WFL Publisher
Science and Technology

Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.8 (2): 1058-1061. 2010

www.world-food.net

Influence of site variation on growth rate and wood properties of *Pinus eldarica*

H. Khademi-Eslam, A. H. Hemmasi, M. Talaeipour and M. Kiaei *

Department of Wood Science and Technology, Science and Research Branch, Islamic Azad University (IAU), Tehran, Iran.
** Ph.D. Student of Wood Science and Technology Department. *e-mail: mjdkia59@yahoo.com*

Received 26 November 2009, accepted 29 March 2010.

Abstract

The effect of site variation on growth rate and physical and mechanical properties of *Pinus eldarica* was studied. For this purpose, the number of fifteen normal trees from three sites (Valardeh, Bandebon, Benafeshdeh) that located in the forestry of Western Mazandran (North of Iran) was selected. Disks and logs of wood were sawn at breast height. The testing samples were prepared in radial axis of the tree from pith to the bark to determine growth rate and physical characteristics from mature wood to measure mechanical properties. The wood from Benafeshdeh (Site 3) had a high growth rate and low density and mechanical strength properties. The average annual ring width (growth rate) varied between the sites from 2.56±1.73 to 4.15±2.37 mm. The mean oven dry density was 0.454±0.068 g cm^{-3}, basic density 0.40±0.062 g cm^{-3} and volume shrinkage 11.25±2.35% in this material. The average weight density of the test samples (p_{12}) was 0.531±0.065 gcm^{-3}, modulus of elasticity (MOE) 59988.47±19479.89 kg cm^{-2}, modulus of rupture (MOR) 714.82±212.92 kg cm^{-2} and maximum crushing stress 439.69±120.26 kg cm^{-2} in mature wood. In addition, effect of growth rate on the physical and mechanical properties of pine wood was observed.

Key words: *Pinus eldarica*, site, density, growth rate, physical properties, mechanical strength.

Introduction

Parks and forestry offices have imported about 48 foreign species of fast-growing softwoods in Iran since 1956. It has embarked on their planting in different ecological conditions [28]. One of the softwood species, which is planted in most points of Iran and has shown a good adaptability, is *Pinus eldarica* (from Georgia) of which a great amount have been planted. Debazac and Tomasson[10] have known *Pinus eldarica* as a sub-species of *Pinus brutia* but Critchfiled and Little [8] consider it as a variety of *Pinus brutia*. The mechanical properties are controlled by anatomical characteristics such as wood density, grain angled, tracheid length and microfibril angle of the S_2 layer in the cell wall [27]. Wood formation is attributed to many factors including site, environment, genetics, stand conditions, management and age [25, 31]. 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 [14, 19]. Wood density is mainly influenced by genotype, ageing of the cambium and growth rate. In conifers, increasing growth rate usually leads to a greater increase in early wood (low density) than in latewood (high density) formation and also delays the transition from juvenile wood to mature wood [15, 16, 29].

Wood resistance to compression (as well as other physical and mechanical properties) depends also on its microstructure. Dimensions of individual structural elements of wood influences its strength, i.e. the more elements and the thicker their walls, the higher is wood strength. On the base of presented data[21], it is stated that increase of wall thickness of late tracheids by 36% for pine wood and by 30% for larch wood, density increases, respectively, by 18% and 20% for larch wood, and density increases strength parallel and perpendicular to grain by 83% and 70%. Cell size and relative cell dimensions have a major influence on the quality of pulp and paper products [6] and on solid wood products. Fiber length and width, wall thickness and lumen size have effects on the bulk, burst, tear, fold and tensile strengths of paper [31]. However, there are definite correlations between tracheid length and certain lumber mechanical properties [5]. Wood with long tracheid has greater tensile strength than wood with short ones [31]. Also Omidvar [18] found positive and strong relationship between MOR and tracheid length of pine (*Pinus taeda*) wood .

This study focused on examination of growth rate, physical and mechanical properties of pine wood from three different sites in western Mazandran province, which has been formed for 31 years in Iran.

