VARIATION OF WITHIN-STEM BIOMETRICAL AND PHYSICAL PROPERTY INDICES OF WOOD FROM *CUPRESSUS SEMPERVIRENS* L.

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Variations in average tracheid dimensions (such as length, diameter, lumen diameter, and wall thickness) and its biometrical ratios including slenderness ratio, flexibility ratio, and Runkell ratio, oven-dry and basic density, longitudinal, radial, tangential, and volume shrinkage, maximum moisture content, and porosity of cypress trees wood (*Cupressus sempervirens* L. var. horizontalis), which was cultivated in the north of Iran, were studied from the pith to bark (radial position), and along the stem from the base upwards. To measure the mentioned traits, the test specimens were prepared from three stands and 9 discs at different height levels (5, 25, and 50% of the total tree height) based on ASTM-D143 standard. Results indicated that the tracheid length, tracheid cross-sectional dimensions, and its biometrical ratios irregularly varied at each height level, along the stem from the bottom to top, but within the discs, at the same height level biometrical traits in the radial position regularly increased from the pith to bark. Within the tree, wood oven-dry and basic density, longitudinal, radial, tangential, and volume shrinkage varied at each height level, decreasing along the stem from the base upwards. Within the discs, at the same height level, wood density and shrinkage, except for longitudinal shrinkage in the radial position, increased from the pith to bark. The maximum moisture content and porosity varied at each height level, increasing along the stem from the bottom to the top of the tree. Moreover, within the discs, at the same height level in the radial direction porosity decreased and maximum moisture content increased except for at 5% of height level from the pith to bark.

Keywords: Cupressus sempervirens L.; Tracheid dimensions; Biometrical ratios; Wood density; Wood shrinkage; Maximum moisture content; Porosity; Variation within-tree

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INTRODUCTION

Cypress is grown in plantations on sites that are unsuitable for agricultural cultivation, where it produces wood of very good quality (Uzielli and Berti 1979; Tischler 1981; Papamichael and Paraskevopoulou 1982), which is used extensively in furniture, joinery, vine props, shipbuilding, and in building construction, where it is used chiefly as roofing poles (Paraskevopoulou 1991). In Iran, Mediterranean cypress (*Cupressus sempervirens L.*) occurs in natural forests in the Roodbar, Manjil, Dilaman, Zarringol, Aliabade Katool, Arasbaran, and mainly in Polzoghal (Hassan-Abad in

Chalous) regions, where it is a very important element of the vegetation, but there is a prohibition against cutting it due to the shortage of this species. Thus plantation trees of cypress (*C. sempervirens* L.) are as an important substitute resource for the targeted applications, and the trees are cultivated extensively in our country, especially in all of the northern areas, including the Ramsar region.

The wood properties have been reported to depend on such factors as climate, provenance, ecological conditions, as well as wood positions in different parts of tree, between, and within species (Koch 1985).

Wood properties such as density and fiber length determine the end-product quality in industrial processes and are both positively correlated with tear strength (Fuglem et al. 2003).

Paraskevopoulou (1991) studied the variation of wood structure and properties of *C. sempervirens* var. horizontalis in a natural population in Greece. He indicated that the average specific gravity, over all trees (individual tree values ranged from 0.396 to 0.594 g/cm^3), decreased and tracheid length (with individual tree values ranging from 2.32 to 3.00 mm) increased across discs from the pith outwards, although the tracheid length decreased from the base of the tree up to 35% of total tree height, after which it decreased.

Wood density is one of the most important properties (Brazier and Howell 1979), and a commonly or general used indicator of wood quality and cell size, since it is a good predictor of timber strength, stiffness, ease of drying, machining, hardness and related to tracheid properties, pulp yield, and various paper making properties (Elliot 1970; Panshin and De Zeeuw 1980; Jyske et al. 2008). It is affected by the proportion of cell wall material in the wood (cell wall thickness), the cell diameter, and the chemical content of the wood, and is hence dependent on the ratio of cell wall thickness and cell diameter (Cave and Walker 1994; Kibblewhite 1999).

Basic density is closely related to end-use quality parameters such as pulp yield and structural timber strength (Harvald and Olesen 1987). Indeed in many conifers, the basic density of the latewood zone is more than twice that of earlywood; thus, any increase in the proportion of latewood inevitably leads to an increase in whole ring basic density (Elliot 1970; Ward 1975). In a study carried out by Harvald and Olesen (1987) on the variation of basic density within the juvenile wood of Sitka spruce, it was found that basic density decreased with increasing height in the stem. Previous studies also have examined genetic variation among trees for basic density and fiber length in trembling aspen (*Populus tremuloides*) (e.g., Brown 1961; Einspher et al. 1967; Yanchuk et al. 1984).

