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Wood density and tracheid length of Aleppo pine (*Pinus halepensis* Mill.) grafts in relation to cambium age and growth rate

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Abstract

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Wood density, tracheid length and growth rate were measured in Aleppo pine scions, 21–23 years old, and in Brutia pine rootstocks. In regard to the relationship between cambial age and dry density the results showed that the density increased with cambial age in both scions and rootstocks while the differences between Aleppo pine and Brutia pine were small. The relationship between cambial age and tracheid length showed an increase of tracheid length with cambial age. Differences between scions and rootstocks were small. From the last relationship it can be extracted that juvenile wood is produced in both scions and rootstocks although the Aleppo pine branches which were used for grafting were genetically matured. Between ring width and dry density and between ring width and tracheid length no statistical correlations were found either in scions or in rootstocks. The tracheid length in mature wood was higher than in juvenile wood. An increase of tracheid length with ring width was observed only in the case of juvenile wood.

Keywords: wood quality; juvenile wood; mature wood; scions; rootstocks

Grafting is the art of joining living tissues of two different plants belonging to the same species or genus in order to create a novel plant organism where the scion is the vegetative part and the rootstock is the rooting system.

Grafting is widely used as a means of vegetative propagation of forest trees and shrubs. Currently, grafting of forest species attracts a growing interest as it offers the opportunity of conserving clones (genotypes) with specific characteristics especially those that are difficult to propagate by other vegetative techniques and can combine desirable traits of two different genotypes in a new plant organism. Other benefits resulting from the application of grafting by selecting the suitable rootstock include: the rejuvenation of mature scions by successive grafting onto a juvenile rootstock, greater resistance to diseases or hardiness to stressful environmental conditions especially those of soil or reduction of the time for the first flower and fruit production. Grafting is widely used to propagate conifers. Selected rootstocks can be used to improve graft success, reduce incompatibility, and increase seed production (Jayawickrama et al. 1991; White et al. 2007).

Grafting is related with terms such as maturation, cyclophysis, ontogenetic ageing and phase change, which refer to morphological, anatomical and physiological changes that occur in woody plants with increasing cambial age (Greenwood, Hutchinson 1993).

Information on the utilization of grafting technique in wood production and relative investigations on quality characteristics of wood produced by scions are very scarce in the literature. Density and fibre length are regarded as basic wood quality indicators. Specific gravity and tracheid length of slash pine grafts were not found to be affected by different rootstocks (Anonymous 1963; Jayawickrama et al. 1991). Miyata et al. (1991) reported differences in the contents of three chemical constituents (ethanol-benzene extractives, holocellulose and lignin) between juvenile and mature wood of *Pinus densiflora* Siebold & Zuccarini and *Pinus thunbergii* Parlatore, 26 years old grafts.

Cambium age and growth rate are the main factors affecting wood properties, primarily cell dimensions and density in both coniferous and deciduous species. Reports on variation patterns of wood density and cell dimensions with cambial age are associated with the process of cambium maturation and the assessment of the period of juvenile tree development. In conifers (fir, spruce, pine, etc.) lower wood density and shortest fibre length were observed near the pith in the region of juvenile wood. Growth rate (ring width) affects mainly the wood density. Wide rings have a lower latewood proportion and it results in lower wood density. The effect of cambial age is evident on tracheid length and a common variation pattern is a rapid increase in tracheid length during the first years, followed by a more gradual increase until a maximum is reached (Dinwoodie 1961; Panshin, de Zeeuw 1980; Zobel, van Buijtenen 1989; Zobel, Sprague 1998; Saranpää 2003).

The aim of this work is the investigation of certain wood quality characteristics (density, tracheid length) and their relationships with growth rate and cambial age on Aleppo pine scions, 21–23 years old, grown on Brutia pine rootstock.

