CELLULOSE CHEMISTRY AND TECHNOLOGY

WOOD PHYSICAL PROPERTIES AND TRACHEID DIMENSIONS OF NON-NATIVE SOFTWOODS IN IRAN

MOHAMMAD FARSI[*] and MAJID KIAEI[**]

[*]*Department of Wood and Paper Science and Technology, Sari Branch, Islamic Azad University,*
Sari, Mazandaran, Iran
[**]*Department of Wood and Paper Science and Technology, Chaloos Branch, Islamic Azad University,*
Chaloos, Mazandaran, Iran
✉*Corresponding author: Mohammad Farsi, moh_farsi@iausari.ac.ir*

Received December 14, 2012

This study was conducted to investigate some physical properties (basic density, volumetric shrinkage), tracheid dimensions (tracheid length, tracheid diameter, lumen diameter, and cell wall thickness) and biometrical properties (flexibility coefficient, slenderness coefficient and Runkel coefficient) of 9 species of non-native softwoods of the world imported to and grown in the northern region of Iran. For this purpose, 27 healthy trees from scots pine species with seed origins in Spain, Serbia (part of former Yugoslavia), Armenia, spruce species with seed source in Serbia, Lajim and Kelardasht, and species of black pine, yellow pine and larch from a Vanemek-Neka site in northern Iran were selected randomly and a disk was cut from each one at breast height. Test samples were cut from the disks to measure physical properties (based on the ISO standard), tracheid dimensions (using the Franklin method) and biometrical indexes. The ANOVA results showed a significant difference among softwood species in terms of physical properties, tracheid dimensions and biometrical properties. There was no significant difference in Runkel coefficient. Seed source had some meaningful effects on the physical properties, tracheid dimensions and biometrical properties of scots pine (except flexibility coefficient and Runkel coefficient) and spruce wood (except basic density and Runkel coefficient). The relationship between various wood properties and quantitative features (survival, height and diameter) of the trees showed no significant correlation between these mentioned traits in non-native softwood species. All of the investigated species presented important indicators for the production of paper in terms of biometrical coefficients. However, planting scots pine with seed origins in Serbia and Armenia seems to be more suitable due to higher wood production over a short time period and better compatibility with the site conditions.

Keywords: softwood species, seed source, physical properties, tracheid dimensions, biometrical properties

INTRODUCTION

In terms of softwood species, Iran is considered one of the poorest countries of the world, with only about 0.5% of its forests in the north being covered with coniferous species. The main native softwood species in Iran are cypress and juniper. Rapid growth, proper adaptability to different habitat conditions and proper application of softwoods in wood and paper industries determined the cultivation of these particular pine species. Besides, since 1956, about 48 species of softwoods have been imported to Iran and planted in different regions,[1-2] including yellow pine, larch, scots pine, black pine and spruce species.

Yellow pine (*Pinus ponderosa*) is native to the northwest of the U.S.A. and is geographically spread from 31 to 51 degrees latitude in the north. Yellow pine is one of the most widespread species of pine among the native American pines, so that its distribution ranges from the north, from Alberta and British Columbia at Canada border, to Washington State, Oregon, and southern California, and extends towards the East to New Mexico. Scots pine (*Pinus sylvestris*) is a Euro-Asian species and covers vast lands in the high latitudes of the northern hemisphere and it has spread from Siberia in Asia to Europe, and among pine species, it has the highest levels of natural spread. Larch (*Larix deciduas*) is also native to

Cellulose Chem. Technol., ***48*** *(5-6), 445-454 (2014)*

central Europe and its major habitats are the Alps, Carpathians, Souderton, southern and central Poland. It needs a humid climate and grows poorly in high clay soils. It can tolerate this kind of poorly drained soils and grows better in acidic reacting soil than in neutral one. Black pine (*Pinus nigra*) is native to the west Mediterranean Sea and to the zone from the Black Sea to Austria. This species is highly resistant to cold and dry climates and requires Mediterranean climate, low soil moisture being a limiting factor for its growth. Spruce (*Picea Abies*) is native to European elevations extending from the Balkans to Russia. It grows best in cold and humid climates and on well drained loamy sandy soils. This species is tolerant of shade and is sensitive to northern slope shade, low and wet places and soils that are drained poorly.[1-3]

Wood density is an important feature of wood quality, which can affect wood strength properties, wood shrinkage and paper pulp yield.[4] In softwoods, the increased growth rate by changing the amount of late wood causes reduced density and mechanical properties of wood. Wood density of softwoods in the radial axis of the tree increases from center to bark and decreases in longitudinal axis from the bottom to top of the tree.[5-10] Scots pine growing in the central part of Lithuania has lower density, higher amount of lignin, and more extracts than *Pinus Contorta*, but equal contents of cellulose and ash.[11] In a study on the effect of seed source on the wood density of *Pinus radiata* grown in two sites in Greece, it has been reported that the effect of seed source (Australia, New Zealand and Spain) on the wood density of *Pinus radiata* was not significant, while the independent effects of site and the interactions between seed source and site on the density were noteworthy.[12]