Materials and Methods

Study material originates from fifteen trees of *Pinus eldarica* sampled from the three sites of the western Mazandran province in north of Iran. These sites were Valardeh-Marzanabad (1), Bandebon-Kelardashat (2) and Benafeshdeh (3). *Pinus eldarica* was mixed with *Pinus sylvestris* and *Picea abies* at Site 2 and with *Pinus sylvestris* and *Cupressus sempervirens* at Sites 1 and 3, respectively. The data on environmental conditions of the study locations are recorded in Table 1.

Determination of growth rate and physical properties: Disks and logs of wood were sawn at breast height (about 1.3 m). A 10 cm-thick disc was removed from breast height level to study growth rate and physical properties. On the disks prepared, the operations of dating and cross dating were done and annual width ring was determined using Lintab 5 ring width measuring system (Rinnteech Company, Germany) and normal binocular.

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

Symbol	1	2	3
Site	Valardeh	Bandebon	Benafeshdeh
Latitude	E 51° 18'	E 51° 10'	E 51° 14'
Longitude	N 36° 27'	N 36° 29'	N 36° 30'
Altitude (m)	500	1200	1400
Age	31	31	31
rainfall (mm)	350	534	550
Temp (°C)	14.42	9.8	9.6
Soil type	Silty-clay-loam	Clay	Clay – loam

Physical properties (oven dry density, basic density and volume shrinkage) were determined according to ISO-3131 standard. The specimens were taken from radial axis of the tree from pith to the bark (in four geographical directions).

Determination of mechanical properties: From each tree, two logs were removed from breast height, the first one 50 cm long and the second 15 cm, to calculate static bending (modulus of elasticity and modulus of rupture) and compression parallel to grain properties (maximum crushing stress), respectively. The specimens were taken from mature wood. The age demarcation point between juvenile and mature wood was estimated around 25 years [7]. The mechanical properties (static bending and compression parallel to grain) were determined according to ASTM-D143-94 standard (Second method).The specimens were conditioned in 65±3% RH and 20±2°C temperature for at least four weeks before testing, until the specimens were reached to the equilibrium moisture content of 12%. Load was applied in the tangential direction.

Statistical analysis: Statistical significance of differences in the wood properties between the sites was analysed using ANOVA in a statistical program SPSS and categorized by Duncan's multiple-range test. The results were considered at significance level of $p \leq 0.05$. Also relation between growth rate with physical and mechanical properties were determined using Pearson correlation coefficients at significance levels of $p \leq 0.05$ and $p \leq 0.01$.

Results

Growth rate and physical properties: The annual ring width and density of fifteen stems at breast height were measured from pith to the bark (Table 2). The average annual ring width was 3.42±2.05 mm, oven dry density 0.454±0.068 g cm^{-3}, basic density 0.40±0.062 g cm^{-3} and volume shrinkage 11.25±2.35% in the material (Figs 1 and 2). Differences between the sites were tested at the level of $p \leq 0.05$ and significant distinctions were marked with letters a, b, c (Table 2). The slowest growth rate and the highest densities and volume shrinkage were found in Site 1. The effect of sites on the annual ring width and physical properties were statistically significant, but this difference in the densities and volume shrinkage between Sites 1 and 2 wasn't significant at the level mentioned above.

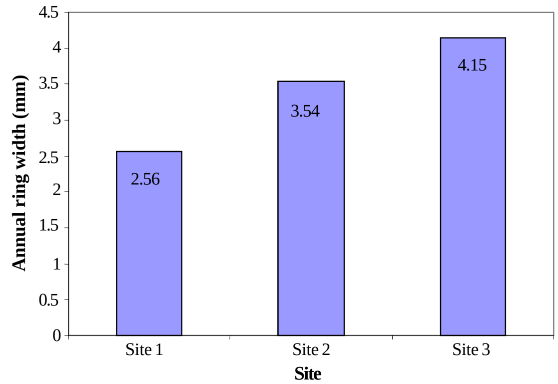

Figure 1. The effect of site on growth rate.

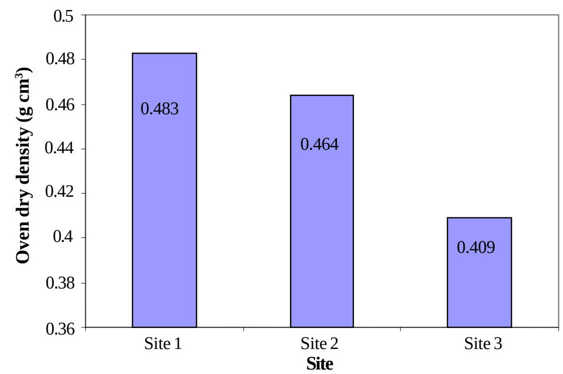

Figure 2. The effect of site on oven dry density.