It has been found that pith-to-bark variation in longitudinal shrinkage is a key factor for distortion in timber drying. However, the difference in the longitudinal shrinkage between two faces of the timber can explain spring or bow characteristics much better when the variation in shrinkage along the timber is considered (Kilger et al. 2003). Deresse et al. (2002) found that longitudinal shrinkage of red pine (*Pinus resinosa* Ait.) declined significantly with increasing growth ring number from the pith, and the influence of the growth ring number changed significantly at around 15th growth ring, with the longitudinal shrinkage leveling off after that. Also Herritsch (2007) showed similar trends for radiata pine, where tangential shrinkage remained relatively constant in the transition wood and the outerwood.

The variation in anisotropic shrinkage of plantation-grown *Pinus radiata* wood was studied by Wang et al. (2008). They showed that longitudinal shrinkage varied from 0.02 to 2.34%, with peak values near the pith, decreasing towards the bark, and with more pronounced variation at 0.1 m height. Also the longitudinal shrinkage showed a decreasing trend with increasing height in the stem above the ground. Tangential and radial shrinkage were found to increase with growth ring number from the pith, but the variation along the stem height did not show a clear trend.

As is well known, moisture content (MC) of sapwood is significantly higher than that of heartwood in coniferous trees. The MC is important because of its direct relation to the weight and processing of the timber and due to the fact that it varies considerably among species (Haygreen and Bowyer 1982). The green density of *Cupressus luistanica* wood is 0.91 g/cm^3 with a moisture content of 155% for freshly felled trees. The moisture content is up to 105% in the heartwood, whereas sapwood moisture content averaged 180% but with some samples as high as 225% (Bannister and Orman 1960).

There is increasing demand for new species from fast-growth plantations as alternative timbers for coniferous wood, but there is little or no information about the variation of wood tracheid dimensions and its biometrical ratios, density, shrinkage, and above mentioned properties within stem and among trees in cypress. These characteristics are a means of assessing suitability for pulp and paper making and the dimensional stability of wood. Thus, the aim of the present study was to investigate the variation of physical and biometrical properties within tree stem of wood from plantation Mediterranean cypress (*C. sempervirens* L.) species growing under fast-growth conditions in Iran.

EXPERIMENTAL

Materials

All the cypress trees (*C. sempervirens* L.) were randomly selected, taking into account stem straightness and the absence of obvious decay, and cypress wood was selected according to TS 2476, as defect-free, clear, and normally grown (without zone lines, reaction wood, decay, and insect damage, or fungal infection) wood from a plantation in the northern city of Ramsar, Iran. It was grown on a Mediterranean climate at the elevation of 200-250 meters above see level with geographical direction of 36°56′ - 37°49′ N and 50°27′ - 50°43′ E. Three trees were cut from one provenience. The pattern clay of the study area of cypress is lime and dolomite. The mean annual precipitation and temperature of this area is usually about 1200 mm and 18 °C.

The characteristics of the study *C. sempervirens* L. trees are listed in Table 1.

Table 1. Characteristics of the Study *C. sempervirens* L. Trees

Tree No.	Diameter (cm)	Height (m)
1	24.52	11
2	22.29	12
3	22.29	15

Preparation of Test Samples

In each tree, sample discs of 30 cm length were taken from three height levels, at 5%, 25%, and 50% of the total tree height. Rough boards at 25 mm thickness were radially sawn in the four direction of radius. Then test specimens were cut from these rough boards (Fig. 1) having dimensions of 20 × 20 × 20 mm according to ASTM D143-94 and used for measuring the oven-dry and basic density, longitudinal, radial, tangential, and volume shrinkage, maximum moisture content, and porosity.

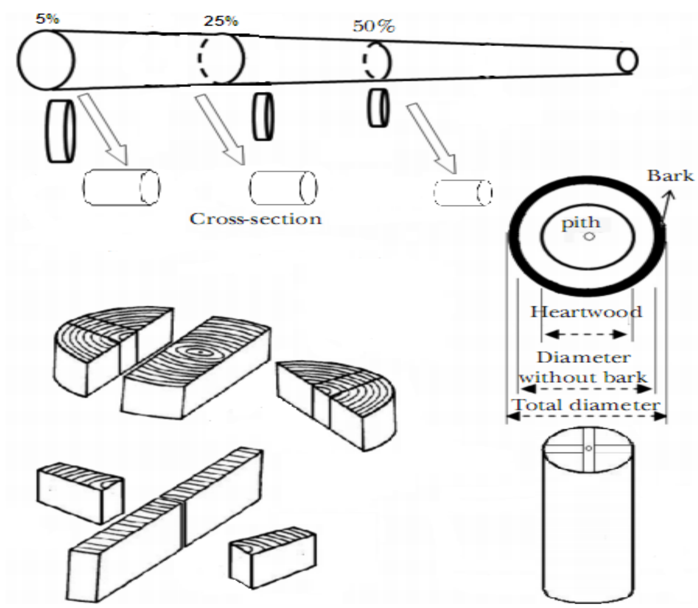

Figure 1. Specimen preparation from the discs

Specimens were randomly used in our experiments. From each sample disc in each tree, 5 specimens in 5% of height level, 4 specimens in 25% of height level, and 3 specimens in 50% of height level were collected randomly, depending on the tree diameter at the three height levels of the stem. In sum, 12 (5 + 4 + 3) cubic pieces (20 × 20 × 20 mm) were selected from each tree, and three discs randomly from the pith to the bark and finally were tested.