MATERIAL AND METHODS

The wood material for this work was taken from an experimental plantation of the Laboratory of Forest Genetics and Tree Improvement, established in 1990 in the area of "Macedonia" airport, Thessaloniki, Greece. The aim of this plantation was to assess the technique of grafting Aleppo pine scions on Brutia pine rootstocks. The Aleppo pine scions were taken from natural forest stands

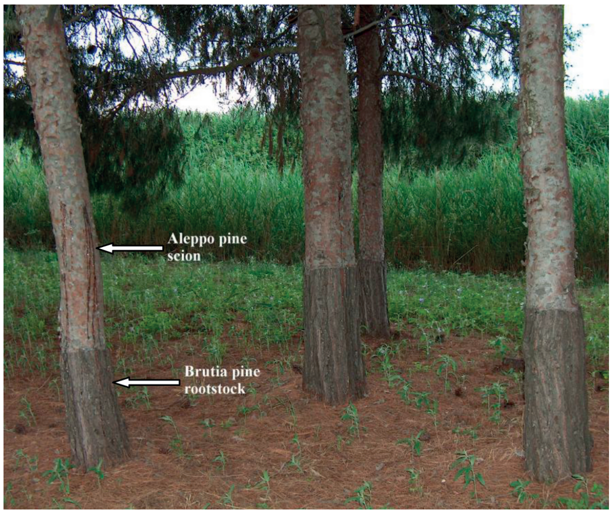

Fig. 1. Experimental plantation of Aleppo pine grafts on Brutia pine rootstocks

grown in the Chalkidiki peninsula and the Brutia pine seedlings (as rootstocks) originated from the Thasos island, North Aegean (Skaltsogiannis, Tsaktsira 2014).

The growth of grafts up to now is satisfactory and the compatibility between scions and rootstocks seems to be very good. As shown in Fig. 1, a distinct macroscopic difference between scions and rootstocks was the smoother outer bark surface of scions due to topophysis (the scions originated from genetically matured branches) compared with the strongly wrinkled bark surface of rootstocks (White et al. 2007). Also, the bark of Brutia pine rootstocks was found thicker, ranging between 2.3 and 3.3 cm, than that of Aleppo pine scions, ranging between 0.7 and 1.5 cm (Fig. 2).

After 23 years (2013), three trees (A, B, C) were felled and disks, 2 cm in thickness, were taken from Brutia pine rootstocks (A_1, B_1, C_1) and Aleppo pine scions (A_3, B_3, C_3) at the inherent scion-rootstock surfaces, respectively (Table 1).

The measurements of density, growth rate, ring width and fibre length were carried out on the larger radial dimension of the disks and according to standard laboratory methods (Tsoumis 1968, 1991). From each disk two adjacent radial increments were taken, one for dry density and ring width and the other for fibre length measurements. The dry density was measured for each annual ring separately using the water displacement method (Tsoumis 1991). Before measurements the density samples were extracted with dichloromethane to remove natural resin content and to achieve accurate figures at density (Chavenetidou, Foti 2007).

From the second radial strip, tracheid length for each ring was measured after maceration of the ma-

(a) (c) (b) (d)

Fig. 2. Macroscopic appearance of scion (a, c) and rootstock (b, d) bark in longitudinal direction (a, b) and in cross section (c, d)

terial (Tsoumis 1968). Fifty tracheids (twenty-five tracheids of early wood and twenty five tracheids of latewood) of each annual ring were measured using a microscope with a screen (Visopan).

Table 1. Age, minimum–maximum radius and mean diameter of tree disks

Species	Tree sample	Age (yr)	Radius* (cm)	Mean diameter* (cm)
Aleppo pine	A_3	23	10.22–13.91	24.12
	B_3	21	9.87–11.96	23.69
	C_3	23	11.31–13.02	21.82
Brutia pine	A_1	23	9.44–14.25	22.42
	B_1	22	10.97–11.40	24.34
	C_1	23	10.99–13.62	24.61

*without bark

RESULTS

The values of growth rate, density and tracheid length are presented in Table 2.

The radial pattern between annual ring width and cambial age of both scions and rootstocks is shown in Fig. 3. No differences between scions (Aleppo pine) and rootstocks (Brutia pine) were observed and both relationships follow the same pattern.

The relationships between cambial age and dry density, cambial age and tracheid length, ring width and dry density and ring width and tracheid length are shown in Figs 4–9.

The equations of the relationship between cambial age and dry density (second-degree polynomial equations) are presented in Table 3 and between cambial age and tracheid length (logarithmic equations) are presented in Table 4.