The characteristics of wood fibers are important factors affecting the pulp and paper industry, as well as other cellulosic industries. By studying the mentioned characteristics, the suitability of woody and non-woody species for pulp and paper industry can be predicted. The strength characteristics of paper produced from the wood of trees from different regions may vary due to anatomical variation. Fibers that have thick walls are coarser; therefore, there will be more empty space between them, but, on the contrary, the fibers that have broad fiber cavity and thin walls have a higher tendency to strip when they are beaten and, as a result, the connections between fibers and, naturally, the tensile strength and resistance will improve. Burst strength and tensile strength are two features that are significantly affected by both length and wall thickness of the fibers; hence, flexibility coefficient has a significant effect on the mentioned resistances.[5,13]

Forests and Range Research Institute (FRRI) implemented a project in 1997 on the adaptation of nine different species of softwoods (yellow pine, scots pine, spruce, black pine and larch) in three high regions in Mazandaran and Gilan forests, northern Iran (3 altitude classes in each region). Now, nearly twenty years after the project implementation, it is essential to examine the various non-native wood species properties. The objectives of this research were a) to examine the physical properties, tracheid dimensions and biometrical properties of major non-native softwoods grown in the north of Iran (yellow pine, scots pine, spruce, black pine and larch), b) to investigate the effect of seed source on the physical properties, tracheid dimensions and biometrical properties of scots pine (with seed origins from Spain, Armenia and Serbia) and spruce (with seed origins from Lajim, Kelardasht and Serbia) and c) to determine the relationship between physical properties, tracheid dimension and biometrical indexes, and tree quantitative characteristics (height, diameter and survival).

EXPERIMENTAL

Materials

The research project site was Vanemek-Neka in the north of Iran, located at 760 meters above the sea level (altitude) and at an average gradient of 10%. The most important herbaceous species covering the project area are *Carex brunnra*, Pennyroyal, *Juncos acutus*, Sweet Basil, *Hypericum androsaemum* and elderberry. Determining the physical and chemical properties of the soil was done by drilling a profile with the dimensions of 75 cm by 5.1 m and by 2 m in depth in the tenth year of implementing the research project. The soil of the region is deep to very deep, and the greater the soil depth the higher the clay amount and the heavier the soil texture in the lower horizons. In terms of soil fertility, the studied area has favorable conditions for tree growth. Also, the soil is active lime-free.[2]

The results of ten year climate data obtained from Vanemek meteorological stations, from 1990 to 1999, showed that the absolute maximum temperature (July) was 42 °C, the minimum temperature (January) was -12 °C and the mean annual temperature was 15.7 °C. The total mean rainfall over the ten years was 1186 mm, fluctuating between 765 mm in 1995 and 1923 ml in 1993. According to the performed investigations based on the climagram of Emberger's formula, this region is placed in the cold and wet climate category with very cold winters, and based on De Martonne's classification, it is located in a very wet climate. In the research by Kiasari *et al.* on this region, it is shown that the conditions of the area are best for scots pine originating from Serbia and Armenia, and worst for larch, in terms of survival. Scots pine with Serbian seed source has the highest values in terms of height and diameter at breast height (Table 1).[2]

In this study, 27 normal trees of nine exotic softwood species (yellow pine and scots pine with seed origins in Spain, Armenia, Serbia, species of spruce with seed origins in Lajim, Kelardasht and Serbia, and species of black pine and larch) (Table 2) grown in the Vanemek-Neka site in northern Iran were chosen and a disk was cut from each of them at breast height. Because of the small diameter of the trees, it was not possible to obtain samples along radial axis from the pith to the bark. Therefore, first the central part was isolated from the disks, then samples from the disk surface were obtained.