The specimens were soaked in distilled water for 72 h to ensure that their moisture content was above the fiber saturation point. Then the dimensions in all three principal directions were measured with a digital caliper to the nearest 0.001 mm. Specimens were weighed to the nearest 0.001 g for saturated weight, and the saturated volume was calculated based on these dimension measurements. Finally, the samples were oven dried at 103 ± 2 °C to 0% moisture content. After cooling in desiccators, the oven-dry weights of the specimens were measured. The values of the wood oven-dry and basic density, maximum moisture content, porosity and longitudinal, radial, tangential, and volume shrinkage in percentage were calculated using the following equations,

$$MC\ (max) = [(M_S - M_O) \div M_O] \times 100 \qquad (1)$$

where $MC\ (max)$ is the maximum moisture content, M_O is the oven dried weight, and M_S is the saturated weight of specimen.

$$D_O = (M_O \div V_O) \times 100 \quad (2)$$

where D_O, M_O, and V_O are the oven dried density, weight and volume of specimen respectively,

$$D_B = (M_O \div V_S) \times 100 \quad (3)$$

where D_B is the basic density, M_O is the oven dried weight and V_S is the saturated volume of specimen,

$$C = (1- 0.67\, D_O) \times 100 \quad (4)$$

where C is the porosity, D_O is the oven-dry density, and

$$\begin{aligned} B_L &= [(L_S - L_O)/L_S] \times 100 \\ B_R &= [(R_S - R_O)/R_S] \times 100 \\ B_T &= [(T_S - T_O)/T_S] \times 100 \\ B_V &= [(V_S - V_O)/V_S] \times 100 \end{aligned} \quad (5)$$

where B_L, B_R, B_T, and B_V are the longitudinal, radial, tangential, and volume shrinkage, L_O, R_O, T_O, and V_O are the oven dried dimensions, and L_S, R_S, T_S, and V_S are the saturated dimensions.

From each sample disc in each tree, 10 specimens (2 × 2 × 10 mm) in 5% of height level, 10 specimens in 25% of height level, and 10 specimens in 50% of height level were collected randomly, depending on the tree diameter at the three height levels of the stem, where distance of between selected samples decreased with increasing height in the stem above the ground. In sum, 30 (10 + 10 + 10) splinter pieces (2 × 2 × 10 mm) were selected from each tree, and three discs were taken randomly from the pith to the bark and finally were tested.

Samples for tracheid dimensions measurements were macerated in a mixture (1:1) of 30% of hydrogen peroxide and glacial acetic acid in a 64 ºC oven for 24 hours (Franklin 1964 modified method in order to lessen the reduction in tracheid length).

After maceration samples were washed with distilled water, and the 2 × 2 × 10 mm splinters were shaken gently in the distilled water until the individual tracheids of the wood were separated. From each splinter 2 slides were prepared and 10 whole tracheids on each slide were measured. Each slide was projected on an Olympus research microscope using a 1 × eyepiece and 4 × objective lens for tracheid length and at a 10 × objective lens for cross-sectional dimension. First the image of each tracheid was calibrated on monitor board with screw micrometer, and tracheid dimensions were determined with special plastic slide rule. The special transfer ratio was determined on the basis of microscope magnification and monitor magnification with a special microscope slide and on the monitor board. Then, the mean of tracheid length raw data (mm) was multiplied with a 5.3844153/1000 transfer ratio, and the mean of cross-sectional dimension raw data (μm) was multiplied with a 2.1428571 transfer ratio.

The biometrical ratios such as slenderness ratio (S_R), flexibility ratio (F_R), and Runkel ratio (R_R) of tracheids were calculated as follows (Ogbonnaya et al. 1997),

$$S_R = \frac{T_L}{T_D}$$
$$F_R = \frac{T_{LD}}{T_D} \times 100 \qquad (6)$$
$$R_R = \frac{2T_{WT}}{T_{LD}} \times 100$$

where T_L, T_D, T_{LD}, and $2T_{WT}$ are the tracheid length, tracheid diameter, tracheid lumen diameter, and tracheid two-wall thickness, respectively.

Statistical Analysis

Statistical analysis was conducted using the SPSS program in conjunction with analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to test statistical significance at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Within-Tree Variation

The results of ANOVA indicated that radial position at 5% and 25% of height level and height had significant effect and height had no significant effect on tracheid length of wood (P<0.05). The pattern of variation in tracheid length of wood, as a function of height in the stem, is shown in Table 2.

Table 2. Variation in Biometrical and Physical Properties of Wood in Longitudinal Direction at Different Height Levels within the Stem of *C. sempervirens* L.