Table 2. Growth rate, density and tracheid length of Aleppo pine grafts and Brutia pine rootstocks

Species	Tree sample	Age (yr)	Mean (minimum–maximum)*		
			growth rate (mm)	dry density ($g \cdot cm^{-3}$)	tracheid length (mm)
Aleppo pine	A_3	23	5.24 (0.75–14.35)	0.50 (0.43–0.63)	2.52 (1.25–3.64)
	B_3	21	5.20 (1.79–12.31)	0.56 (0.50–0.71)	2.43 (1.39–3.18)
	C_3	23	5.29 (0.97–11.92)	0.55 (0.49–0.63)	2.70 (1.73–3.37)
Brutia pine	A_1	23	5.15 (0.75–14.94)	0.55 (0.52–0.60)	2.46 (1.10–3.22)
	B_1	22	5.09 (1.23–11.59)	0.56 (0.46–0.65)	2.71 (1.27–3.29)
	C_1	23	5.35 (1.44–11.63)	0.57 (0.50–0.69)	2.36 (1.17–3.53)

*for growth rate and dry density 21–23 measurements and for tracheid length 1,050–1,150 measurements

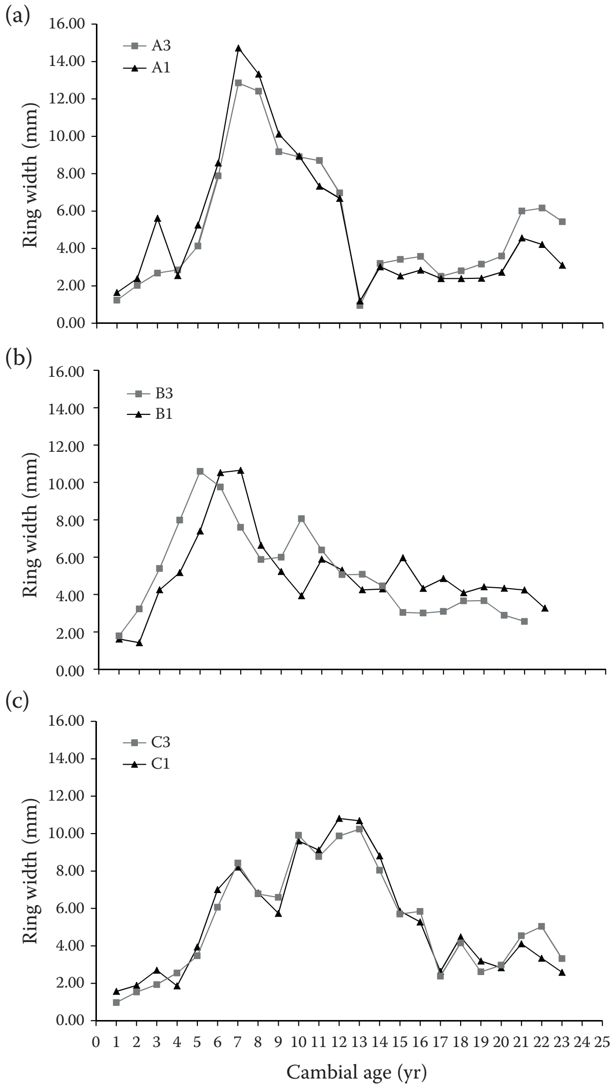

Fig. 3. Radial pattern of annual ring width and cambial age of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