Methods

Physical properties

After preparing the samples (based on the standard ISO-3131), the experiments, which included weighing and measuring dimensions, were done. In the first step, the volume and weight of the samples (after cutting the sample) were measured. In the second step, the samples were placed in water for 48 hours, so that all the samples were submerged and/or saturated with water. The weight and volume of the saturated samples were determined using a digital scale and a caliper. In the third stage, the samples were placed in an oven for 48 h, at 103 ± 2 °C, until the samples dried completely. The volume and weight of the samples were measured in a dry state. Special basic density is the most important intrinsic property of wood and is obtained from dry weight divided by the saturation volume. Shrinkage changes the dimensions of the wood, which occurs by the influence of various phenomena and moisture changes between the two limits of fiber saturation point and dry mode of the wood and is obtained by the relation below (where β_v: volumetric shrinkage, v_s: saturation volume and v_0: dry volume). The number of samples for measuring physical properties was 50 for each species of softwood.

$$\beta_v = \frac{v_s - v_0}{v_s} \times 100$$

Tracheid dimensions

The number of samples for measuring tracheid dimensions was 15 samples for each species of softwood and 30 tracheids were measured for each prepared sample (450 tracheids for each kind of wood). Franklin method (1954)[14] was used for separating fibers. In this method, a ratio of 50 to 50% of acetic acid and hydrogen peroxide was used. First, the sample wood picks were placed inside a microquant, then pre-prepared acetic acid and hydrogen peroxide were poured on the wood samples by a calibrated pipette and the microquant was placed in an oven and heated for 48 h at 64 °C. After whitening, the samples from the microquant were washed 4 to 5 times by a calibrated pipette with distilled water until the odor of hydrogen peroxide and acetic acid was completely removed. To examine tracheid dimension, an Image Analysis System was used.

Biometrical properties include flexibility coefficient, slenderness coefficient and Runkel coefficient. Flexibility coefficient shows the resistance of the paper against rupture and burst and if flexibility coefficient increases, the resistance of the paper will increase; this coefficient is obtained from the lumen diameter divided by the tracheid diameter.[15] Slenderness coefficient shows the quality of the paper and is obtained from the tracheid length divided by the diameter of the fibers.[16] Runkel coefficient shows paper resistance against rupture and is obtained from the two-cell-wall thickness divided by the fiber diameter.[17]

Table 1
Tree status of the major world softwoods planted within the project in Vanamak-Neka

Softwood species	Tree status	Tree age	Seed source	Plantation
Pinus sylvestris (Scots pine)	Potted	3 years (2+1)	Armenia	Asalem
Pinus sylvestris (Scots pine)	Potted	3 years (2+1)	Spain	Asalem
Pinus sylvestris (Scots pine)	Potted	3 years (2+1)	Serbia	Chalmardy
*Pinus nigr*a (Black pine)	Potted	3 years (2+1)	Austria	Kelardasht
Picea abies (Spruce)	Potted	3 years (2+1)	Kelardasht*	Kelardasht
Picea abies (Spruce)	Potted	3 years (2+1)	Lajim*	Lajim
Picea abies (Spruce)	Potted	3 years (2+1)	Serbia	Pajet
Pinus ponderosa (Yellow pine)	Potted	4 years (3+1)	USA	Kelardasht
Larix deciduas (Larch)	Potted	3 years (2+1)	Serbia	Pajet

*The main source of these trees is Serbia, but after natural regeneration in Kelardasht and Lajim regions in Iran, the source names change to Kelardasht and Lajim, respectively

Table 2
Average quantitative features of softwoods from Vanamak-Neka region

Softwood species	Source	Survival (%)	DBH (cm)	Height (m)
Scots pine	Armenia	87	10.06	7.20
Scots pine	Spain	74.33	8.03	4.32
Scots pine	Serbia	89.33	10.47	7.47
Black pine	Austria	57.67	8.95	5.13
Spruce	Kelardasht	62.33	8.39	6.32
Spruce	Lajim	77.67	7.94	6.01
Spruce	Serbia	62.67	7.46	5.47
Yellow pine	USA	64.67	4.67	3.31
Larch	Serbia	8.50	5.20	3.74

The age of the trees was 16-18 years old for all studied species; DBH: tree diameter at breast height

Statistical analysis

In this study, the effect of treating the softwood samples on their physical properties, tracheid dimensions and biometrical properties and the effect of seed origin on the mentioned properties of scots pine and spruce were studied. Variance analysis test was used to determine significant differences and Duncan's table was used for grouping the means. Also, the relationship between physical properties, tracheid dimensions and biometrical indexes, and the quantitative characteristics of trees growing in Vanemek-Neka site, at softwoods species level, was evaluated using Pearson matrix correlation.

RESULTS AND DISCUSSION

Basic density

The results of variance analysis (ANOVA) indicated that the effect of softwoods treatment was significant on basic density, so that the maximum value of basic density was obtained for larch species (0.498 g cm^{-3}) and its minimum value for Kelardasht spruce wood (0.332 g cm^{-3}). The effect of seed source on scots pine wood density was meaningful, while it was insignificant on spruce wood density. Among the scots pines, the basic density was higher for Spanish seed origin (0.443 g cm^{-3}) and lower for Armenian seed origin (0.396 g cm^{-3}). In addition, the basic density of spruce wood with Lajim seed source (0.351 g cm^{-3}) was slightly higher than those with Serbian and Kelardasht seed origin (0.343 g cm^{-3}) and (0.332 g cm^{-3}), respectively (Fig. 1).