Height Levels of Total Tree	T_L	T_D	T_{LD}	$2T_{WT}$	S_R	F_R	R_R	D_O	D_B	B_L	B_R	B_T	B_V	MC (max)	C
50%	4.8 a 0.9	61.7 a 9.0	42.6 a 7.0	19.1 a 2.6	78.8 a 12.9	69.0 a 2.6	45.2 a 5.7	0.45 a 0.03	0.41 a 0.02	0.44 a 0.35	3.03 a 0.50	5.83 a 0.93	8.99 a 1.14	155.62 b 12.31	69.99 b 1.83
25%	4.9 a 1.2	63.2 a 10.8	44.2 a 9.5	19.1 a 2.0	77.4 a 11.9	69.4 a 3.7	44.6 a 7.8	0.47 a 0.03	0.42 a 0.02	0.56 ab 0.38	3.11 a 0.60	6.08 a 0.76	9.51 ab 0.98	145.69 b 11.70	68.87 b 1.81
5%	5.0 a 1.2	64.7 a 13.3	44.7 a 11.3	20.0 a 3.4	77.6 a 12.7	68.5 a 5.2	46.9 a 12.1	0.50 b 0.03	0.45 b 0.02	0.96 b 0.70	3.24 a 0.69	6.12 a 1.24	10.17 b 1.04	133.33 a 13.53	66.69 a 1.86

Values are mean ± standard deviation. Results with different letters are significantly different (Duncan's test). T_L, T_D, T_{LD}, T_{WT}, S_R, F_R, R_R, D_O, D_B, B_L, B_R, B_T, B_V, *MC* (max), and *C* are mean tracheid length (mm), tracheid diameter (µm), tracheid lumen diameter (µm), tracheid wall thickness (µm), slenderness ratio, flexibility ratio (%), Runkel ratio (%), oven-dry (gr/cm^3) and basic density (g/cm^3), longitudinal (%), radial (%), tangential (%), and volume (%) shrinkage, maximum moisture content (%), and porosity (%) respectively.

Within-tree tracheid length of wood at each height level decreased from the base upwards; however, tracheid length of *C. sempervirens* L. wood was the highest at 5% of total tree height. Within the samples, at the same height level, tracheid length of wood increased from the pith to the bark (Table 3).

Table 3. Variation in Biometrical Property of Wood in Radius and Longitudinal Directions, According to Stem Height and Samples from the Pith to the Bark in *C. sempervirens* L.

Height Levels of Total Tree	Samples from the Pith to the Bark									
T_L (mm)	1	2	3	4	5	6	7	8	9	10
50%	4.5^{a} 1.2	4.2^{a} 0.9	4.2^{a} 0.7	4.7^{a} 0.4	4.2^{a} 1.0	4.6^{a} 0.7	4.9^{a} 0.5	5.5^{a} 0.6	5.7^{a} 1.4	5.8^{a} 1.0
25%	4.1^{ab} 1.2	3.9^{a} 1.2	4.3^{ab} 0.7	4.8^{ab} 1.4	5.0^{ab} 0.9	4.8^{ab} 0.6	5.1^{ab} 1.8	4.8^{ab} 0.6	6.1^{ab} 0.7	6.3^{b} 1.7
5%	3.4^{a} 1.3	4.2^{ab} 1.2	4.2^{ab} 0.3	5.2^{ab} 0.4	5.2^{ab} 1.3	5.4^{ab} 1.2	5.4^{ab} 0.7	5.6^{b} 0.9	5.2^{ab} 1.3	6.1^{b} 1.3
T_D (µm)	1	2	3	4	5	6	7	8	9	10
50%	66.9^{a} 17.2	61.9^{a} 13.2	59.2^{a} 12.2	59.9^{a} 3.3	60.8^{a} 7.5	60.9^{a} 9.0	64.2^{a} 7.6	60.9^{a} 5.5	62.1^{a} 13.2	60.1^{a} 8.9
25%	64.3^{a} 7.2	58.4^{a} 14.0	63.3^{a} 7.6	61.1^{a} 16.2	66.9^{a} 10.1	58.1^{a} 6.3	56.3^{a} 8.5	59.4^{a} 5.0	70.1^{a} 12.4	74.6^{a} 16.0
5%	49.5^{a} 15.8	58.1^{a} 9.2	63.6^{a} 11.4	67.1^{a} 9.5	68.2^{a} 14.2	68.4^{a} 23.5	65.9^{a} 8.8	62.1^{a} 4.7	70.6^{a} 16.4	73.7^{a} 15.0
T_{LD} (µm)	1	2	3	4	5	6	7	8	9	10
50%	47.7^{a} 12.6	42.1^{a} 8.5	40.5^{a} 8.5	40.9^{a} 2.1	42.5^{a} 4.6	42.6^{a} 7.8	44.4^{a} 5.4	41.9^{a} 4.5	42.6^{a} 11.6	40.9^{a} 8.6
25%	45.6^{a} 6.0	40.9^{a} 13.2	45.1^{a} 6.8	42.5^{a} 13.7	46.9^{a} 10.6	39.4^{a} 6.1	38.5^{a} 8.5	39.8^{a} 2.8	49.9^{a} 12.3	53.0^{a} 13.3
5%	31.6^{a} 14.6	39.6^{a} 6.6	43.7^{a} 10.0	46.2^{a} 8.2	49.6^{a} 13.0	48.1^{a} 21.1	45.3^{a} 5.3	43.6^{a} 4.7	49.9^{a} 13.5	49.6^{a} 12.3
$2T_{WT}$ (µm)	1	2	3	4	5	6	7	8	9	10
50%	19.1^{a} 4.6	19.8^{a} 4.7	18.7^{a} 3.7	18.9^{a} 1.8	18.3^{a} 3.3	18.3^{a} 1.2	19.8^{a} 3.1	19.0^{a} 3.4	19.4^{a} 1.6	19.2^{a} 1.1
25%	18.7^{ab} 1.3	17.4^{a} 0.9	18.1^{ab} 0.9	18.6^{ab} 2.5	20.0^{ab} 2.1	18.7^{ab} 0.3	17.8^{a} 0.0	19.6^{ab} 3.3	20.2^{ab} 2.0	21.6^{b} 2.9
5%	17.9^{a} 2.3	18.5^{a} 3.0	19.9^{a} 1.9	20.9^{a} 4.7	18.6^{a} 1.6	20.3^{a} 2.4	20.6^{a} 3.8	18.5^{a} 0.1	20.7^{a} 2.9	24.1^{a} 7.0
S_R	1	2	3	4	5	6	7	8	9	10
50%	67.7^{a} 1.0	68.4^{a} 3.9	72.4^{a} 10.5	78.8^{ab} 8.1	68.8^{a} 7.4	75.1^{ab} 6.0	76.9^{ab} 12.6	90.9^{bc} 18.8	92.0^{bc} 5.3	96.8^{c} 6.0
25%	63.6^{a} 11.3	66.8^{ab} 3.8	68.3^{ab} 3.1	78.5^{abc} 4.1	73.9^{abc} 2.9	82.3^{abc} 5.3	88.4^{c} 20.0	80.2^{abc} 7.7	88.3^{c} 16.5	83.6^{bc} 6.9
5%	68.9^{a} 3.1	71.2^{a} 9.0	68.1^{a} 14.0	78.9^{a} 12.4	76.7^{a} 20.2	83.4^{a} 25.5	82.2^{a} 8.1	90.1^{a} 8.4	74.3^{a} 5.9	82.1^{a} 1.1