The relation between the growth rate with physical properties of pine wood by Pearson correlation coefficients are shown in Table 3 (fifteen point is equal to the average of fifteen trees). According to this table, growth rate showed a negative correlation with physical properties and had weaker correlation between growth rate with volume shrinkage (r = 0.5) than oven dry density (r = 0.701) and basic density (r = 0.760).

Mechanical properties: The mechanical strength properties of wood described by the MOR, MOE and MCS are presented in Table 4. The average modulus of rupture was 714.82±212.92 kg cm^{-2}, Modulus of elasticity 59988.47±19479.89 kg cm^{-2}, maximum crushing stress 439.69±120.26 kg cm^{-2} and weight density of the test samples (p_{12}) 0.531±0.065 g cm^{-3} in mature wood (Figs 3-5). Differences between the sites were tested at the level of $p \leq 0.05$ and significant distinctions were marked with letters a, b, c (Table 4). The influence of site on the MOE, MOR, MCS and weight density was statistically significant. The difference in the MOE, MOR and weight density of the test samples (p_{12}) (exception MCS) between Sites 1 and 2 wasn't significant.

The worst mechanical properties were found in the rapidly-growing Site 3 (clay-loam soil) which produced wood with the

Table 2. Average growth rate and physical properties (standard deviation) of *Pinus eldarica* wood.

Site	Basic density (g cm^{-3})	Oven dry density (g cm^{-3})	Volume shrinkage (%)	Annual ring width (mm)
1	$0.435_{(0.066)}^{a}$	$0.483_{(0.072)}^{a}$	$12.42_{(2.27)}^{a}$	$2.56_{(1.73)}^{a}$
2	$0.409_{(0.032)}^{a}$	$0.464_{(0.042)}^{a}$	$11.60_{(2.02)}^{a}$	$3.54_{(1.70)}^{b}$
3	$0.358_{(0.057)}^{b}$	$0.409_{(0.065)}^{b}$	$9.93_{(2.07)}^{b}$	$4.15_{(2.37)}^{c}$
Mean	$0.400_{(0.062)}$	$0.454_{(0.068)}$	$11.25_{(2.35)}$	$3.42_{(2.05)}$
Min	0.30	0.33	6.33	0.12
Max	0.67	0.73	18.25	11.70

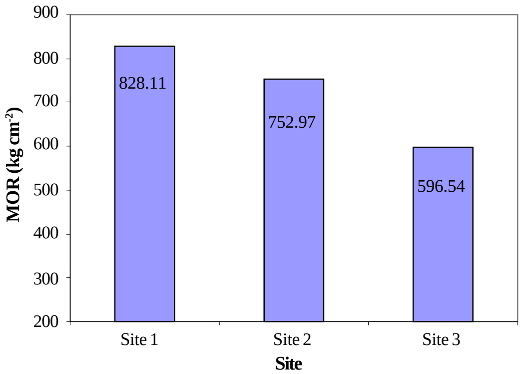

Figure 3. The effect of site on modulus of rupture.

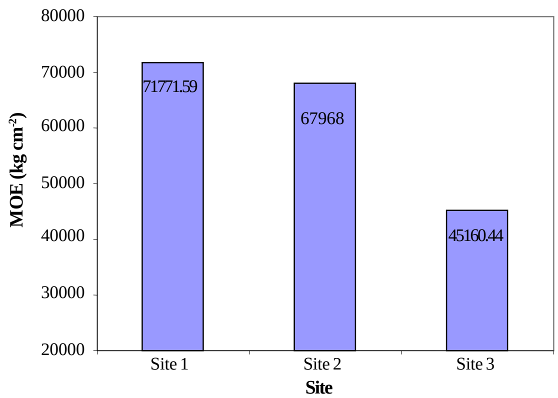

Figure 4. The effect of site on modulus of elasticity.

