Growth rate and ring width variability of teak, *Tectona grandis* (Verbenaceae) in an unmanaged forest in East Timor

Vicelina B. Sousa[1], Sofia Cardoso[1], Teresa Quilhó[2] & Helena Pereira[1]

1. Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Tapada da Ajuda 1349-017 Lisboa, Portugal; vsousa@isa.utl.pt, hpereira@isa.utl.pt, sofiacardoso@isa.utl.pt
2. Centro de Florestas e Produtos Florestais, Instituto de Investigação Científica Tropical, Tapada da Ajuda, 1347-017 Lisboa, Portugal; terisantos@isa.utl.pt

Received 12-X-2010. Corrected 07-V-2011. Accepted 02-VI-2011.

Abstract: Teak (*Tectona grandis*) is one of the most valuable timbers in international trade and an important species for tropical forestry. Teak is found on the island of East Timor but no information is available on teak growth from this region. A pure stand planted in 1940-50 in the North of East Timor and left unmanaged was studied. Fifteen trees were sampled in October-November 2003 and stem discs taken at three height levels of its height (1.7m, 9.5m and 18.7m), and cores were collected at DBH. Transverse surfaces of the discs and cores were polished for ring identification. Core cross sections were first digitized and disc cross sections were observed under the microscope. Three randomly selected *radii* were analyzed in each disc. Ring width measurement and ring counting were done using image analysis software. The distinction between heartwood and sapwood was performed macroscopically by colour difference, and heartwood radius and sapwood width were measured. The relationship between stem and heartwood radius was studied for each disc and heartwood percentage by radius was determined. Radial ring width curves are presented for the different axial positions within the stem, and ring width variability was analyzed. Growth rates were calculated and age-radius relationships were estimated using cumulative growth curves. Growth rings were large and well defined in the juvenile phase, reflecting the specie's fast-growing character. The year-to-year variation of ring width showed a similar pattern among trees. Mean ring width ranged between 4.3-7.3mm for the first 20 years and 3.3-5.1mm for 30 to 45 years. Pith eccentricity was evident in the lower part of the stem and ring wedging occurred. On average, heartwood represented 84% of the radius and sapwood contained 6 to 11 rings. The age-related variation of ring width and the occurrence in the lower part of the tree stems of eccentricity and wedging rings, highlights the importance of appropriate stand management, particularly regarding basal density distribution over time, whenever optimized timber production is envisaged. Rev. Biol. Trop. 60 (1): 483-494. Epub 2012 March 01.

Key words: *Tectona grandis*, growth rings, ring width, heartwood, variability.

Teak (*Tectona grandis* L.f.) is known world wide. It is one of the most important tree species in tropical regions and probably the most highly-valued hardwood due to the quality, attractiveness and durability of its heartwood (Bishop 1999).

Teak is a large deciduous or semi-deciduous tree depending on climate seasonality, growing in a wide range of climatic and edaphic conditions *e.g.* mean annual temperature 14-36ºC and annual rainfall 600-4000mm, but preferring contrasting dry and wet seasons (Orwa *et al*. 2009).

Teak is native to the Asia-Pacific region, covering an area of about 23 million hectares in India, Laos, Myanmar, Thailand and Indonesia (Bhat & Ok Ma 2004). It has also been introduced into many tropical countries, *e.g.* Togo (Kokutse *et al*. 2004), Kenya (Jacoby 1989), Nigeria (Akachuku & Abolarin 1989), Costa Rica (Bermejo *et al*. 2004), Brazil (Nogueira *et al*. 2006), Panama (Posch *et al*. 2004), Venezuela (Kammesheidt 2001) and Australia (Robertson & Reilly 2004).

East Timor ("Timor Leste" in Portuguese), an island in Southeast Asia, is characterized by tropical and subtropical moist mountain forests of approximately 507 000ha that represent 34.3% of the land area (FAO 2005). East Timor is the Eastern part of Timor island (08º20'-09º37' S - 123º59'-127º19' E), while the Western part is Indonesian. East Timor was a colony under Portuguese jurisdiction until 1974, when it was annexed by Indonesia, after which a long guerilla war led to independence in 2002. The country is now struggling to achieve a livelihood for its population, and forests are considered one of the strong drivers for economic development since they include some valuable timber species, particularly teak.

There is general agreement in the literature that teak growth varies according to location (Priya & Bhat 1997) but most of the available data comes from Asian countries, especially India (Ram *et al*. 2008, 2010). Tree ring width is one of the most important variables for studying tree growth and climate influence (Tian *et al*. 2009), and growth rate helps to clarify forest dynamics, an important factor in the sustainable management of forest resources (*e.g*. Jacoby 1989, Fritts 1976, Priya & Bhat 1997, Pant 2003). Ring width is also considered a good anatomical indicator of age (Priya & Bhat 1998, Bhat *et al*. 2001), and *T. grandis* is one of the tropical species that shows clear growth rings and suitable for climatic analysis (Chowdhury 1964, Détienne 1989, Bhattacharyya & Shah 2009).

Teak is widely cultivated mainly for sawn wood and veneer (Bhat *et al*. 2001). There is no information on teak growth in East Timor, where the species is also found and where it is an important asset for the forest economy.

The main objectives of this study are to describe *T. grandis* growth in the Northeast region of East Timor using ring width analysis and annual and cumulative growth curves. Heartwood proportion and sapwood width variation along the tree stem were also evaluated. These are the first exploratory results published on teak growth from East Timor and we hope the data will be useful for designing a sustainable forest economy in spite of the limitations that the country's political and economic situation imposed on field observation and sampling.