Table 3 (continued). Variation in Biometrical Property of Wood in Radius and Longitudinal Directions, According to Stem Height and Samples from the Pith to the Bark in *C. sempervirens* L.

Height Levels of Total Tree	Samples from the Pith to the Bark									
F_R (%)	1	2	3	4	5	6	7	8	9	10
50%	71.3 [a] 0.8	68.1 [a] 0.7	68.4 [a] 0.8	68.4 [a] 1.8	70.0 [a] 2.3	69.7 [a] 2.8	69.2 [a] 2.8	68.8 [a] 4.4	68.2 [a] 3.8	67.6 [a] 4.9
25%	70.8 [a] 1.4	69.3 [a] 5.5	71.2 [a] 2.0	68.9 [a] 3.9	69.6 [a] 6.0	67.6 [a] 2.9	67.9 [a] 5.1	67.1 [a] 3.4	70.7 [a] 5.1	70.7 [a] 2.6
5%	62.3 [a] 8.9	68.1 [a] 2.0	68.3 [a] 3.5	68.9 [a] 5.8	72.2 [a] 4.3	68.8 [a] 7.0	68.8 [a] 2.4	70.1 [a] 2.3	70.2 [a] 3.2	67.1 [a] 8.8
R_R (%)	1	2	3	4	5	6	7	8	9	10
50%	40.3 [a] 1.7	46.7 [a] 1.5	46.3 [a] 1.7	46.3 [a] 3.8	42.9 [a] 4.6	43.6 [a] 5.8	44.7 [a] 5.8	45.7 [a] 9.3	47.0 [a] 7.9	48.5 [a] 11.3
25%	41.3 [a] 2.9	45.0 [a] 11.2	40.6 [a] 3.9	45.4 [a] 8.2	44.4 [a] 13.1	48.2 [a] 6.2	47.9 [a] 11.4	49.4 [a] 7.8	41.9 [a] 10.1	41.5 [a] 5.2
5%	62.7 [a] 22.9	47.0 [a] 4.2	46.6 [a] 7.3	45.9 [a] 12.7	38.8 [a] 8.5	46.4 [a] 14.7	45.4 [a] 5.2	42.7 [a] 4.6	42.8 [a] 6.7	50.8 [a] 20.5

Values are mean ± standard deviation. Results with different letters are significantly different (Duncan's test). T_L, T_D, T_{LD}, T_{WT}, S_R, F_R, and R_R, are mean tracheid length, tracheid diameter, tracheid lumen diameter, tracheid wall thickness, slenderness ratio, flexibility ratio, and Runkel ratio, respectively.