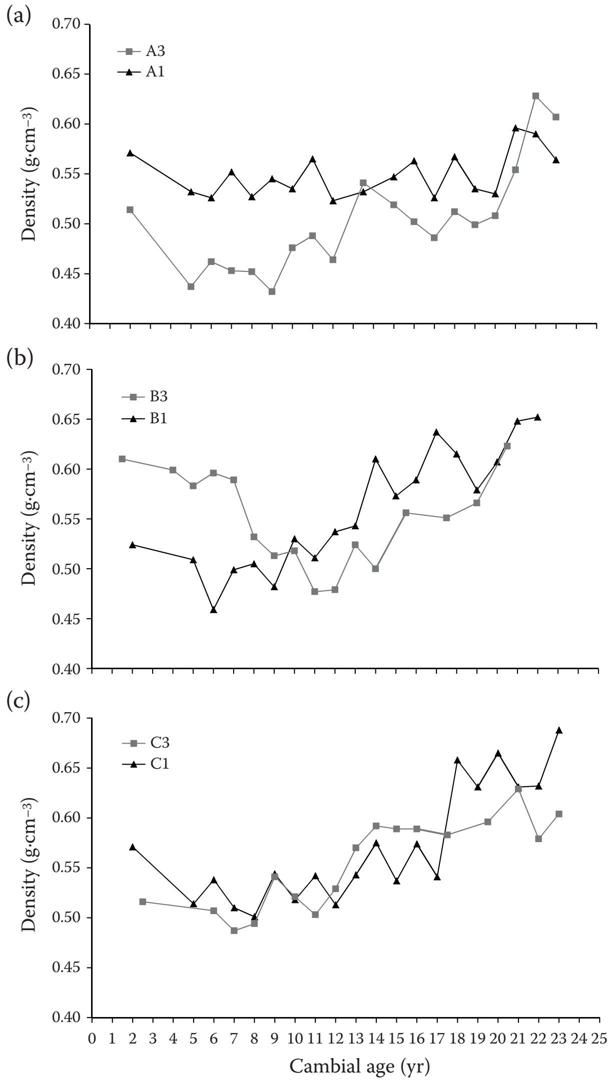

Fig. 4. Radial pattern of density and cambial age of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

The radial pattern between density and cambial age of both scions and rootstocks is shown in Fig. 4 and the relationships between age and density are shown in Fig. 5.

In both scions and rootstocks, a tendency of density to increase with age can be observed. The density differences between Aleppo pine and Brutia pine are small and not consistent throughout the cambial age (Figs 4 and 5).

The cambial age-dry density correlations are statistically significant at P = 95% except the scion Aleppo pine B_3 (Table 3).

Table 3. Equations of dry density-cambial age correlations (WD = $a + b \times$ CA + $c \times$ CA^2)

Species	Sample	*n*	*a*	*b*	*c*	R^2	*F*-value
Aleppo pine	A_3	19	0.505	–0.011	0.001	0.722	20.769*
	B_3	16	0.678	–0.023	0.001	0.259	2.274
	C_3	17	0.468	0.007	–9.63E-006	0.737	19.642*
Brutia pine	A_1	19	0.571	–0.006	0.000	0.342	4.167*
	B_1	19	0.491	0.000	0.000	0.807	33.415*
	C_1	20	0.572	–0.012	0.001	0.808	35.660*

WD – wood density, *a*, *b*, *c* – constants of the equation, CA – cambial age, *n* – number of annual rings, R^2 – coefficient of determination; *statistically significant (P = 95%)

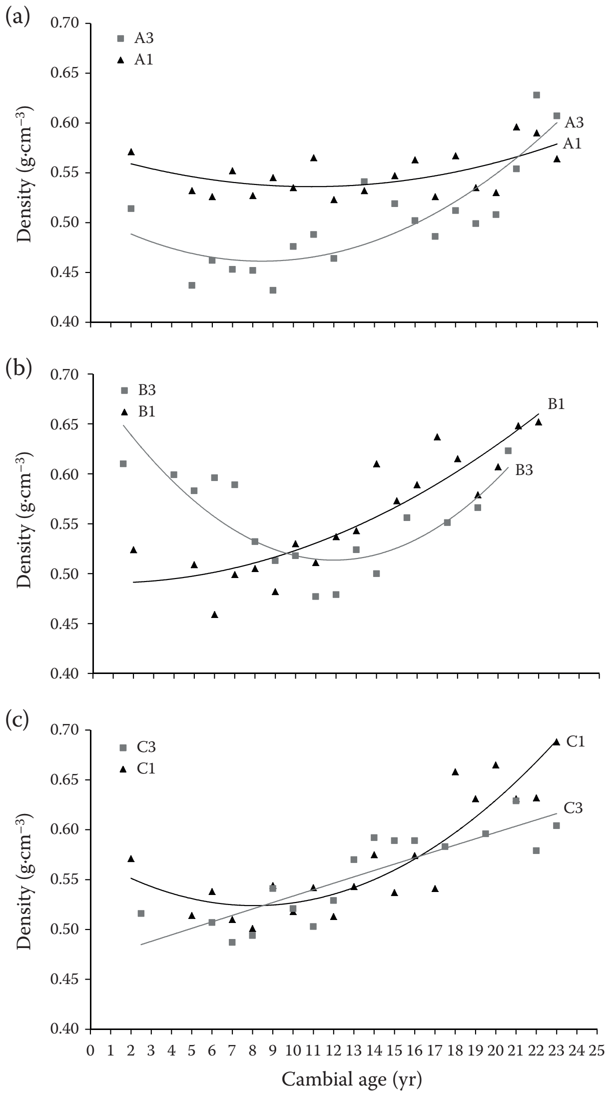

Fig. 5. Correlation between density and cambial age of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