MATERIALS AND METHODS

Sample collection and preparation: The study area is located in the Northeast of East Timor, in the Lautem district between Los Palos and Fuiloro (08º30' S - 126º59' E, altitude 380m). It experiences a tropical climate with distinct wet and dry seasons determined by monsoon influence. The average yearly temperature is 23.8ºC and rainfall is 1 923.9mm. Peak rainfall occurs from May to June, and the dry season is August-October (mean monthly rainfall under 32mm), while July and November are transition months (125mm and 94mm respectively).

The wood samples were collected in October-November 2003, at the end of the dry season, in a pure teak stand of 3.76ha with 4mx2m spacing established in the period 1940-1950 (under the Portuguese administration). The stand has now a mean tree density of 165 trees/ha. The soils are of medium texture and pH 7.2, and the site has a declivity of less than 5%. No further records on stand establishment and management practices are available. Sampling was done in four circular 1 000m^2 permanent plots with mean basal area of 2.34m^2 (ranging from 2.06-2.59m^2), mean tree height of 25.0m (mean height ranged in the plots from 22.0-25.6m), dominant tree height of 29.1m (ranging from 26.2-32.9m) and mean diameter at breast height (DBH) of 42.5cm (ranging from 37.5-43.1cm).

Teak harvesting is illegal in East Timor and special authorization was requested from the Ministry of Agriculture. Authorization was given to harvest only three trees. Selection of trees was done based on DBH diameter class (40cm) *i.e*. dominant trees (one per plot), stem straightness and no apparent defects. The mean diameter at breast height of the harvested trees was 46.8cm and mean tree height was 26.8m.

From each tree stem discs of 5cm thickness were taken at 1.7m, 9.5m and 18.7m of stem height corresponding to the lower, medium and upper part of the stem. In addition increment cores of 5mm in diameter were also taken at 1.3m (DBH) from 12 living trees, by selecting three trees per plot (two cores per tree in opposite directions) as follows: one with diameter approximated to the average plot diameter, and the other two corresponding to the mean diameter plus and minus the standard deviation. Tree characteristics are shown in table 1.

For observation and measurement the transverse surfaces of the discs and cores were polished with sandpaper.

Sample measurements and growth analysis: Ring width measurement and ring counting were done using Leica QWin Stantard image analysis software. Core cross sections were first digitized using a scanner (Epson expression^{TM} 1680), at 1 200 dpi. Disc cross sections were observed under a simple microscope (Olympus SZH10) at x30 magnification. Three randomly selected *radii* were analyzed in each disc. Ring counting on the stem discs followed the "broken radius" concept described by Worbes (2002). All ring width measurements were performed perpendicular to ring boundaries.

The distinction between heartwood and sapwood was performed macroscopically by colour difference, and heartwood radius and sapwood width were measured. The relationship between stem and heartwood radius was studied for each disc and heartwood percentage by radius was determined.

Radial ring width curves are presented as raw data for the different axial positions within the stem, and ring width variability was analyzed. Growth rates were calculated, *i.e.* the mean annual increment was determined for each tree at one height level by dividing average tree radius by average tree ring count. Age-radius relationships were estimated using cumulative growth curves that were calculated for each tree over its lifetime and averaged to obtain mean growth curves.

Analysis of variance and t-Student tests were performed to determine the significant level in the variation of ring width. Statistical calculations were carried out with SPSS 15.0 software, for a significant level of 95%.

RESULTS

The teak stem discs showed irregular shapes and eccentric growth was frequent, especially in the lower part of the stem. Pith eccentricity was greater at 9.5m, as shown by the difference in *radii* (Table 2), while in the upper part of the stem, at 18.7m, greater circularity of the stem cross-section was evident.

Growth rings were distinct and ring boundaries marked by one (usually) or more lines of wide vessels and banded parenchyma. Earlywood could be distinguished from latewood by its wider vessels and parenchyma and thinner-walled fibres (Fig. 1A, B). At 1.7m the number of rings varied from 44 to 47 in the stem cross-sections of the harvested trees (Table 2) and in the cores taken at DBH from 42 to 54 (Table 3).

The frequent occurrence of eccentric rings led to a considerable ring width variation in the radius and around the circumference. Some of

TABLE 1
Characteristics of teak trees from East Timor in the Northeast region between Los Palos and Fuiloro

Tree	1*	2*	3*	4	5	6	7	8	9	10	11	12	13	14	15
DBH (cm)	50.0	42.0	48.3	46.3	29.1	38.6	43.2	45.4	36.3	43.4	48.5	39.2	56.7	31.5	43.9
H (m)	23.1	29.6	26.8	25	24.2	23.8	22.7	29.7	22.5	30.3	26.5	29.4	24.5	26.0	30.6

* = harvested trees.

TABLE 2

Growth ring quantitative data of *T. grandis* wood at 1.7 m, 9.5 m and 18.7 m stem height levels

Stem height (m)	Tree 1			Tree 2			Tree 3		
	Radius (mm)	Number of rings	Ring width (mm)	Radius (mm)	Number of rings	Ring width (mm)	Radius (mm)	Number of rings	Ring width (mm)
1.7	188 ± 58	47± 8	3.05 ± 1.75 (0.35 - 12.58)	158 ± 18	44± 3	3.25 ± 1.95 (0.58 - 12.27)	209 ± 32	45± 4	4.39 ± 4.23 (0.22 - 21.22)
9.5	138 ± 81	34 ± 9	3.97 ± 1.86 (0.63 - 11.43)	127 ± 21	39 ± 2	2.99 ± 1.74 (0.58 - 10.43)	156 ± 50	43 ± 3	3.31 ± 2.53 (0.38 - 22.96)
18.7	74 ± 19	17 ± 0	3.81 ± 1.97 (0.53 - 10.24)	89 ± 36	18 ± 0	4.41± 1.76 (0.63 - 18.04)	83 ± 3	24 ± 1	2.98 ± 1.89 (0.18 - 11.18)

Mean of three *radii* per disc ± standard deviation and as minimum-maximum values in parentheses. Note that wedged and false rings are included.