The results of ANOVA indicated that radial position and height had no significant effect on tracheid diameter and lumen diameter of wood ($P<0.05$). The pattern of variation in tracheid diameter and lumen diameter of wood, as a function of height in the stem, is shown in Table 2.

Within-tree tracheid diameter and lumen diameter of wood at each height level decreased from the base upwards; however, tracheid diameter and lumen diameter of *C. sempervirens* L. wood was the highest at 5% of total tree height. Within the samples, at the same height level, tracheid diameter and lumen diameter of wood increased from the pith to the bark, with the exception of the 50% of height level (Table 3).

The ANOVA results also indicated that radial position had significant effect on tracheid wall thickness of wood at the 25% of height level ($P<0.05$), but height had no significant effect on tracheid wall thickness of wood. The pattern of variation in tracheid wall thickness of wood, as a function of height in the stem, is shown in Table 2.

Within-tree tracheid wall thickness of wood at each height level decreased from the base upwards; however, tracheid wall thickness of *C. sempervirens* L. wood was the highest at 5% of total tree height. Within the samples, at the same height level, tracheid wall thickness of wood decreased from the pith to the bark, with the exception of 50% of height level (Table 3).

The ANOVA results indicated that radial position at 25% and 50% of height level had significant effect and height had no significant effect on slenderness ratio of tracheid ($P<0.05$). The pattern of variation in slenderness ratio of tracheid, as a function of height in the stem, is shown in Table 2.

Within-tree slenderness ratio of tracheid at each height level increased from the base upwards; however, slenderness ratio of *C. sempervirens* L. tracheid was the highest at 50% of total tree height. Within the samples, at the same height level, slenderness ratio of tracheid increased from the pith to the bark (Table 3).

The results of ANOVA indicated that radial position and height had no significant effect on flexibility and Runkell ratio of tracheid ($P<0.05$). The pattern of variation in flexibility and Runkell ratio of tracheid, as a function of height in the stem, is shown in Table 2.

Within-tree flexibility and Runkell ratio of tracheid at each height level increased and decreased from the base upwards respectively; however, flexibility and Runkell ratio of *C. sempervirens* L. tracheid were the highest at 5% of total tree height. Within the samples, at the same height level, flexibility and Runkell ratio of tracheid increased from the pith to the bark at 5% and 50% of height level, respectively (Table 3).

The results of ANOVA indicated that height had significant effect and radial position had no significant effect on oven-dry and basic density of wood ($P<0.05$). The pattern of variation in oven-dry and basic density of wood, as a function of height in the stem, is shown in Table 2.

Within-tree dry and basic density of wood at each height level decreased from the base upwards; however, oven-dry and basic density of *C. sempervirens* L. wood was the highest at 5% of total tree height. Within the samples, at the same height level, oven-dry and basic density of wood increased from the pith to the bark (Table 4).

ANOVA showed that the radial position and height had significant effects on longitudinal shrinkage ($P < 0.05$). The pattern of variation in longitudinal shrinkage, as a function of the height in the stem, is shown in Table 2. Within-tree longitudinal shrinkage at each height level decreased along the stem, from the base upwards; however, wood longitudinal shrinkage was the highest at 5% of total tree height.

As shown in Table 4, within the samples, at the same height levels, longitudinal shrinkage decreased from the pith outwards.

ANOVA showed that the radial position had significant effects on tangential, volume at total height level, and radial shrinkage at 5% and 25% of height level ($P < 0.05$). The pattern of variation in radial, tangential, and volume shrinkage, as a function of the height in the stem, is shown in Table 2. Within-tree radial, tangential, and volume shrinkage at each height level decreased along the stem, from the base upwards; however, wood radial, tangential, and volume shrinkage was the highest at 5% of total tree height. Also height had no significant effects on radial and tangential shrinkage, but had significant effects on volume shrinkage.

As shown in Table 4, within the samples, at the same height levels, radial, tangential, and volume shrinkage increased from the pith outwards. ANOVA indicated that radial position had no significant effect and height position had significant effect on maximum moisture content ($P<0.05$). The pattern of variation in maximum moisture content, as a function of height in the stem, is shown in Table 2. Within-tree maximum moisture content at each height level increased from the base upwards; however, for *C. sempervirens* L. the maximum moisture content was highest at 50% of total tree height. Within the samples, at the same height level maximum moisture content increased from the pith to the bark exceptionally 5% of height level (Table 4).

Table 4. Variation in Physical Property of Wood in Radius and Longitudinal Directions, According to Stem Height and Samples from the Pith to the Bark in *C. sempervirens* L.