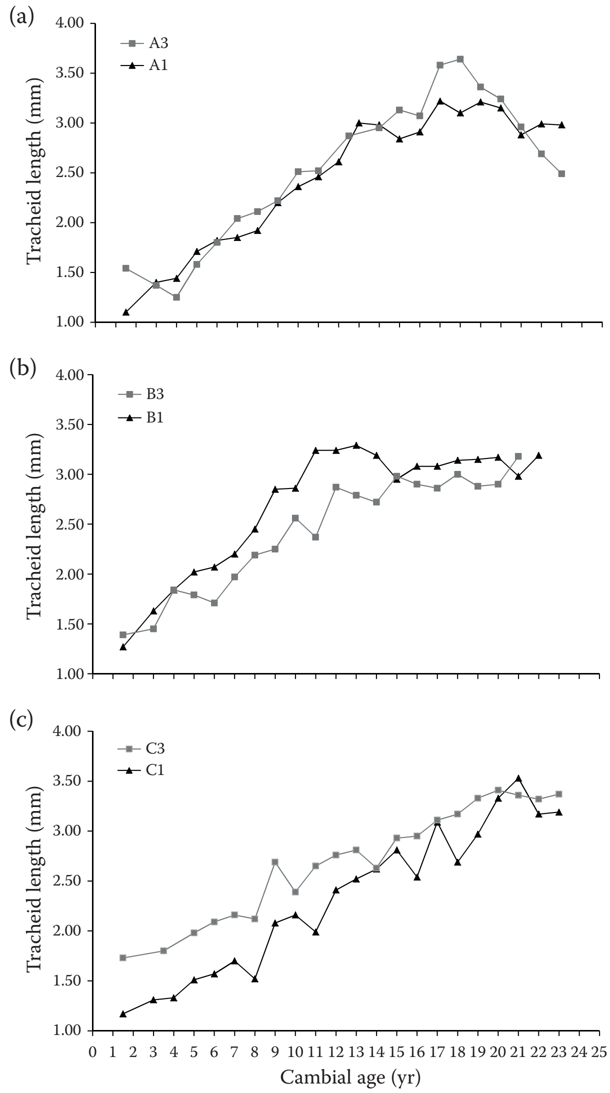

Fig. 6. Radial pattern of tracheid length and cambial age of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

The radial pattern of tracheid length-cambial age is similar between scions and rootstocks as shown in Fig. 6. The relationships between tracheid length and cambial age are shown in Fig. 7. From both figures, an increase of tracheid length with age is observed. The differences between scions and rootstocks appeared to be small throughout the cambial age.

The correlations of cambial age-tracheid length were found to be statistically significant at P = 95% in all cases (Table 4).

Table 4. Equations of tracheid length-cambial age correlations (TL = $a + b \times \ln(CA)$)

Species	Sample	n	a	b	R^2	F-value*
Aleppo pine	A_3	21	0.5466	0.8507	0.7319	51.856
	B_3	20	0.7066	0.7662	0.9029	167.430
	C_3	21	0.7710	0.8053	0.9010	172.959
Brutia pine	A_1	22	0.3825	0.8908	0.9099	202.064
	B_1	21	0.8448	0.8125	0.8782	136.994
	C_1	22	0.1552	0.9469	0.8708	134.840

TL – tracheid length, a, b – constants of the equation, CA – cambial age, n – number of annual rings, R^2 – coefficient of determination; *statistically significant (P = 95%)