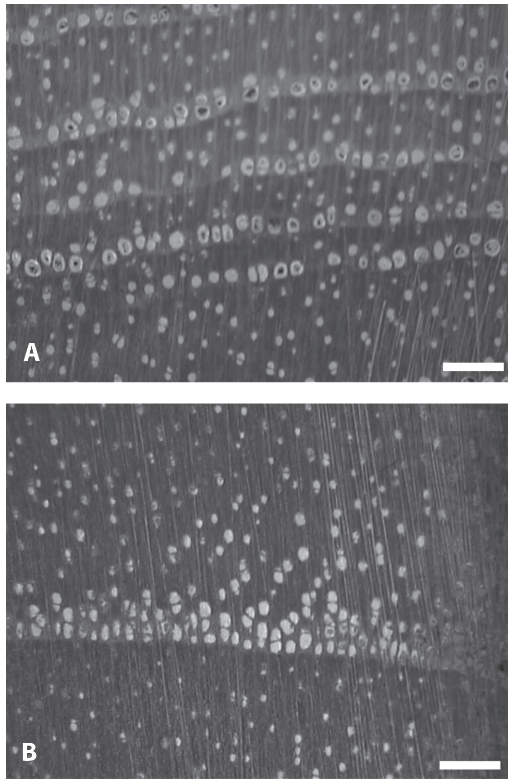

Fig. 1. Growth ring boundaries in *T. grandis* wood are marked by one (A) or more (B) tangential lines of wide vessels and banded parenchyma. Bars = 1mm.

TABLE 3

Growth ring quantitative data of *T. grandis* wood at DBH

Tree	Radius (mm)	Number of rings	Ring width (mm)
4	201	50	3.95 ± 2.14 (0.73 - 9.9)
5	111	49	2.22 ± 1.54 (0.29 - 6.97)
6	168	39	4.21 ± 4.42 (0.73 - 20.07)
7	188	47	3.92 ± 2.17 (0.6 -10.74)
8	235	51	4.53 ± 2.21 (0.31 -10.01)
9	164	53	3.04 ± 1.68 (0.73 - 8.27)
10	164	44	3.64 ± 2.87 (0.7 - 14.96)
11	267	46	5.69 ± 3.15 (0.44 - 15.07)
12	179	46	3.81 ± 2.62 (0.83 - 11.03)
13	266	45	5.80 ± 5.48 (0.8 - 20.98)
14	151	40	3.67 ± 3.15 (0.64 -13.49)
15	232	44	5.16 ± 5.24 (0.38 - 31.3)

Mean ± standard deviation and minimum-maximum values in parentheses. Note that wedged and false rings are included.

the rings were very narrow, especially in the outer part of the stem and regardless of direction, and therefore measurement of sapwood rings was in general more difficult.

Wedging rings occurred in the lower part of the stem. This was an important factor of ring width variation around the circumference and meant that rings were missing or indistinct in certain regions of the cross-section. No relation with direction was observed. Figures 2A-D show examples of wedging and indistinct rings, which were more frequent in the discs at 1.7m and 9.5m stem height and practically absent at 18.7m. The maximum difference in number of rings along the three *radii* in the disc samples was large in the lower part of the stem (Table 2): at 1.7m ring counts differed by 14 in tree 1, by 5 in tree 2 and by 7 in tree 3, while at the top (18.7m) it varied only by 1 ring in tree 1, none in tree 2 and 2 in tree 3.

Mean ring width was 3.6mm and 4.3mm in discs (at 1.7m) and cores (at 1.3m) respectively (Tables 2 and 3).

Observation of stem discs showed that ring width was highly variable along the radius and between *radii* (Table 2). Growth rings went from extremely narrow to very wide, ranging from 0.2 to 23.0mm. No significant differences between trees were found and average ring width was 3.6±0.5mm, 3.6±0.8mm and 3.6±0.7mm in tree 1, tree 2 and tree 3 respectively.

In spite of the considerable year-to-year radial variation of growth ring width, a radial pattern was observed, with a decrease in ring width from the pith towards the periphery. The widest rings were found within approximately the innermost 18 rings.