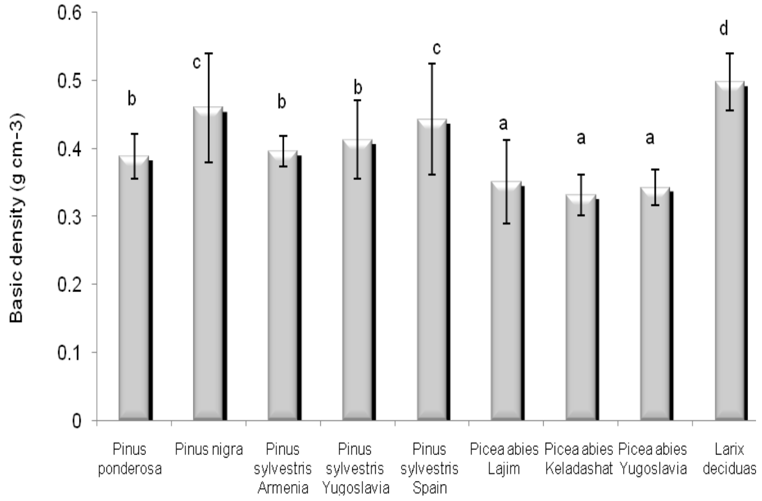

Figure 1: Average basic density of non-native softwood species

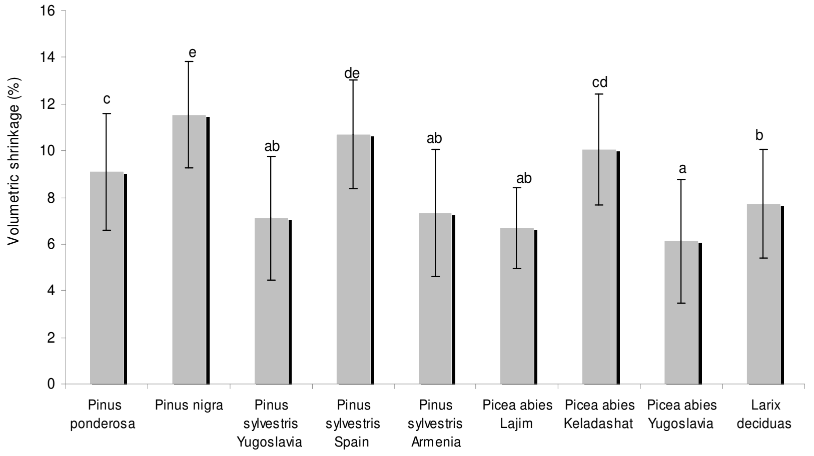

Figure 2: Average volumetric shrinkage of non-native softwood species

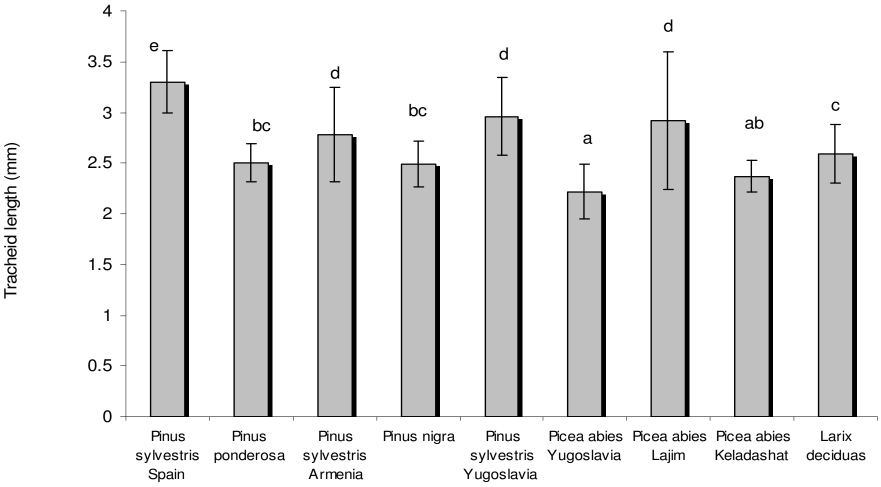

Figure 3: Average tracheid length of non-native softwood species

Volumetric shrinkage

Variance analysis (ANOVA) showed that the effect of softwoods treatments on volumetric shrinkage was significant, so that the greatest amount of volumetric shrinkage was achieved for black pine wood (11.53%) and the lowest for the Serbian spruce wood (6.12%). The effects of seed origin on the shrinkage of scots pine and spruce was meaningful. Among scots pines, shrinkage was more than 10.70% for the Spanish seed source and less than 7.11% for the Serbian seed origin. Among spruce woods, maximum and minimum amounts of volumetric shrinkage were observed for Kelardasht (10.60%) and Serbia (6.12%) seed sources, respectively. Despite the high density, larch species have good dimensional stability (Fig. 2).