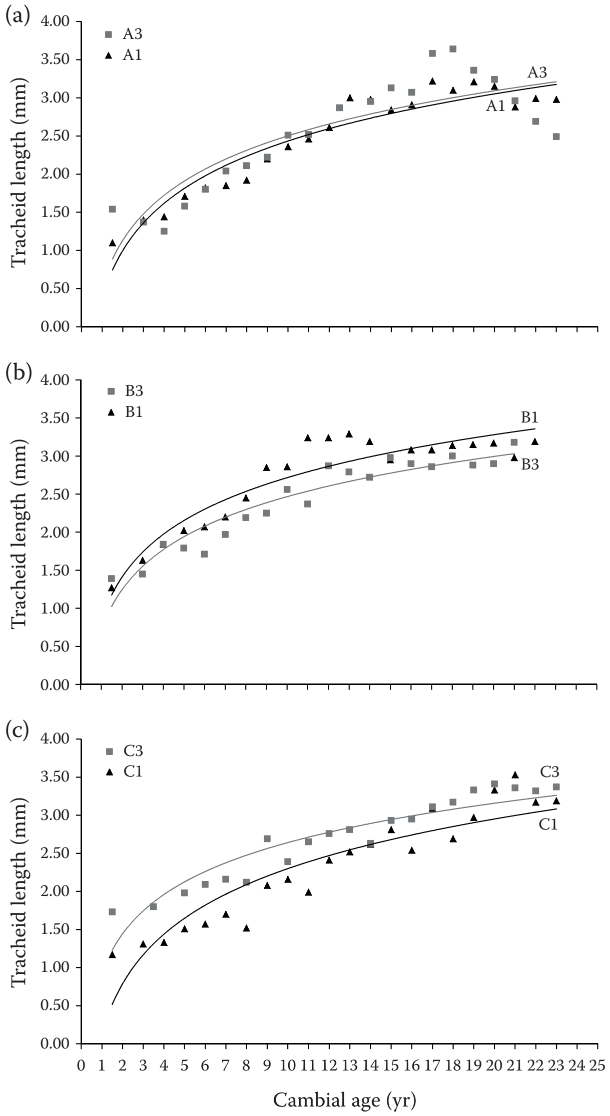

Fig. 7. Correlations between tracheid length and cambial age of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

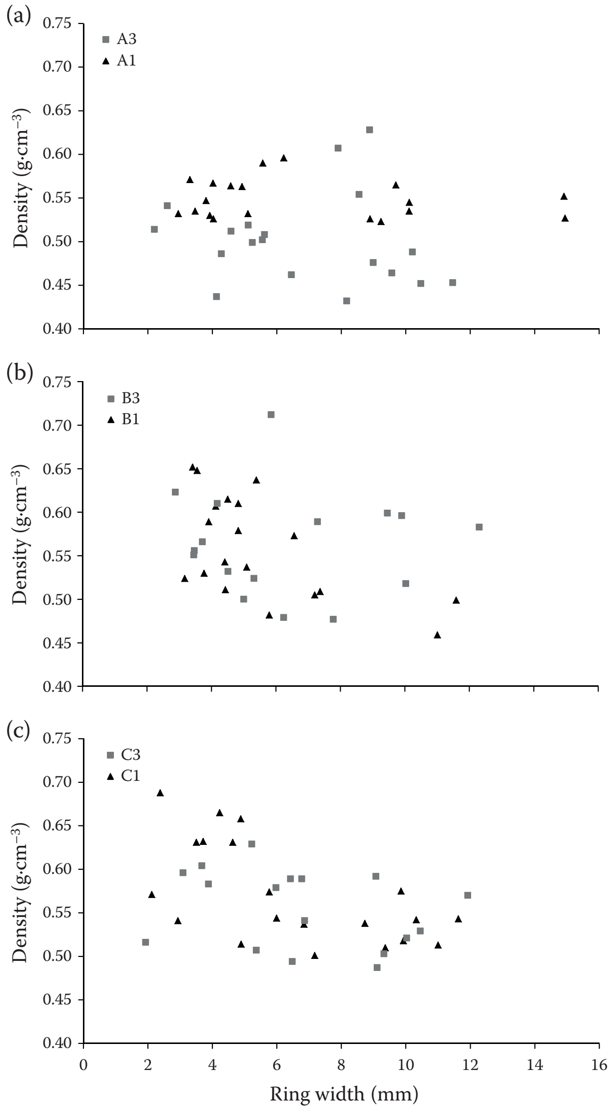

Fig. 8. Radial pattern of density and ring width of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c)

From the relationship of cambial age-tracheid length (Fig. 7) it can be extracted that juvenile wood is produced in both scions and rootstocks. It is worthy to mention that although the Aleppo scions used for grafting were genetically matured (flowering branches), juvenile wood was also formed. According to cambial age-tracheid length curves (Fig. 7), the juvenile wood is estimated to be extended up to the 12th annual ring for both species (Panshin, de Zeeuw 1980; Zobel, Sprague 1998).