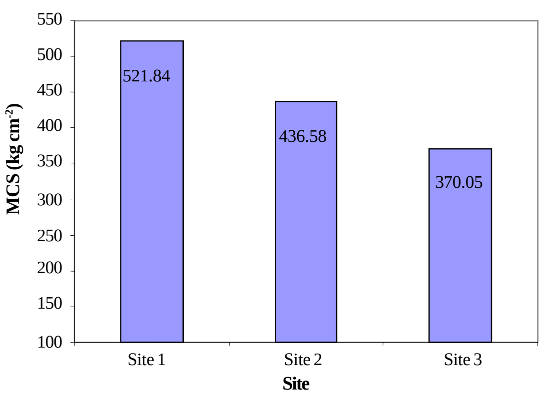

Figure 5. The effect of site on maximum crushing stress.

Table 3. Pearson correlation for the relationship between growth rate and physical properties.

Properties	Oven dry density	Basic density	Volume shrinkage
Growth rate	-0.701*	-0.760*	-0.500 ^{ns}

* Significant at level 5%, ns: not significant.

Table 4. Average mechanical properties (standard deviation) of *Pinus eldarica.*

Site	Weight density (g cm^{-3})	MOR (kg cm^{-2})	MOE (kg cm^{-2})	MCS (kg cm^{-2})
1	$0.578_{(0.076)}^{a}$	$828.11_{(240.02)}^{a}$	$71771.59_{(18844.29)}^{a}$	$521.84_{(95.20)}^{a}$
2	$0.545_{(0.048)}^{a}$	$752.97_{(176.44)}^{a}$	$67968_{(13282.94)}^{a}$	$436.58_{(113.87)}^{b}$
3	$0.486_{(0.036)}^{b}$	$596.54_{(143.91)}^{b}$	$45160.44_{(12932.76)}^{b}$	$370.05_{(103.08)}^{c}$
Mean	$0.531_{(0.065)}$	$714.82_{(212.92)}$	$59988.47_{(19479.89)}$	$439.69_{(120.26)}$
Min	0.40	372	115871	220
Max	0.71	1411	31690	689

lowest weight density. The strength properties were best on Site 1, which produced wood with the highest weight density.

The relation between the growth rate with mechanical properties of pine wood by Pearson correlation coefficients are shown in Table 5 (fifteen point is equal to the average of fifteen trees). According to this table, growth rate showed a negative correlation with mechanical properties and had weaker correlation between growth rate with MOR (r = 0.366) than MOE (r = 0.864), MCS (r = 0.858) and weight density (r = 0.723).

Table 5. Pearson correlation coefficients for the relationship between growth rate and mechanical properties.

Properties	MOR	MOE	MCS	P_{12}
Growth rate [1]	- 0.366 ^{ns}	- 0.864**	- 0.858**	- 0.723*

MOR modulus of rupture, MOE modulus of elasticity, MCS maximum crushing stress, P_{12} weight density of the test samples, ** Significant at level of 1%, * Significant at level of 5%, ns non-significant and 1 Average for the sampling rings after 25 rings from the pith.

Discussion

In this study, the growth rate, physical properties (oven dry density, basic density and volume shrinkage), static bending (modulus of elasticity and modulus of rupture) and compression parallel to the grain (maximum crushing stress) of pine wood in three sites were determined. Results showed that the effect of site on annual ring width was statistically significant so that the greatest and the lowest values were observed in Sites 3 and 1, respectively. The average annual ring width in three sites was 3.42 mm which is more than in Azadi (2.60 mm), Chitgar (2.75 mm) and Sorkh-Hesar (2.7 mm) located in Tehran [24] but less than in Zaghmarz (5.40 mm)[11] and Chatan site (4.95 mm) [13]. More variation in growth rate level in different sites is due to changes in weather conditions (temperature and rainfall) during the growing period [22].