Tracheid dimensions

Tracheid length

The results of variance analysis showed that the effect of softwoods treatments on tracheid length was significant, so that the maximum amount of tracheid length (3.3 mm) was obtained for Spanish scots pine, while its minimum amount was recorded for Serbian spruce wood (2.22 mm). The effect of seed source on the tracheid length of scots pine and spruce was significan; among scots pines, tracheid length was higher for scots pine with seed sources in Spain and was lower for seed sources in Armenia (2.78 mm). Moreover, the value of this property in Lajim spruce (2.92 mm) was greater than those of spruce with Kelardasht (2.37 mm) and Serbian seed origins (Fig. 3).

Tracheid diameter

Variance analysis results showed that the effect of softwoods treatments on tracheid diameter was significant: the maximum tracheid diameter was found in the scots pine of Serbia (42.34 µm) and the least one in yellow pine (29.78 µm). The effect of seed source on the tracheid diameter of scots pine and spruce was significant, so that among scots pines, the tracheid diameter of scots pine of Serbian origin was more than 42.34 µm, while for that of Spanish origin it was less than 32.72 µm. Also, the value of this property in Kelardasht spruce (34.84 µm) was higher than that for spruces with seed origins of Lajim (31.21 µm) and Serbia (31.42 µm) (Fig. 4).

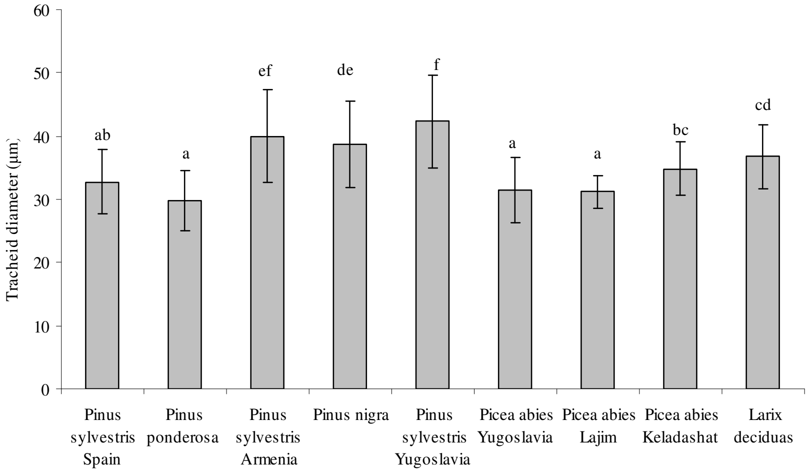

Figure 4: Average tracheid diameter of non-native softwood species

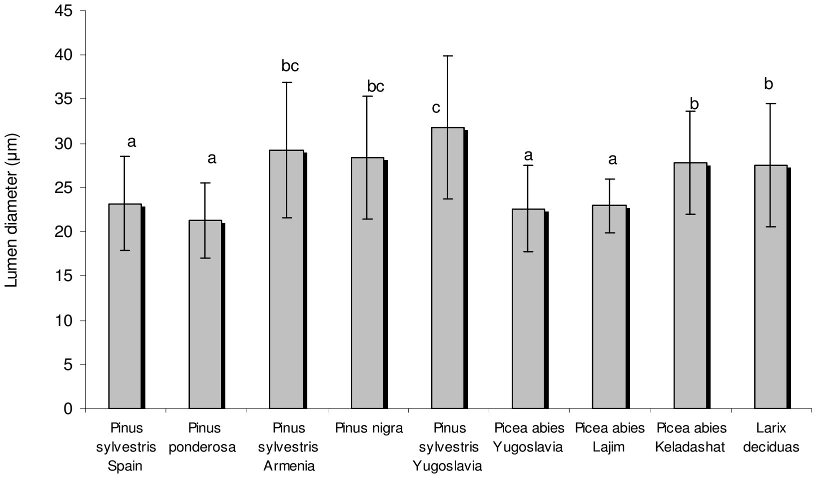

Figure 5: Average lumen diameter of non-native softwood species

Lumen diameter

Variance analysis results showed that the effect of softwoods treatments on lumen diameter was significant: the maximum lumen diameter (31.74 µm) was in Serbian scots pine and the minimum in yellow pine (21.31 µm). The effect of seed source on the lumen diameter of scots pine and spruce was also significant: among scots pines, the lumen diameter of scots pine wood with Serbian origins was greater than that of the others, while that of scots pine with Spanish seed sources was the lowest (23.19 µm). Moreover, the value of this property in Kelardasht spruce was greater (27.80 µm) than those for spruce with Lajim (22.95 µm) and Serbian (22.64 µm) seed origins (Fig. 5).