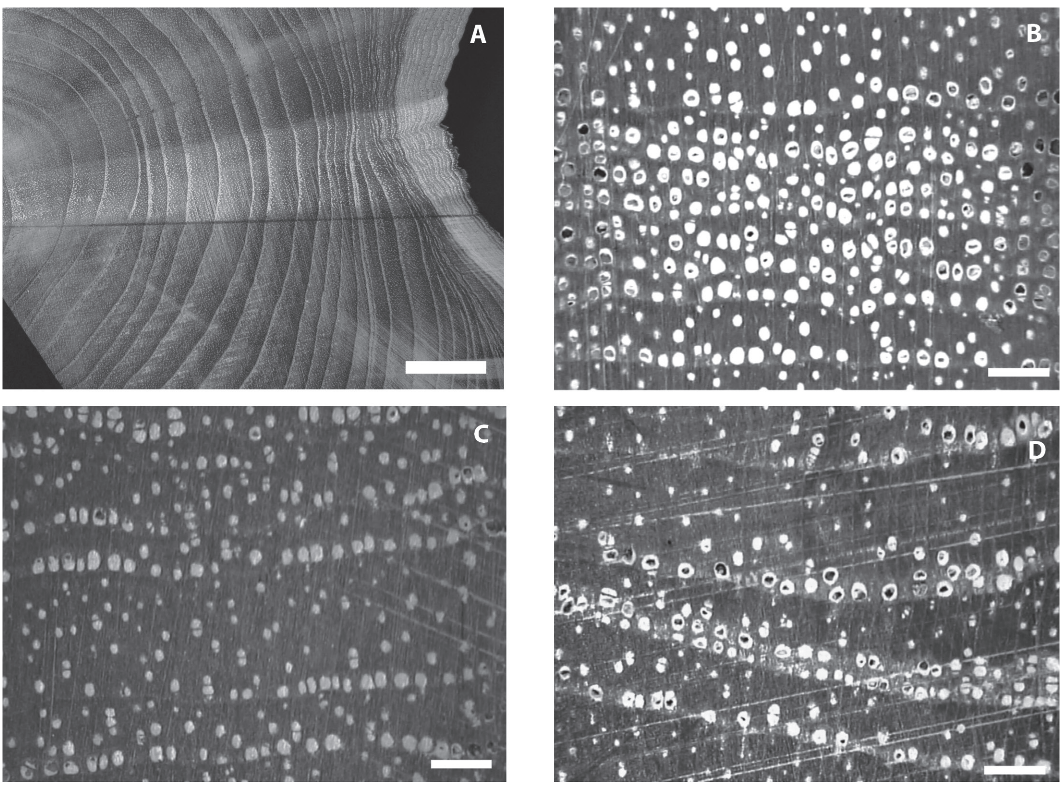

Fig. 2. Abnormal growth rings in teak wood. A. Wedged out rings. Bar = 2cm. B, C. Indistinct growth rings. D. False rings. Bars = 1mm.

The axial variation of ring width was small and no longitudinal trend was observed. Average ring width varied from 3.1 to 4.4mm, 3.0 to 4.0mm and 3.0 to 4.4mm respectively at 1.7m, 9.5m and 18.7m. Fig. 3 shows an example of the radial variation of ring width for tree 1 at the three height levels.

Tree height level and radius were not statistically significant factors of variation but tree x height level and tree x radius x height level interactions were significant ($p<0.001$). Cambial age was a highly significant factor of variation ($p<0.001$), accounting for most of the total ring width variability.

The results obtained for ring width measurement in cores taken at DBH are summarized in table 3. The year-to-year variation was high, as shown by the high standard deviations and interval ranges obtained. The radial variation of ring width shows the same tendency to decrease along the radius from the inner part towards the periphery (Fig. 4)

Mean tree ring width was not significantly different between trees. Cambial age was a highly significant factor ($p<0.001$), accounting for most of total ring width variability.

In general the trees with the greatest growth had the highest initial growth rate. Growth was faster in the first years of tree age and slowed thereafter, but some trees showed a pronounced initial growth. Figure 5 (A, B) shows the cumulative radial growth for the studied teak

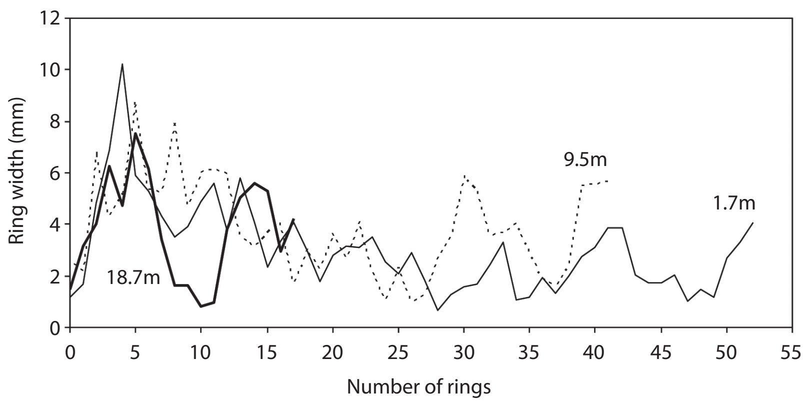

Fig. 3. Radial variation of ring width in tree 1 at three height levels of 1.7, 9.5 and 18.7m.

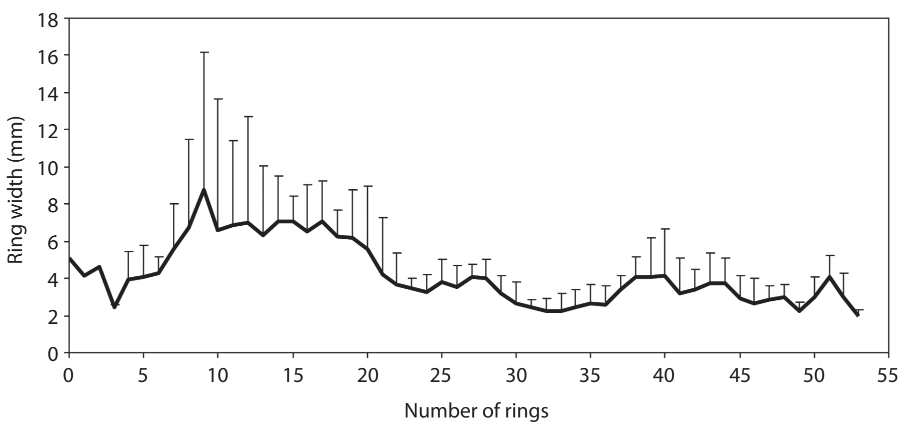

Fig. 4. Radial variation of tree ring width in cores from *T. grandis* trees sampled at DBH. Mean and standard deviation bars.

TABLE 4

T. grandis mean annual growth (mm) (at 1.7 m of stem height) for different growth periods

Tree	Mean annual growth (mm)				
	0-10 yr	10-20 yr	20-30 yr	30-45 yr	0-45 yr
1	4.54 ± 0.86	4.61 ± 021	3.96 ± 0.22	3.34 ± 0.14	3.07 ± 0.06
2	6.40 ± 0.79	4.82 ± 0.38	3.79 ± 0.24	3.58 ± 0.13	3.29 ± 0.04
3	7.42 ± 1.47	8.67 ± 0.79	6.17 ± 0.64	5.14 ± 0.25	4.51 ± 0.11

Mean and standard deviation of three *radii*.