Height Levels of Total Tree	Samples from the Pith to the Bark				
D_O (g/cm^3)	1	2	3	4	5
50%	0.44 [a] 0.03	0.45 [a] 0.03	0.46 [a] 0.04	-	-
25%	0.45 [a] 0.02	0.47 [a] 0.04	0.47 [a] 0.02	0.48 [a] 0.03	-
5%	0.50 [a] 0.01	0.50 [a] 0.02	0.49 [a] 0.05	0.49 [a] 0.02	0.51 [a] 0.04
D_B (g/cm^3)	1	2	3	4	5
50%	0.41 [a] 0.03	0.41 [a] 0.02	0.41 [a] 0.03	-	-
25%	0.41 [a] 0.02	0.42 [a] 0.04	0.43 [a] 0.02	0.43 [a] 0.03	-
5%	0.45 [a] 0.01	0.46 [a] 0.02	0.44 [a] 0.04	0.44 [a] 0.02	0.46 [a] 0.04
B_L (%)	1	2	3	4	5
50%	0.89 [b] 0.09	0.28 [a] 0.16	0.16 [a] 0.12	-	-
25%	0.89 [c] 0.25	0.79 [bc] 0.20	0.39 [ab] 0.39	0.15 [a] 0.00	-
5%	1.46 [b] 0.50	1.80 [b] 0.31	0.69 [a] 0.27	0.45 [a] 0.10	0.23 [a] 0.08
B_R (%)	1	2	3	4	5
50%	2.58 [a] 0.43	3.18 [a] 0.38	3.33 [a] 0.46	-	-
25%	2.55 [a] 0.04	2.89 [ab] 0.38	3.25 [ab] 0.78	3.73 [b] 0.27	-
5%	2.71 [a] 0.84	2.71 [a] 0.23	3.23 [ab] 0.55	3.66 [ab] 0.74	3.88 [b] 0.23
B_T (%)	1	2	3	4	5
50%	4.75 [a] 0.69	6.35 [b] 0.59	6.39 [b] 0.18	-	-
25%	5.14 [a] 0.18	6.05 [ab] 0.65	6.44 [b] 0.73	6.70 [b] 0.32	-
5%	4.70 [a] 0.91	4.99 [a] 0.65	6.71 [b] 0.85	7.21 [b] 0.47	7.01 [b] 0.46
B_V (%)	1	2	3	4	5
50%	7.72 [a] 0.69	9.60 [b] 0.91	9.63 [b] 0.57	-	-
25%	8.39 [a] 0.32	9.49 [ab] 0.85	9.85 [ab] 1.08	10.29 [b] 0.57	-
5%	9.42 [ab] 1.04	9.23 [a] 0.56	10.34 [ab] 1.22	11.00 [b] 0.67	10.84 [ab] 0.56
MC (max) (%)	1	2	3	4	5
50%	150.41 [a] 14.80	156.57 [a] 10.56	159.89 [a] 14.35	-	-
25%	145.11 [a] 7.77	143.64 [a] 17.63	147.93 [a] 11.51	146.08 [a] 15.31	-
5%	125.07 [a] 6.80	123.73 [a] 10.94	139.63 [a] 18.62	143.17 [a] 4.14	135.04 [a] 1738
C (%)	1	2	3	4	5
50%	70.65 [a] 1.76	69.99 [a] 1.77	69.32 [a] 2.41	-	-
25%	69.99 [a] 1.34	68.87 [a] 2.53	68.65 [a] 1.16	67.99 [a] 2.31	-
5%	66.87 [a] 0.39	66.65 [a] 1.33	67.09 [a] 3.36	67.09 [a] 1.39	65.75 [a] 2.69

Values are mean ± standard deviation. Results with different letters are significantly different (Duncan's test). D_O, D_B, B_L, B_R, B_T, B_V, *MC* (max), and *C* are mean oven-dry and basic density, longitudinal, radial, tangential, and volume shrinkage, and maximum moisture content respectively.

ANOVA showed that radial position had no significant effect and height position had significant effect on porosity ($P < 0.05$). The pattern of variation in porosity, as a function of the height in the stem, is shown in Table 2. Within-tree porosity at each height level increased along the stem, from the base upwards; however, porosity was the highest at 50% of total tree height.

As shown in Table 4, within the samples, at the same height levels, porosity decreased from the pith outwards.

There has been little information on the mean values of dry and basic density, longitudinal, radial, tangential, and volume shrinkage, maximum moisture content, porosity, tracheid length, tracheid diameter, tracheid lumen diameter, tracheid wall thickness, slenderness ratio, flexibility ratio, and Runkel ratio and on the trend of variation along and across the stem of the studied traits of plantation cypress wood. The mean values of specific gravity, green density, tracheid length, and tracheid cross-sectional dimensions of the trees of this study were somewhat greater than those reported previously by Uzielli and Berti (1979), Paraskevopoulou (1991), Bannister and Orman (1960), and Hasegava et al. (2010), who refer to a natural population and plantation material.

The increase in average tracheid length across discs is common to many tree species (Dinwoodie 1961). Generally, in conifers, there seems to be a decrease in specific gravity and tracheid length with an increase in height (Ishengoma et al. 1995; Kibblewhite 1984; Malan 1989; Muneri and Balodis 1998), and significant differences have been found at different sampling heights for ring width, latewood width, and latewood percentage (Malan 1989), where Malan (1989) found a decrease in tracheid length with height, he did find an increase from the ground level to about 15% of tree height before it decreased. This trend was also shown by Muneri and Balodis (1998).