Cell wall thickness

Variance analysis (ANOVA) results showed that the effect of softwoods treatments on cell wall thickness was meaningful: the maximum cell wall thickness (5.72 µm) was observed in Armenian scots pine and the minimum in Kelardasht spruce wood (3.52 µm). The effect of seed source on the cell wall thickness of scots pine and spruce was also significant, among scots pines, cell wall thickness was higher in Armenian and lower in Spanish (4.765 µm) scots pine wood.

Moreover, the value of this property was greater in Lajim spruce (4.125 µm) than in Kelardasht (3.52 µm) and Serbian (4.385 µm) spruce (Fig. 6).

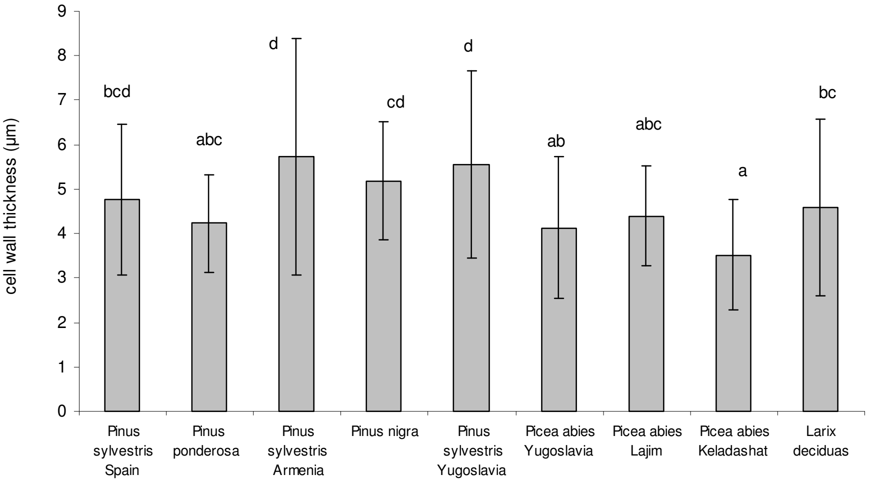

Figure 6: Average cell wall thickness of non-native softwood species

Table 3
Average biometrical indexes of exotic softwood species grown in Vanamak-Neka site

Softwood species	Flexibility coefficient	Slenderness coefficient	Runkel coefficient
Spanish scots pine	70.66^{a}	102.83^{c}	0.45^{a}
Yellow pine	71.35^{a}	85.44^{b}	0.41^{a}
Armenian scots pine	71.37^{a}	71.46^{a}	0.44^{a}
Black pine	72.65^{a}	66.56^{a}	0.39^{a}
Serbian scots pine	73.22^{a}	70.78^{a}	0.40^{a}
Kelardasht spruce	79.04^{b}	69.19^{a}	0.28^{a}
Serbian spruce	73.71^{a}	71.73^{a}	0.37^{a}
Lajim spruce	71.82^{a}	95.23^{c}	0.40^{a}
Larch	74.35^{ab}	72.08^{a}	0.38^{a}

Biometrical coefficients

Variance analysis results showed that the impact of the softwood species on the flexibility coefficient was significant. The maximum flexibility coefficient was observed in Kelardasht spruce (79.04%) and the lowest in Spanish scots pine (70.66%). The effect of seed origin on the flexibility coefficient of spruce was significant, while it was not significant in scots pine. Among the species of spruce, the maximum flexibility coefficient was found in Kelardasht spruce (79.04%) and the minimum in Lajim spruce (71.82%) (Table 3).

Variance analysis results showed that there was a significant difference between softwood species in terms of slenderness coefficient. The highest slenderness coefficient was observed in the scots pine with seed origin from Spain (102.83) and the lowest coefficient in black pine (66.56). The impact of seed source on the slenderness coefficient of scots pine and spruce was significant: among scots pines, the highest slenderness coefficient was found in Spanish scots pine species (102.83) and the lowest in Serbian scots pine (70.78). In spruce species with different seed origins, the maximum and minimum values belonged to spruce with seeds from Lajim (95.23) and Kelardasht (69.19), respectively (Table 3).

Variance analysis results showed that the effect of softwood species on Runkel coefficient was significant, while the effect of seed sources on Runkel coefficient of spruce and scots pine wood was not significant. In general, the highest and the lowest Runkel coefficients were observed in the scots pine of Spain (0.45) and spruce of Kelardasht (0.28), respectively (Table 3). The Runkel coefficients of all types of imported non-native softwoods were below one.