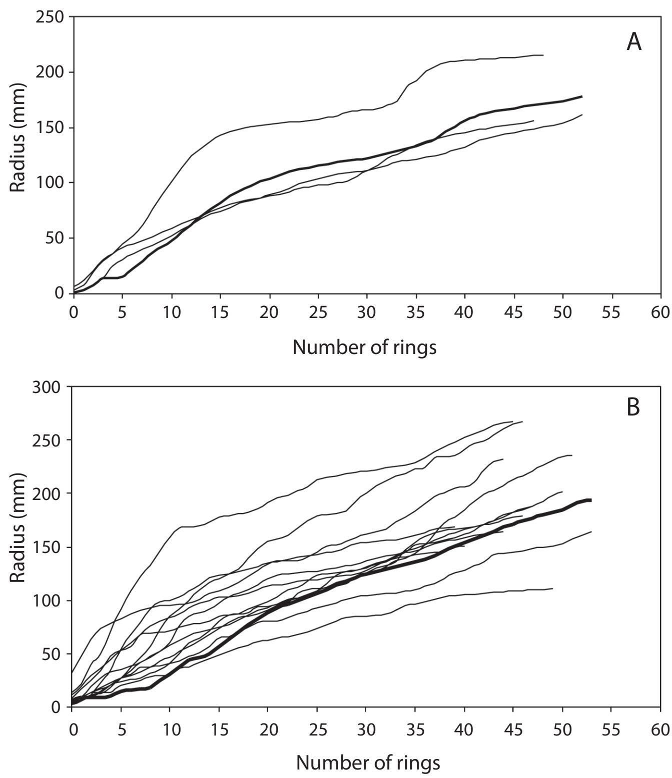

Fig. 5. Cumulative radial growth curves of *T. grandis* trees. A. At 1.7m. B. At DBH. Mean represented by thicker lines.

trees at 1.7m (Fig. 5A) and at 1.3m (Fig. 5B). There were differences in absolute growth and in growth dynamics. For instance, for a total growth period corresponding to 40 rings the radial length varied from 132.5 to 230.7mm.

The measurements made on the stem discs enabled growth rates to be calculated for different age periods (Table 4). The mean growth rate was higher for the initial years, corresponding to 4.5mm/year, 4.4mm/year and 7.3mm/year during the first 20 years, and 3.3 mm/year, 3.6 mm/year and 5.2 mm/year from 30 years onwards for tree 1, tree 2 and tree 3, respectively.

The golden brown heartwood, often streaked grey or black, was clearly distinct from the yellowish-white sapwood (Fig. 2A). As shown in table 5, at 1.7m and 9.5m heartwood

TABLE 5
Sapwood (SW) width and heartwood (HW) percentage of stem radius of *T. grandis* at 1.7m, 9.5m and 18.7m heights

Stem height (m)	Tree 1			Tree 2			Tree 3		
	Radius (mm)	SW (mm)	HW (%)	Radius (mm)	SW (mm)	HW (%)	Radius (mm)	SW (mm)	HW (%)
1.7	188 ± 58	22.3 ± 8.6	88.4 ± 1.4	158 ± 18	18.7 ± 4.0	88.2 ± 2.0	209 ± 32	9.0 ± 1.7	93.3 ± 1.6
9.5	138 ± 81	14.0 ± 11.3	90.4 ± 2.6	127 ± 21	17.7 ± 3.1	86.1 ± 0.3	156 ± 50	9.7 ± 1.5	93.3 ± 2.6
18.7	74 ± 19	25.7 ± 8.1	65.5 ± 2.3	89 ± 36	29.7 ± 11.1	66.3 ± 1.4	83 ± 3	12.3 ± 4.5	85.0 ± 5.5

Mean and standard deviation of three *radii* per disc.

accounted for 90% of the stem radius and at 18.7m it varied between 66% and 85%.

Sapwood width was regular along the stem circumference and longitudinally within the stem, measuring on average 18±7mm and corresponding to 9±2 rings. In the tree cores sapwood width was on average 24±9mm and included 8±2 rings.

DISCUSSION

The growth rings in the studied *Tectona grandis* trees from East Timor were in general distinct with boundaries marked by lines of wide vessels and banded parenchyma, which are indicative of a ring-porous wood. *T. grandis* has been classified as a ring-porous wood species (Freitas 1958, 1963, Priya & Bhat 1997, 1998, Bhat *et al*. 2001, Worbes 2002, Shah *et al*. 2007), although references have also been made to ring to semi-ring porosity variation (Bhattacharyya *et al*. 1992), and semi-ring porosity (Détienne 1989). The growth ring distinctiveness confirms previous statements about *T. grandis* rings (*e.g*. Worbes 2002, Morataya *et al*. 1999) and was also reported for Indian (Kumar *et al*. 2002) and African teak (Détienne 1989). In spite of the overall good ring definition, narrow and faint rings were observed, particularly in the outer sapwood region, suggesting the presence of wedging or false rings. The occurrence of false rings and the indistinctiveness of sapwood rings were also reported in teak from India (Kumar *et al*. 2002) and Thailand (Pumijumnong *et al*. 1995).