Fig. 8 shows the relationships between ring width and dry density. Correlations between these two parameters were not found to be statistically significant ($R^2 < 0.4$).

Fig. 9 shows the relationship of ring width-tracheid length separately for juvenile (1–12 annual rings) and mature wood in circles (13–23 annual rings). It is clear that in mature wood, the tracheid length is higher than in juvenile wood in both scions and rootstocks. An increase of tracheid length with ring width can be clearly observed in juvenile wood.

DISCUSSION

The present findings on quality characteristics of wood (ring width, tracheid length, density, bark appearance and thickness), referred to grafts of Aleppo pine scions on Brutia pine rootstocks, are comparatively assessed only with seedlings due to lack of relevant literature on grafts.

In Aleppo pine scions the bark appeared to be smooth and less thick than the rough and thick

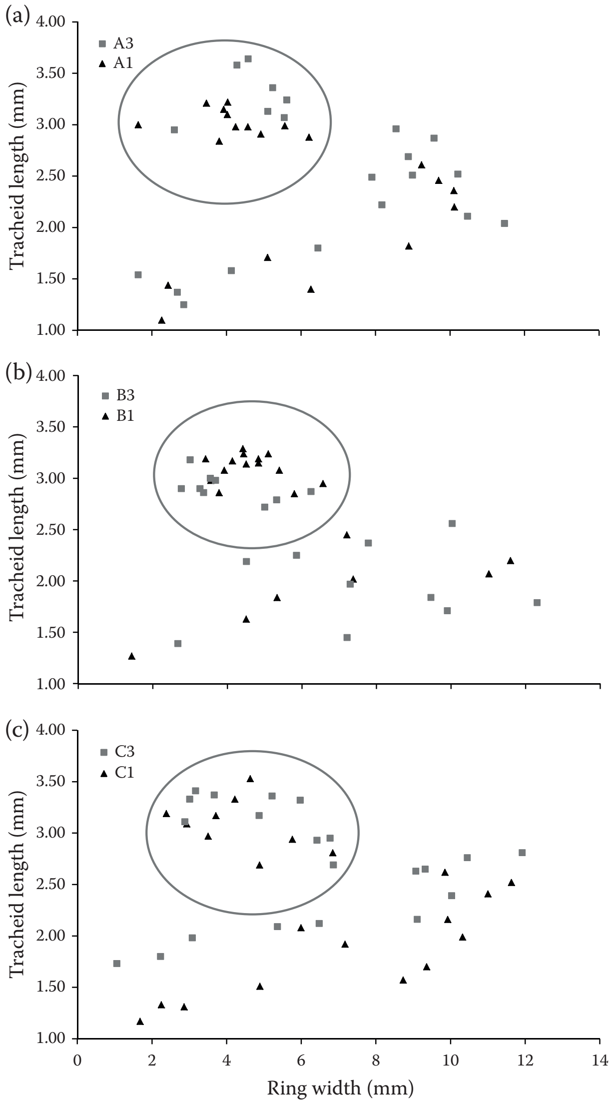

Fig. 9. Radial pattern of tracheid length and ring width of Aleppo pine grafts (A_3–C_3) and Brutia pine rootstocks (A_1–C_1): A_3, A_1 (a), B_3, B_1 (b), C_3, C_1 (c); mature wood in circles

bark of Brutia pine rootstock due to topophysis effect (White et al. 2007).

In both scions (Aleppo pine) and rootstocks (Brutia pine), a small increase of density with cambial age was observed due to a gradual reduction of ring width with cambial age in the region of mature wood that leads to increased density (Panshin, de Zeeuw 1980; Tsoumis 1991). Between ring width-dry density and ring width-tracheid length no statistically significant correlations were found either in scions or in rootstocks.

An increase of tracheid length with cambial age was found in both scions and rootstocks especially during the initial growth period (12 years). This variability is typical of juvenile and mature wood formation (Panshin, de Zeeuw 1980; Zobel, Sprague 1998) although the Aleppo pine scions were genetically matured (flowering age). In both scions and rootstocks a clear increase of tracheid length with ring width was observed only in the case of juvenile wood (Greenwood, Hutchinson 1993).

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