The relationship between physical properties (basic density and volumetric shrinkage), tracheid dimensions (tracheid length, tracheid diameter, lumen diameter, cell wall thickness) and biometrical properties (flexibility coefficient, slenderness coefficient and Runkel coefficient), and the quantitative characteristics of the mentioned trees (survivability, diameter and height) showed no significant differences among the mentioned properties of the nine imported softwood species. The relationship between fiber dimensions and survivability was positive, while between fiber dimensions and tree height it was negative.

Variations among species, within the same species (from tree to tree) and within a tree (changes in tree height and radial changes from the pith to the bark), as well as changes in the rings (early wood and late wood) are factors that can affect the properties of wood. These variations are increased by the habitat, climate and seed source factors.[13,18] The present study indicated significant differences between softwood species in terms of physical and biometric properties, which may be caused by variations within species, even though all the investigated species belong to the pine family.

The effect of seed origin on tracheid length of scots pine and spruce and on the basic density of scots pine is significant, while it is insignificant as regards the basic density of spruce wood. Also, the relationship between the physical and biometric properties and the quantitative features of trees showed that there was no significant correlation between the mentioned properties, which agrees with the results obtained by the world's leading researchers,[12,19] who stated that the density of *Pinus radiate* presented a weak negative correlation with the diameter at breast height, a property which is not dependent on the height of trees.

Since all the mechanical properties of wood have a strong relationship with density, while some of the resistance properties of wood have a stronger relation with density, it is expected that high density larch species would have higher resistance than others, which is very important in the design of wood structures. The dependence between wood density and mechanical properties of wood for many species of softwoods has been demonstrated.[2,18] Also, many of the mechanical properties of wood are dependent on the tracheid dimensions including the length and diameter of tracheid.[5]

Table 4
Relationship between physical and biometric properties and quantitative features of imported softwood species

Pearson correlation	Survival	DBH	Height
Basic density	-0.517	-0.280	-0.448
Volumetric shrinkage	-0.108	0.066	-0.493
Tracheid length	0.405	0.242	-0.504
Tracheid diameter	0.123	0.458	-0.284
Lumen diameter	0.055	0.403	-0.260
Cell wall thickness	0.281	0.463	-0.254
Flexibility coefficient	-0.177	-0.001	0.066
Slenderness coefficient	0.258	-0.122	-0.228
Runkel coefficient	0.212	0.079	-0.139

All relationships between wood properties aren't significant; DBH: tree diameter at breast height

Since the larch species have the most basic density of the other species, therefore, these factors may affect the production of pulp. In equal digester volume, larch wood species produced more pulp than others. Therefore, greater paper strength is expected from larch wood. As known, there is a positive relationship between wood density and optical properties, on the one hand, and between wood density and tear resistance, on the other hand, and a negative relationship between wood density and the tensile strength of paper.[11,20]

Wood with a basic density of 0.4-0.6 g cm^{-3} is suitable for the production of paper pulp.[21] This property is observed in scots pine species with seed sources from Serbia, Armenia (roughly) and Spain, black pine and larch. The basic density of scots pine with seed origins from Spain is 0.443 g/cm^3, which is almost equal to the basic density of the wood planted in Spain[9] (0.443 g cm^{-3}) and in southern Finland (0.443 g cm^{-3}).[8]

Based on IAWA classification, the fibers of all major softwood species of the world, grown on Vanemek-Neka site, are considered long, and from the softwood species family, the longest fibers belong to the scots pine of Spain (3.3 mm). In general, the higher the fiber length of a specific species, the more suitable it is for the production of paper. But researches have shown that the suitability threshold of tracheid length is 2 mm, for producing kraft paper with good tear strength, and after this threshold, longer cells have little effect on the quality of the final product. It has been also reported in other studies that larger cells have no significant effect on increasing the tensile strength of paper,[13] which may apply to all the above-mentioned species, since the tracheid length of the studied species was found to be higher than 2 mm.

In terms of flexibility coefficient, fibers can be classified into four groups: 1) very flexible fibers with a flexibility coefficient higher than 75; 2) flexible fibers with a flexibility coefficient of 50-75; 3) hard and rough fibers with a flexibility coefficient of 30-50; and 4) fibers with high stiffness and a flexibility coefficient lower than 30.[22] According to this classification, Kelardasht spruce softwoods belongs to the first group and the remaining species to the second group. Very flexible (first group) and flexible (second group) fibers, present in all the investigated species, are suitable for paper production. Of course, hard and rough fibers with a flexibility coefficient of 50-30 are not suitable for the manufacture of paper and are mostly used for paperboard products.[22]

The higher the slenderness coefficient, the higher and better paper quality will be; however, an acceptable value of the slenderness coefficient for the paper industry is above 33%.[23] These properties have been observed in all softwood species grown on Vanemek-Neka site.