Formation of wedging rings is generally related to poor light conditions and tree competition and to buttresses if located in the outer part of the stem (Worbes 2002). Since no silvicultural management practices (*e.g*. thinning) were applied and the stand is characterized by its homogeneity *e.g*. regarding slope, the wedging rings observed in our samples were probably related to tree competition leading to eccentricity in ring formation although others factors may be considered *i.e*. site quality. The effects of competition on teak growth have been reported in many regions, *e.g*. Puerto Rico (Devall & Parresol 2003), Costa Rica (Morataya *et al*. 1999), Australia (Robertson & Reilly 2004) and India (Ram *et al*. 2010).

The few extreme 25 to 35mm wide rings that were observed appeared to be associated with knots or wound tissue inducing anomalously high or low growth in the surrounding area (Fritts 1976).

The dimensions of these 50-60 year-old teak trees in East Timor (with mean DBH of 38-43cm and height of 22-29m) are comparable to other teak trees from other locations. An example of teak trees with high growth given by very favourable conditions in India reported diameters around 48cm and heights around 31m at 40 years of age (Priya & Bhat 1999).

T. grandis in India showed rapid initial growth, slowing down after 15 or 20-25 years, which corresponds to the juvenile stage (Priya & Bhat 1998, Bhat *et al*. 2001, Kumar *et al*. 2002). Growth decrease is rapid from 25 to 30 years and is then slower up to 60 years (Bhat *et al*. 2001). Kumar *et al*. (2002) found that in

Indian teak growth rates in the juvenile phase converged after 20 years. Teak growth periodicity is influenced by tree age, with 6.6mm wide rings in juvenile wood and 2.5 mm rings in mature wood (Priya & Bhat 1999, Bhat *et al*. 2001). Therefore mean growth rate is higher in young trees below 21 years than in 65-year-old mature trees (Bhat & Priya 2004).

The age-related growth variation with more rapid initial growth was observed in the East Timor teak trees (Fig. 4 and 5). In general, the duration of this phase was about 20 years, which is in agreement with Bhat & Priya (2004). Overall the first 20 rings from East Timor teak were considerably wider than rings grown from 30 years onwards (6.1 mm/year, 5.6mm/year and 4.0mm/year for the periods 0-20, 20-30 and 30-45 years respectively, table 4). The wider growth rings of East Timor teak showed considerably more latewood than earlywood which is in agreement with other authors, *e.g*. Priya & Bhat (1998, 1999), who stated that the wider rings are generally related to greater formation of latewood, whereas earlywood width remains more or less constant.

Ring width of *T. grandis* from East Timor compared favourably with teak growth in other regions such as India, Australia and Java, over the same growth period. For example, the initial growth was higher than the reported data from India for 7-year-old and 13-year-old trees, which showed a variation in ring width from 1.9 to 5.8mm and 2.4 to 5.4mm, respectively (Priya & Bhat 1999). In trees from Costa Rica the mean annual increment found at DBH was higher at around 20mm at the age of 10 years and decreasing to 15mm at 45 years (Perez 2008).

The radial variation of ring width was the main source of variation for East Timor teak. This is in agreement with Worbes (1989), who identified the lack of radial uniformity as the variation factor in growth rings of tropical trees. Besides the age factor, stem eccentricity and deviations from circularity were also a significant factor for ring width variation. By contrast, the axial variation of ring width was small. Height variability was high for teak grown in Nigeria (Akachuku & Abolarin 1989). In addition to differences in soil characteristics, tree competition would influence stem development and ring width, resulting in between-tree differences.

Although there were no records on the past history of the studied teak stand in East Timor, it is probable that tree competition was a factor affecting growth and ring width. The growth curves suggest a more favourable growth environment with a reduced competition at about 35 years of age, leading to a subsequent short period of increased growth rate. This highlights the need to manage teak stands in relation to tree density by appropriate thinning practices, strengthened by the recent studies of Kokutse *et al*. (2010) in young teak plantations.

For economic reasons teak rotations of 20-30 years are now preferred to the traditional rotations of 50-70 years (Bhat & Ok Ma 2004), and this raises the question of heartwood dynamics with age. The evaluation of heartwood content and its vertical development is important since heartwood is the valued timber component of teak stems.

In the studied trees heartwood represented 87% of the stem radius for tree mean diameter of 37cm at 40-60 years of age. Sapwood contained 6-11 rings, indicating that the formation of heartwood begins early in teak. A large heartwood proportion is therefore achieved early, as reported for Indian teak in which heartwood attained 90% of 15-20cm diameters during the juvenile stage (Okuyama *et al*. 2000). In 11-13-year-old teak plantations in Togo about 30% of the wood surface was already heartwood, but greater formation of heartwood was reported in Asian teak compared to African teak (Kokutse *et al*. 2004). In Costa Rica the highest heartwood proportion of total tree volume was 61% in 47 year-old trees (Cordero & Kanninen 2003). Perez & Kanninen (2005) suggested that moderate and heavy thinnings yielded the highest percentage of heartwood volume while no clear relationship was found between heartwood volume and stand density.

Heartwood-formation in teak is more diameter- than age-dependent (Cordero & Kanninen 2003, Kokutse *et al*. 2004, Perez

& Kanninen 2005), as also reported for other species, *e.g. Acacia melanoxylon* (Knapič *et al*. 2006), *Eucalyptus globulus* (Gominho & Pereira 2000, 2005) and *Pinus sylvestris* (Björklund 1999).

Sapwood proportion (area) in teak from Costa Rica remained constant till 70% of tree height (Cordero & Kanninen 2003).

Regarding other wood quality parameters, also wood mechanical and physic properties of teak from East-Timor were similar to those reported for plantations of other origins, showing density variation of low magnitude (Miranda *et al*. 2011).

In summary, the tree growth characteristics and heartwood development of teak in East Timor confirmed the potential commercial importance of this species for the economy of the region. Growth performance was good with a high initial growth rate and comparable to Indian teak, with a large proportion of heartwood forming at an early stage. The age-related variation of ring width and the occurrence in the lower part of the tree stems of eccentricity and wedging rings highlights the importance of appropriate stand management, particularly regarding thinning and basal density distribution over time, whenever optimized timber production is envisaged.

