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Effect of growth Rate and Latewood content on basic Density of Wood from 120-to 154-Year-old Natural-grown Teak (*Tectona grandis* L. f.)

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Abstract

The relationship between the radial variations of growth ring features and basic density were investigated in juvenile and mature wood for five 120-to150-year-old trees of Tectona grandis L. grown naturally in moist deciduous forest of Thane, Maharashtra. The study showed that the mean basic density of growth rings in juvenile wood was 0.665 (0.602-0.702) g cm^{-3} and 0.613 (0.562-0.665) g cm^{-3} in mature wood. The annual growth in juvenile period was high with a ring width mean of 4.03 mm and the latewood content represented 76.36 % of the annual growth, while in mature period was low with a ring width mean of 1.24 mm and the latewood content represented 59.41% of the annual growth. The patterns of radial variation of ring width, latewood content and basic density were more inherent in the juvenile wood than mature wood of all trees due to cambial ageing. The basic density of five individual trees showed an insignificant correlation between ring-width and latewood content in juvenile wood, whereas a significant positive correlation was found in mature wood of most of individual trees. The mean ring width value of all trees showed a highly significant positive correlation with basic density in both types of wood but mean latewood content showed a non-significant or low significant correlation.

Keywords: Growth rate, juvenile wood, mature wood, ring-width, teak, basic density.

Introduction

Wood is a non-homogenous, anisotropic material throughout the tree stem. The structure and properties of wood vary from pith to periphery, from the tree base to the top, from stem to branch and root[1]. The variation in wood properties results from environmental differences, genetic differences, and their interactions. Wood density has a strong additive genetic component, where minor environmental differences may not easily affect. However, it can greatly be changed by large differences in environment. Review showed that wood density of hardwoods has received far more study than any other property because of its relation to strength, workability, pulpability and ease of measurement. It is, in fact, not a single wood property but a combination of wood properties like latewood proportion, wall thickness, cell size, and others[2].

Wood density is not only influenced by genotype, environment but also affected by cambial age and growth rate. Ring width, which reflects the radial growth of a tree resulting from vascular cambial activity, has been used as the indicator of growth rate. Studies suggest that variation in basic density is influenced by ring width in both juvenile and mature wood of ring-porous hardwood. The reason is that, generally, the earlywood zone of ring-porous hardwoods has a relatively high proportion of vessels and the width of earlywood remains fairly constant from year to year, however, in latewood proportion, vessels are fewer and it increases as ring-width increases[3].

The relationship between growth rate and wood density is very complex in hardwoods; it has been much studied, and sometimes, it creates confusion. Wood density of diffuse-porous hardwood is almost independent of growth rate, in contrast, there is a positive correlation between growth rate and wood density in the ring-porous hardwood. In ring-porous woods, wide rings imply wood of high density. There are, of course, exceptions mostly due to the amount and structure of latewood[4].

Teak (*Tectona grandis* L. f.) is a ring-porous tropical hardwood known for its strength, durability, and aesthetic qualities. Old growth natural teak has been used primarily for yachts, decking, interior panelling and fine furniture[5]. India is considered to be the only known centre for genetic diversity and variability of teak, having its natural distribution zone confined predominantly to peninsular region below 24 ° N latitude[6].

Several studies reported contradictory findings with regard to the relationship between growth rate in terms of ring width and wood density in teak from tropical regions[7-11]. The moist deciduous forest of Thane is well known for natural-grown teak in Maharashtra state of peninsular India. No detailed studies have been reported so far from this location on old growth natural teak of different age-group. Hence, the present study was undertaken to investigate the relationship between the radial variations of growth ring features (ring width and latewood content) and basic density in juvenile and mature wood of 120-to154-year-old teak trees.

Material and Methods

The present study was carried out in the Institute of Wood Science and Technology, Bangalore. Wood samples were collected from different trees of various age-groups from natural teak forest of Thane, Maharashtra. Sampling details are given below.

Sampling: Five cross-sectional discs, one from each individual, of different age-groups, were collected from the left over stumps (20-30 cm above ground level) located at natural-grown teak trees (coded T1 to T5) at Shirshad forest range of Thane, Maharashtra (table-1).

Table-1
Details of environmental conditions and characteristics of teak discs sampled for the study

Factor	Thane (Location)
Latitude (N)	$19^0\,12'$
Longitude (E)	$73^0\,02'$
Forest Type	Tropical moist deciduous forest
Mean annual rainfall	2500 mm
Mean temperature range	24.4-30.2 ^{0}C
Soil Type	Red laterite well drained soil
Age group (years)	120,130, 134, 148,154
Mean Diameter (cm)	40.4 - 47.7
Mean Heart wood (%)	85.91

The surfaces of five discs were smoothened using different grades of sand paper to expose the growth rings and prepare the wood for microscopic analysis. The age of trees were determined by counting each annual growth ring in the disc [figure-1(a)]. The age used to demarcate the border between juvenile and mature wood was determined from literature studies. In teak, the age demarcation point between juvenile and mature wood was estimated around 20 years[12,13]. A long radial strip of 1.5 cm width was cut from each disc including all rings from pith to bark and transported to the laboratory for detail study.

Ring-width, latewood content and basic density: The width of each annual growth ring in the radial strip was measured to the nearest 0.01 mm under a Leica stereo-zoom microscope using LAS live measurement software. The transition from earlywood to latewood is gradual in each growth ring of teak. While determining ring width, latewood width was measured in all the radial strips after making an arbitrary demarcation between earlywood and latewood, by identifying the earlywood with wide vessels, parenchyma and thin-walled fibres and latewood with narrower vessels and more thick-walled fibres [figure-1(b)]. Latewood content (%) was calculated by the formula: (latewood width/growth ring width) × 100.