When Runkel coefficient is above 1, fibers have thick cell walls and the cellulose obtained from them is less used in the paper industry. However, when its value is equal to 1, fibers have average cell walls and the cellulose obtained is suitable for paper production. When the coefficient of this value is below one, fibers have thin cell walls and the cellulose obtained such fibers is most frequently used in paper industry.[23] Thus, the fibers from all the softwood species under study are suitable for paper production, due to the low value of this coefficient.

CONCLUSION

1- There are significant differences among the imported softwood species as to physical properties, tracheid dimensions and biometrical indexes, except Runkel index.

2- The seed source had a significant effect on the physical properties, tracheid length and biometrical indexes, except basic density and Runkel index in spruce species, and flexibility and Runkel index in scots pine species.

3- All softwood species investigated in the present study are suitable for the paper industry in terms of density, tracheid length and biometric coefficient (Runkel coefficient, flexibility coefficient and slenderness coefficient), but considering the desired high volume wood production in a short period of time, scots pine species with seeds from Armenia and Serbia are more suitable than other softwood species, as in addition to presenting suitable indicators for paper production, they achieve the desired diameter and length in a short time. As Iran forest resources are relatively poor, the results of this study show that the cultivation of this species (scots pine of Armenian and Serbian origin) is necessary and important.

REFERENCES

[1] H. Zare, Native and Imported Conifers by Iranian Ministry of Jihad-e-Agriculture, Agriculture Research, Education and Extension Organization, No271, Tehran, Iran, 2001.

[2] M. Kiaei, *Turk. Agric. For.*, **35**, 31 (2011).

[3] S. M. N. Kiasari, S. A. Mousavi, S. Amini, A. Borhani, B. Jafari *et al.*, *Journal of Sciences and Techniques in Natural Resources*, **6**(**4**), 25 (2011).

[4] P. W. West, "Growing Plantation Forests", Springer Verlag, Berlin, 2006.

[5] A. Panshin and C. de Zeeuw, "Textbook of Wood Technology", 4th ed., McGraw-Hill, New York, 1980.

[6] L. A. Bouffier, B. L. Gartner and J. C. Domec, *Wood Fiber Sci.*, **35**(**2**), 217 (2003).

[7] R. Mutz, E. Guilley, U. H. Sauter and G. Nepveu, *Ann. Sci. Forest.*, **61**, 831 (2004).

[8] J. Repola, *Silva Fenn.*, **4**(**4**), 673 (2006).

[9] R. Munoz, M. Canas and R. R. Soalleiro, *Ann. Sci. Forest.*, **65**, 507 (2008).

[10] M. Kiaei, H. Khademi-Eslam, A. H. Hemmasi and A. Samariha, *Cellulose Chem. Technol.*, **46**(**1-2**), 125 (2012).

[11] I. Sable, U. Grinfelds, A. Jansons, L. Vikele, I. Irbe *et al.*, *Bioresource*, **7**(**2**), 1771 (2012).

[12] D. I. Matziris, *Silvae Genetica*, **28**, 104 (1979).

[13] B. J. Zobel and J. P. van Buijtenen, "Wood Variation: Its Causes and Control", Springer-Verlag, Berlin, Heidelberg, New York, 1989.

[14] F. L. Franklin, *Tropical Woods*, **88**, 35 (1964).

[15] F. F. Wangaard, *Tappi J.*, **45**, 548 (1962).

[16]M. Kiaei, A. N. Sadegh and R. Moya, *Cellulose Chem. Technol.*, **47**(**1-2**), 49 (2013).
[17] Runkel, *Das Papier*, **3**, 476 (1949).
[18]S. Y. Zhang, *Wood Sci. Technol.*, **31**, 181 (1997).
[19]R. Burdon and J. Harris, *New Zeal. J. For. Sci.*, **3** (**3**), 286 (1973).
[20]R. Wimmer, G. M. Downes, R. Evans, G. Rasmussen and J. French, *Holzforschung*, **56**, 244 (2002).
[21]G. M. Downes, I. L. Hudson, C. A. Raymond, G. H. Dean, A. J. Michell *et al.*, "Sampling Plantation Eucalypts for Wood and Fibre Properties", CSIRO Publishing, Melbourne, Australia, 1997, 132 pp.
[22]I. Bektas, A. Tutus and H. Eroglu, *Turk. J. Agric. For.*, **23**, 589 (1999).
[23]F. Xu, X. C. Zhong, R. C. Sun and Q. Lu, *Ind. Crop. Prod.*, **24**, 186 (2006).