ACKNOWLEDGMENTS

Wood sampling and transport were thanks to the assistance of PADRTL (Programme for the Support of Rural Development in East Timor) of the Portuguese government, and we appreciate all the help from the local field team. We thank the East Timor authorities, who granted permission for the harvesting of three teak trees. The authors are indebted to Fernando Abreu (Instituto Superior de Agronomia) for providing climatic data. Financial support for the scholarships of Paulo Maio and Filipe Boeyen Suspiro and for laboratorial analysis was provided by research funding from Fundação para a Ciência e Tecnologia (FCT) for Centro de Estudos Florestais (CEF).

RESUMEN

La madera de teca (*Tectona grandis* L.f.) es una de las más valiosas en el comercio internacional y una especie importante para la silvicultura tropical. La teca se encuentra en la isla de Timor Leste, pero no existe información disponible sobre su crecimiento en esta región. Se estudió una plantación pura no manejada que fue establecida entre 1940 y 1950 en el Norte de Timor Leste. Entre Octubre-Noviembre 2003 se cosecharon 15 árboles y al tronco se les extrajeron discos a tres niveles de altura (1.7m, 9.5m y 18.7 m), y se recolectaron núcleos a la altura del pecho (DAP). El conteo y la medición de los anillos se realizaron mediante el software de análisis de imagen. La distinción entre el duramen y la albura se realizó macroscopicamente por la diferencia de color, y se midieron el radio del duramen y el ancho de la albura. Para cada disco se estudió la relación entre el tallo y radio del duramen y el porcentaje del duramen. Las curvas de variación del ancho de los anillos se presentan para las diferentes posiciones axiales dentro del tronco y se analizó la variabilidad del ancho de los anillos. Las tasas de crecimiento fueron calculadas y las relaciones de radio con la edad se calcularon usando las curvas de crecimiento acumulado. Los anillos de crecimiento eran grandes y bien definidos en la fase juvenil, lo que refleja el carácter de crecimiento rápido de esta especie. La variación en la anchura de los anillos año a año mostró un patrón similar entre los árboles. La anchura media del anillo osciló entre 4.3-7.3mm para los primeros 20 años y 3.3-5.1mm para los de 30 a 45 años. La excentricidad de la médula fue evidente en la parte inferior del tallo y se observó la formación de anillos sobrepuestos. En promedio, el duramen representó el 84% del radio y la albura mostró entre 6 y 11 anillos. La variación del ancho de los anillos con la edad, la presencia de excentricidad en la parte inferior del árbol y los anillos sobrepuestos pone de relieve la importancia del manejo forestal con particular atención a la distribución de densidad basal en el tiempo, cuando se pretende la producción optimizada de la madera.

Palabras clave: *Tectona grandis*, anillos de crecimiento, anchura de anillos, duramen, variación.

REFERENCES

Akachuku, A.E. & D.A.O. Abolarin. 1989. Variations in pith eccentricity and ring width in teak (*Tectona grandis* L. f.). Trees Struct. Funct. 3: 111-116.

Bermejo, I., I. Cañellas & A. San Miguel. 2004. Growth and yield models for teak plantations in Costa Rica. Forest Ecol. Manag. 189: 97-110.

Bishop, P. 1999. 100 Woods: A guide to popular timbers of the world. The Crowood, London, England.

Björklund, L. 1999. Identifying heartwood-rich stands or stems of *Pinus sylvestris* by using inventory data. Silva Fennica 33: 119-129.

Bhat, K.M. & H. Ok Ma. 2004. Teak grower's unite. ITTO Tropical Forest Update 14: 3-5.

Bhat, K.M. & P.B. Priya. 2004. Influence of provenance variation on wood properties of teak from the Western Ghat region in India. IAWA J. 25: 273-282.

Bhat, K.M., P.B. Priya & P. Rugmini. 2001. Characterization of juvenile wood in teak. Wood Sci. Tech. 34: 517-532.

Bhattacharyya, A. & S.K. Shah. 2009. Tree-ring studies in India past appraisal, present and future prospects. IAWA J. 30: 361-370.

Bhattacharyya, A., R.R. Yadav, H.P. Borgaonkar & G.B. Pant. 1992. Growth-ring analysis of Indian tropical trees: dendroclimatic potential. Curr Sci. 62: 737-741.

Cordero, L.D.P. & M. Kanninen. 2003. Heartwood, sapwood and bark content, and wood dry density of young and mature teak (*Tectona grandis*) trees grown in Costa Rica. Silva Fennica 37: 45-54.

Chowdhury, K.A. 1964. Growth rings in tropical trees and taxonomy. J. Indian Bot. Soc. 43: 334-342.

Détienne, P. 1989. Appearance and periodicity of growth rings in some tropical woods. IAWA Bull. n.s. 10: 123-132.

Devall, M.S. & B.R. Parresol. 2003. A Dendrochronological study of Teak (*Tectona grandis* L. f., *Verbenaceae*). Peechi, India.

FAO. 2005. State of the world's forests. FAO, Rome, Italy.

Freitas, M.C. 1958. Estudo das madeiras de Timor. II contribuição. Ministério do Ultramar. Memórias da Junta de Investigações do Ultramar, Lisboa, Portugal.

Freitas, M.C. 1963. Madeiras da Índia Portuguesa. Memórias da Junta de Investigações do Ultramar, Lisboa, Portugal.

Fritts, H.C. 1976. Tree rings and climate. Academic, London, England.

Gominho, J. & H. Pereira. 2000. Variability of heartwood content in plantation-grown *Eucalyptus globulus* Labill. Wood Fiber Sci. 32: 189-195.