The average oven dry density was 0.454 g cm^{-3}, basic density 0.4 g cm^{-3} and volume shrinkage 11.60 % which is more than the average of these properties in Zaghmarz site. The average oven dry density in Zaghmarz [11] has been 0.396 g cm^{-3} and the basic density 0.383 g cm^{-3}. The effect of site on the density and the volume shrinkage was statistically significant. The difference in the densities and volume shrinkage between Sites 1 and 2 was not significant. The mean annual ring width was lowest and the wood density and volume shrinkage greatest on Site 1. The volumetric shrinkage and swelling properties are affected by several wood factors such as heartwood-sapwood ratio, fibrillar angle on S_2 layer etc. [3] but most important parameter affecting wood shrinkage is the wood density [12]. It is generally believed that rapid growth rate results in low density and lower mechanical strength properties of wood but some exceptions have been reported [25]. Growth rate influence wood density because of the changes in the relative proportions of secondary cell wall and void volume (e.g. cell lumen) [17, 25] and in the relative amount of chemical components of the cell wall [26]. Also a major factor of site is soil [31], variations in wood quality with tree growth are strongly related to physical and chemical properties of the soil [22]. A low density may be obtained on sites with favorable soil properties for stand growth [9]. In this study, types of soil from of all above sites are different.

In this study, the average MOE was 59,988.47 kg cm^{-2} and weight density of the test samples (p_{12}) 0.531 g cm^{-3} in mature wood. The average modulus of rupture was 714.82 kg cm^{-2} (71.4 MPa) that is more than in Tehran site (670 kg cm^{-2}) [20]. Also modulus of rupture of this species is more than in other species such as *Pinus jefferyi* (64.1 MPa), *Pinus contorta* (64.8 MPa) and *Pinus banksiana* (68.3 MPa) but less than in some species such as *Pinus yunanesis* (100.8 MPa), *Pinus virginiana* (89.6 MPa), *Pinus palutris* (100 MPa), *Pinus elliotti* (112 MPa), *Pinus rigida* (74.5 MPa), *Pinus resinosa* (75.8 MPa), *Pinus massoniana* (76.5 MPa) and *Pinus echinata* (90.3 MPa) [1, 30]. The lowest MOR (596.54 kg cm^{-2}), MOE (45160.44 kg cm^{-2}) and MCS (370.05 kg cm^{-2}) were recorded on Site 3, which produced wood with the lowest weight density (p_{12}) (0.486 g cm^{-3}) and showed the highest growth rate (4.15 mm). The variations in the mechanical properties in the same species are due to different factors, such as growth conditions and ecological factors. In particular, altitude and soil and climate conditions can affect the mechanical properties of wood [4].

Conclusions

This study indicated that pine trees from three sites had different wood properties so that the growth rate (Site 3), density and mechanical properties (Site 1) were greater. These differences may be explained by some regional conditions that affect the growth characteristics and properties of the wood. The pine wood planting in Sites 1 (silty-clay-loam soil) and 2 (clay soil) (because there aren't difference in density and mechanical properties between Sites 1 and 2) due to high density and mechanical properties can be utilized in structural applications than in other sites. This species has ability to grow in silty-clay-loam and clay soils with no influence in wood quality. Therefore, plantation of this species should be considered for Kelardashat and Marzanabad region in north of Iran.

References

[1]Alden, H. A. 1997. Softwoods of North America. Gen.Tech. FPL-GTR-102. Department of Agriculture, Forest Service, Forest Product Laboratory, Madison, WI, U.S., 151 p.

[2]ASTM (American Society for Testing and Materials) 2003b. Test Method for Small Clear Specimens of Timber. ASTM D 143-94. ASTM standards, Vol. 04.10. ASTM, Philadelphia.

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

[4]Bektas, I., Guler, C. and Basturk, A. 2002. Principal mechanical properties of eastern beech wood (*Fagus orientalis* Lipsky) naturally grown in Andirin Northeastern Mediterranean region of Turkey. Turk. J. Agric. For. **26**:147-150.

[5]Bisset, I. J., Dadswell, H. E. and Wardrop, A. B. 1951. Factors influence tracheid length in conifer stems. Aus. Forest. **15**:135-146.

[6]Clark, J. 1962. Effects of fiber coarseness and length, I. Bulk, burst, tears, fold and tensile tests. Tappi Journal **45**:628-634.

[7]Clark, A. and Saucier, J. R. 1989. Influence of initial planting density, geographic location and species on juvenile wood formation in southern pine. Forest Product Journal **39**:42-48.

[8]Critchfiled, W. B. and Little, E. L. Jr. 1971. Geographic distribution of the pines of the world. Misc. Pub. 991. U.S. Department of Agriculture, Forest Service,Washington, DC.