According to the authors' observations from ring width of samples, the ring width in plantation cypress is low in the innermost rings (2 cm, 4 cm, and 6 cm of 5%, 25%, and 50% height levels respectively) and then increases from the pith outward until a maximum is reached with respect to rings (4 cm, 6 cm, and 8 cm at 5%, 25%, and 50% of height levels respectively), after which it falls abruptly and extremely towards the bark (6 cm, 8 cm, and 10 cm at 5%, 25%, and 50% of height levels respectively), where with increase and decrease of ring width in conifers, earlywood is relatively constant, but latewood shows an increase and decrease. Thus, a considerable number of investigations have shown that there is a decrease in specific gravity with increasing ring width and greater ring width is associated with shorter tracheid length (Echols 1958; Panshin and De Zeeuw 1970). The studies performed on the annually ring of spruce (Dinwoodie 1961) and radiata pine (Nicholls and Dadswell 1962) have shown that tracheid length in earlywood is lower than latewood, falls to a minimum further out, and then increases in the final phase of season growth, where the value of length increase is between 12 to 20% of tracheid length in the initial of season growth.

In this study, the average values of intrinsic wood and tracheid characteristics such as T_D, T_{LD}, T_{WT}, S_R, F_R (%), and R_R (%) that were measured play an integral part in determining the quality of pulp or paper. It would appear that T_{WT}, especially of the latewood, specific gravity, and the Runkel ratio are best fiber dimension ratios to indicate of a number of handsheet properties. These attributes refer to the ratio between double the wall thicknesses and lumen diameter and could therefore be considered as traits in a breeding program, where they can account for 80 to 85% (Barefoot et al. 1964; Kibblewhite 1982) of the variation in the handsheet tear, and if this ratio is less than 1, the collapsibility is most desirable.

Desirable values for density may be provided by either the 5% of height level and near the bark of trees, since the preference for high or low density in a species depends on the desired end-use (Dadswell and Nicholls 1959; Nicholls et al. 1963). Blair et al. (1975) reported that high-density wood is preferred for construction and furniture uses and it has generally been assumed to be preferable for pulping. However, if the main purpose is the conversion to sawn lumber, then high density will confer the best strength properties and high density should be the criterion when selecting for this feature. Research has shown that higher density species tend to have stronger timber than lower density species (Tsehaye et al. 1995b; Walker and Butterfield 1996).

Basic density is closely related to wood swelling and shrinkage (Newlin and Wilson 1919), where the total swelling and shrinkage (R) accounted for 177 species of American woods via basic density (D_B) according to the following formula: R=28 D_B , and a such closed relation accounted also for 131 Australian wood species with a 0.76 correlation coefficient at a 99.9% confidence level (Kelsey 1956).

The results showed that volume shrinkage in cypress wood was maximal at the 5% of height level and the cross section bark-surface and minimal at the 50% of height level and close to the pith.

The juvenile wood with thinner cell walls and smaller cell dimensions is sometimes defined as a fixed number of annual rings from the pith outwards and a concern for utilization, particularly for fast-grown trees, which can be desirable for certain pulp and paper products, but the presence of juvenile wood with higher density near to the pith at 5% of height level than 50% of height level induces a greater variability in the raw material and greater longitudinal shrinkage.

Longitudinal shrinkage increased slightly downwards from the 50% of height level, whereas radial wood shrinkage was minimal at the stump height and at the 50% of height level. Tangential shrinkage was minimal at the 50% of height level and remained quite steady within the tree.

Simpson (1991) reported that the maximum moisture content in lumber is important because of its influence in controlling kiln-drying schedules. From a practical standpoint, when determining kiln schedules, the largest number of moisture samples should be selected from the slowest-drying material. Regarding the range of maximum moisture content in our sample, approximately 124 percent was found in the 5% of height level and in the near pith, whereas approximately 166 percent was found in the 50% of height level and in the near bark.

CONCLUSIONS

1. Significant differences in wood tracheid length and slenderness ratio existed between the radial position and height in *C. sempervirens* L. trees.

2. There was a general trend in the radial and axial directions in *C. sempervirens* L. trees, in which wood tracheid dimensions and biometrical ratio varied from the pith to bark and from the base upwards.

3. Significant differences in wood density, and longitudinal, radial, tangential, and volumetric shrinkage existed between the radial position and height in *C. sempervirens* L. trees.

4. There was a general trend in the radial and axial directions in *C. sempervirens* L. trees, in which wood density, radial, tangential, and volume shrinkage increased, from the pith to bark, with the exception of longitudinal shrinkage, and from the base upwards.

5. Significant differences in wood porosity and maximum moisture content existed in the height position, where porosity is linearly and inversely related to wood maximum moisture content and density respectively.

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