Gominho, J. & H. Pereira. 2005. The influence of tree spacing in heartwood content in *Eucalyptus globulus* Labill. Wood Fiber Sci. 37: 582-590.

Jacoby, G.C. 1989. Overview of tree-ring analysis in tropical regions. IAWA Bull. n.s. 10: 99-108.

Kammesheidt, L., A.T. Lezama, W. Franco & M. Plonczak. 2001. History of logging and silvicultural treatments in the Western Venezuelan plain forests and the prospect for sustainable forest management. Forest Ecol. Manag. 148: 1-20.

Knapič, S., F. Tavares & H. Pereira. 2006. Heartwood and sapwood variation in *Acacia melanoxylon* R. Br. trees in Portugal. Forestry 79: 371-380.

Kokutse, A.D., H. Baillères, A. Stokes & K. Kokou. 2004. Proportion and quality of heartwood in Togolese teak (*Tectona grandis* L.f.). For. Ecol. Manage. 189: 37-48.

Kokutse, A.D., A. Stokes, N.K. Kokutse & K. Kokou. 2010. Which factors most influence heartwood distribution and radial growth in plantation teak? Ann. Forest Sci. 67: 407-417.

Kumar, A.N.A., Y.B. Srinivasa & S.S. Chauhan. 2002. Growth rate convergence in teak (*Tectona grandis* L.). Curr. Sci. 83: 808-809.

Miranda, I., V. Sousa & H. Pereira. 2011. Wood properties of teak (*Tectona grandis*) from a mature unmanaged stand in East Timor. J Wood Sci. DOI: 10.1007/s10086-010-1164-8.

Morataya, R., G. Galloway, F. Berninger & M. Kanninen. 1999 Foliage biomass- sapwood (area and volume) relationships of *Tectona grandis* L.F. and *Gmelina arborea* Roxb.: silvicultural implications. Forest Ecol. Manag. 113: 231-239.

Nogueira, G.S., H.G. Leite, J.C.C. Campos, F.H. Takizawa & L. Couto. 2006. Avaliação de um modelo de distribuição diamétrica ajustado para povoamentos de *Tectona grandis* submetidos a desbaste. Rev. Árv. 30: 377-387.

Okuyama, T., H. Yamamoto, I. Wahyudi, Y.S. Hadi & K.M. Bhat. 2000. Growth stresses and some wood quality attributes in planted teak. Malaysia, Kuala Lumpur.

Orwa, C., A. Mutua, R. Kindt, R. Jamnadass & A. Simons. 2009. Agroforestree Database: a tree reference and selection guide version 4.0. World Agroforestry Centre, Nairobi, Kenya. (Downloaded: March 2010, www.worldagroforestry.org/af/treedb/).

Pant, G.B. 2003. Long-term climate variability and change over monsoon Asia. J. Ind. Geophys Union 7: 125-134.

Posch, B., G. Wegener, D. Grosser & L. Wagner. 2004. Physical and mechanical investigations on teakwood (*Tectona grandis* L.f.) from plantations in Panamá. Holz Roh Werkst. 62: 31-35.

Perez, D. 2008. Growth and volume equations developed from stem analysis for *Tectona grandis* in Costa Rica. J. Trop. Forest Sci. 20: 66-75.

Perez, D. & M. Kanninen. 2005. Effect of thinning on stem form and wood characteristics of teak (*Tectona grandis*) in a humid tropical site in Costa Rica. Silva Fennica 39: 217-225.

Priya, P.B. & K.M. Bhat. 1997. Wood anatomical changes associated with insect defoliation in juvenile teak. IAWA J. 18: 307-313.

Priya, P.B. & K.M. Bhat. 1998. False ring formation in teak (*Tectona grandis* L.f.) and the influence of environmental factors. Forest Ecol. Manag. 108: 215-222.

Priya, P.B. & K.M. Bhat. 1999. Influence of rainfall, irrigation and age on the growth periodicity and wood structure in teak (*Tectona grandis*). IAWA J. 20: 181-192.

Pumijumnong, N., D. Eckstein & U. Sass. 1995. Tree-ring research on *Tectona grandis* in Northern Thailand. IAWA J. 16: 385-392.

Ram, S., H.P. Borgaonkar & A.B. Sikder. 2008. Tree-rings analysis of teak (*Tectona grandis* L.F.) in central India and its relationship with rainfall and moisture index. J. Earth Syst.117: 637-645.

Ram, S., H.P. Borgaonkar & A.B. Sikder. 2010 Varying strength of the relationship between tree-rings and summer month moisture index (April- September) over Central India: a case study. Quatern. Internat. 212: 70-75.

Robertson, R.M. & D.F. Reilly. 2004. Performance of a 16-year-old stand of teak (*Tectona grandis* L) in the Darwin area in relation to that in other trials in the Northern Territory. Queensland, Australia.

Shah, K.S., A. Bhattacharyya & V. Chaudhary. 2007. Reconstruction of June-September precipitation based on tree-ring data of teak (*Tectona grandis* L.) from Hoshangabad, Madhya Pradesh, India. Dendrochronologia 25: 57-64.

Tian, Q., X. Gou, Y. Zang, Y. Wang & Z. Fan. 2009. May-June mean temperature reconstruction over the past 300 years based on tree rings in the Qilian mountains of the Northeastern Tibetan Plateau. IAWA J. 30: 421-434.

Worbes, M. 1989. Growth rings, increment and age of trees in inundation forests, savannas and a mountain forest in the neotropics. IAWA Bull.10: 109-122.

Worbes, M. 2002. One hundred years of tree-ring research in the tropics-a brief history and an outlook to future challenges. Dendrochronologia 20: 217-231.