[9]Cutter, B. E., Coggeshall, M. V., Phelps, J. E. and Stoke, D. D. 2004. Impacts of forest management activities on selected hardwoods quality attributes: A review. Wood and Fiber Science **36**:84-97.

[10]Debazac, E. and Tomasson, R. 1965. Contribution a une etude comparee des Pines Mediteranees de la section halepensis. Ann. Sci. Forestieres XXII (2).

[11]Golbabaei, F., Hossinzadeh, A., Nourbakhsh, A., Jahan-Latibari, A. and Sepidehdam, J. 1998. Study on papermaking characteristics of pine wood (*Pinus eldarica*). The Iranian Journal of Wood and Paper Research **5**:1-14.

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

[13]Habibi, M. R., Hossinzadeh, A., Jahan-Latibari, A., Familian, H. and Hossinkhani, H. 2003. Investigation on trend of tracheids varitions of *Pinus eldarica*. The Iranian Journal of Wood and Paper Research **16**:73-92.

[14]Harris, J. M. 1993. Wood quality: forest management and utilization. In Walker, J. C. F. (ed.). Primary Wood Processing. Principles and Practice. Chapman & Hall, London, pp. 560-583.

[15]Koga, S., Zhang, S. Y. and Begin, J. 2002. Effects of precommercial thinning on annual radial growth and wood density in balsam fir (*Abies balsamea*). Wood and Fiber Science **34**:624-645.

[16]Larson, P. R. 1969. Wood formation and the concept of the wood quality. Bulletin of the Yale School of Forestry **74**:1-54.

[17]Mäkinen, H., Saranpää, P. and Linder, S. 2002. Wood-density variation of Norway spruce in relation to nutrient optimization and fiber dimension. Canadian Journal of Forest Research **32**:185-194.

[18]Omidvar, A. A. 1987. The Impact of Annual Ring Width on Technological Quality of Pine Wood (*Pinus taeda*). M.A Dissertation, Noor University of Teacher-Training, 200 p.

[19]Panshin, A. and De Zeeuw, C. 1980. Text Book of Wood Technology. Lth. Ed. Vol. 4. McGraw-Hill Co., New York, USA.

[20]Parsapajouh, D. 1998. Wood Technology. Tehran University Publication. Vol. **4.** No. 1851, Tehran, Iran.

[21]Perelygin, L. M. and Ugoliov, B. N. 1971. Wood Science. Moscow, 288 p. (in Russian).

[22]Rigatto, P. A., Dedecek, R. A. and Monteiro de Matos, J. L. 2004. Influence dos atributos do solo sobre a qualidade da Madeira de *Pinus taeda* para producao de cellouse kraft. Revista Arvore **28**:267-273.

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

[24]Safdari, V. R. 2004. A Dendroclimatological Evaluation of *Fraxinus excelsior* and *Pinus eldarica* at Three Sites in Tehran. PhD thesis, Islamic Azad University (IAU), Science and Research Branch, Tehran, Iran, 141 p.

[25]Saranpää, P. 2003. 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, p. 87-117.

[26]Saikku, O. 1975. The effect of fertilization on the basic density of Scots pine (*Pinus sylvestris* L.). A densitometeric study on the X-ray chart curves of the wood. Communications Institute Forestalis Fenniae **85**(3).

[27]Tokumto, M.,Takeda, T., Nakano, T., Hashizume, T., Yoshida, T., Takei, F., Nagao, H., Tanaka, T. and Nakai, T. 1997. Mechanical properties of full-sized square lumber of Karamatsu. Bull. Shinshu Univ. Forests **33**:75-145 (In Japanese).

[28]Zare, H. 2001. Introduced and Native Conifers in Iran. Ministry of Jihad-e-Agriculture, Agriculture Research, Education and Extension Organization.Technical Publication No. 271. 498 p.

[29]Zhang, S.Y., Simpson, D. and Morgenstern, E. K. 1996. Variation in the relationship of wood density with growth in 40 black spruce (*Picea mariana*) families grown in New Brunswick. Wood and Fiber Science **28**:91-98.

[30]Zhang, S. Y. 1997. Wood specific gravity - Mechanical property relationship at species level. Wood Science and Technology **31**:181-191.

[31]Zobel, B. J. and Van Bujitenen, B. 1989.Wood Variation: Its Causes and Control. Springer-Verlag, New York.