and Guler 2001). But most important parameter affecting wood shrinkage is the wood density (Guler et al. 2007).

The highest of modulus of rupture and compressive strength parallel to the grain values were found in the intermediate altitude. This can be ascribed to the tracheid length and wood density measured for each altitude index. Because wood density and tracheid length values in intermediate altitude is higher than other classes (low and high altitude). Generally, wood density is one of the most important indices of timber strength properties as it has been positively correlated with mechanical properties (Bendtsen 1978; Moulds, 1952; Brunden 1964). As is already known, there is a strong relationship between Modulus of rupture and tracheid length (Panshin and De Zeeuw 1980; Bektas et al. 2003). Additionally, there is a negative relationship between annual ring width and mechanical properties in the wood of coniferous trees (Zhang et al. 1996, Saranpää 2003). Overall, the different morphologies and wood density are responsible for the variation in wood mechanical properties. In the present study, there are positive correlations between wood density and static bending strength of pine wood which reported Raiskila et al (2006) and Zhang (1995).

Softwoods, including eldar pine, can be classified according to static quality values and these are; fewer than 8 is a low quality, between 8 and 9.5 is a fair quality and above the 9.5 is a good quality (Bektas 1997). These values in intermediate altitude is more than other altitudes so that the static quality value for intermediate altitude (9.09) is fair, and low altitude (7.71) and high altitude (7.50) are low.

10. CONCLUSION

1- ANOVA indicates that significant difference in wood biometry, physical, and mechanical strength properties existed between the altitudes in *Pinus eldarica Medw.*

2- All of wood properties such as wood density, volumetric shrinkage, volumetric swelling, tracheid length, cell wall thickness, modulus of rupture, and compressive strength parallel to the grain in intermediate altitude were more than other altitude classes.

3- The pine wood planting in intermediate altitude due to high density and mechanical strength properties can be utilized in structural applications than other sites. Plantation of this species should be considered for this altitude in western part of Mazandaran province.

REFERENCES

Bakhshi, R., "The influence of altitude on wood properties of cypress wood in western part of Mazandran province-Iran", Ph.D Thesis, ***Islamic Azad University of Science and Research Branch, Tehran,*** Iran, 136 (2003)

Bektas I, Guler C "Determination of some physical properties of beech wood (*Fagus orientalis* Lipsky) from Andirin region", ***Turk J Agric For*** 25:209-215 (2001)

Bektas I, Hakki Alma M., As N., Gundogan, R .,"Relationship between site index and several mechanical properties of Turkish calabrian pine (*Pinus brutia Ten*)", ***Fores Prod J***, 53(2): 1-5 (2003).

Bektas I, Hakki Alma M, Goker Y, Yuksel A " Influence of site on sapwood and heartwood ratios of Turkish Calabrian pine", ***Fores Prod J*** 53(4): 48-50(2003).

Bendtsen BA "Properties of wood from improved and intensively managed trees", ***Fores Prod J,*** 28: 61-72 (1978).

Blouin D, Beaulieu J, Daoust G, Poliquin J "Wood quality of Norway spruce grown in plantations in Quebec", ***Wood Fiber Sci J*** 26: 342–353 (1994).

Bozkurt Y, Goker Y "Fiziksel ve Mekanik Agaç Teknolojisi", IU. Yayın No. 3445. ***Orman Fak. Yayin*** No. 388. Istanbul (1987)

Brunden MN "Specific gravity and fiber length in crown formed and stem formed wood" ***Fores Prod J*** 14: 13-17 (1964).

Clark A, Saucier JR "Influence of initial planting density, geographic location and species on juvenile wood formation in southern pine", ***Fores Prod J*** 39: 42-48(1989).

Franklin GL "A rapid method of softening wood for microtome sectioning", ***Tropical Woods J*** ,88:35-36 (1954).

Guler C, Copur Y, Akgul M, Buyukasari U "Some chemical, physical and mechanical properties of juvenile wood from black pine (*Pinus nigra* Arnold) plantations", ***Journal of Applied Science*** 7(5): 755-758 (2007)

Kokutse AD, Baillères H, Stokes A, Kokou K "Proportion and quality of heartwood in Togolese teak (*Tectona grandis* L.f.)". ***Forest Ecology and Management*** 189: 37–48(2004).

Koga S, Zhang SY, Bégin J "Effects of precommercial thinning on annual radial growth and wood density in Balsam fir (Abies balsamea)", ***Wood Fiber Sci J*** 34: 625–642(2002).

Moulds F.R , "Comparative strengths of the timber of Californian grown and South Australian grown Monterey pine (Pinus radiata D. Don.)". ***Australian Forestry*** 16: 100-104(1952).

Olesen P.O .,"The variation of the basic density level and tracheid width within the juvenile and mature wood of Norway spruce". ***Forest Tree Improvement*** 12: 1–21(1977).

Panshin AJ, De Zeeuw C "Textbook of wood technology". 4th ed. ***McGraw-Hill,*** New York. 722 (1980) .

Raskila S, Saranpää P, Fagerstedt K, Laakso T., "Growth rate and wood properties of Norway spruce cutting clones on different sites", ***Silva Fennica*** 40(2):47-255, (2006)

Saranpää P Wood density and growth. In Barnett, J. R. and Jeronimidis, G. (eds). "Wood Quality and Its Biological Basis. Blackwell Publishing Ltd", ***CRC Press, Great Britain***, 87-117 (2003).

Sedjo, S., "The potential of high-yield plantation forestry for meeting timber needs", ***New Forests*** 17: 339-360(1999).

Valente CA, Mendes A, Furtado FP, Carvalho AP "Improvement program for Eucalyptus globulus at Portugel", ***Appita J*** 45: 403–407(1992).

Zare H "Introduced and Native Conifers in Iran. Ministry of Jihad-e- agriculture", ***Agriculture Research, Education and Extension Organization.Technical Publication*** No. 271. 498 (2001) .

Zhang SY.,"Effect of growth rate on wood specific gravity and selected mechanical properties in individual species from distinct wood categories", ***Wood Science and Technology*** 29: 451–465(1995).

Zhang SY, Simpson D, Morgenstern EK "Variation in the relationship of wood density with growth in 40 black spruce (*Picea mariana*) families grown in New Brunswick". ***Wood Fiber Sci J*** 28: 91–99(1996).

Zobel BJ, Van Bujitenen JP "Wood variation: its causes and control", ***Springer-Verlag,*** Berlin, 363 (1980).