The radial strips were then cut along tangential plane to separate each growth-ring into smaller blocks for measurement of basic density. Two or more narrow rings were combined in few blocks of the mature wood zone of the strip, where these rings were too small to separate and measure individually. Green volume of the block was determined by the water displacement method. Basic density of the individual block was then calculated as oven dry weight over green volume. The same basic density value was put for each narrow ring equal to the density of individual block with the assumption that the ring width of each narrow ring in the block was more or less same.

Data analysis: Scatter plots with linear regression lines were produced using MS-Excel in order to find out the relationships between growth ring features *viz.,* ring width and latewood content with basic density. The relationships were compared between juvenile and mature wood of trees using t-test to confirm significant differences, if any.

Results and Discussion

Growth ring features and wood density: Table-2 shows the number of rings, the mean growth ring features (ring width and latewood content), mean wood density and standard deviation in juvenile and mature wood of each individual tree. The mean annual ring width of wood in former and latter was 4.03 mm and 1.24. However, variation among individual trees for annual ring width varied greatly and it ranged from 1.75 mm to 7.52 mm (juvenile wood) and 1.02 mm to 1.51 mm (mature wood). The latewood content in juvenile wood was 76.36 % of the annual ring width and it was 59.41% in mature wood. The mean basic density in juvenile wood was 0.665 g cm^{-3} that ranged between 0.602 g cm^{-3} and 0.702 g cm^{-3}. However, the mean basic density in mature wood was 0.613 g cm^{-3} and it varied between 0.562 g cm^{-3} and 0.665 g cm^{-3}.

The teak tree bearing number T2 revealed a very high wood density in both type of wood. The wider growth rings of Thane teak showed considerably more latewood than narrow rings, whereas earlywood width remained more or less constant [figure-1(b)]. Bhat has reported a similar result, indicating that juvenile wood of teak is characterized by wide growth rings with high proportion of latewood as compared to mature wood[14]. He also reported the high wood density in juvenile wood in comparison to mature wood among slow growing teak trees in Kerala.

Radial variation of ring width, latewood content and wood density: Radial variations for ring width, latewood content and basic density among five studied individuals (T1-T5) are illustrated in Figure-2. Ring width of all five studied trees showed roughly a similar radial trend [figure-2(c)]. Ring width increased or fluctuated initially up to 20 years from pith and then it decreased up to 59 years. Finally, it remained more or less constant towards the periphery. This clearly indicating the fluctuation of growth rate in juvenile period of tree growth and then decreased. In some cases, it became constant after maturation of the cambium. This pattern was observed in almost all individuals, and it indicated that the trait may be controlled by inherent. In several studies, teak showed a rapid initial growth, slowing down after 15 or 20-25 years, which corresponds to the juvenile period[12,13,15,16]. Decreasing trend of growth is rapid from 25 to 30 years and then it is slower towards 60 years[12].

Latewood content in growth ring of all five trees also showed roughly a similar radial trend like ring width [figure- 2(b)]. High proportion of latewood was found in wider rings and it was least in narrow rings. Bhat has reported that the mean latewood proportion in 7, 13, 20, 40 and 147 years teak trees were 92, 90, 48, 44 and 70 percent of the mean ring width respectively[14].

Radial variations of basic density for the five individual trees studied are illustrated in figure-2(a). In tree T1, basic density declined slightly in first few rings from pith and then increased towards middle growth sheaths and finally decreased towards periphery. In tree T2, basic density decreased rapidly up to 30 years and then increased up to 60 years, thereafter, it remained more or less constant and finally, it decreased towards periphery. In trees, T3, T4 and T5, the basic density increased up to 10 years and then slightly decreased towards middle and finally, it remained more or less constant towards the periphery with a slight decrease in few outer rings.

Relationship between ring width and basic density: Association of radial variations in mean ring width and basic density of five individuals (T1-T5) with cambial age from pith is illustrated in figure-4. Generally, mean ring width and basic density values gradually decreased up to 59 years and finally, it remained more or less constant towards the periphery with a slight decrease in few outer rings. Correlation coefficients between ring width and basic density of five individual trees and their mean values in juvenile and mature wood are shown in figure-3. It is clear from scatter plots that there was no significant correlation between ring width and basic density in juvenile wood of trees bearing no. T1, T3, T4 and T5 except T2. However, the mean value of all trees show a significant positive correlation at 1% and 0.1% level in juvenile wood; while a significant positive correlation was found at 0.1% level in mature wood of all sampled trees, except T5 and it was non-significant.

Table-2
Number of rings, mean ring width, latewood content and basic density in juvenile and mature wood of teak trees (T1-T5) (Values presented are mean ± standard deviation)

Tree No.	Type of Wood	No. of rings (N)	Ring-width (mm)	Latewood content (%)	Basic density (g/cm^3)
T1	Juvenile	20	3.41 ± 0.88	78.67 ± 7.41	0.602 ± 0.031
	Mature	134	1.02 ± 0.68	58.59 ± 13.61	0.562 ± 0.070
T2	Juvenile	20	1.75 ± 1.20	71.01 ± 9.14	0.702 ± 0.055
	Mature	128	1.14 ± 0.82	59.16 ± 16.13	0.665 ± 0.061
T3	Juvenile	20	7.52 ± 2.06	71.96 ± 7.80	0.693 ± 0.018
	Mature	114	1.50 ± 1.23	56.17 ± 14.99	0.624 ± 0.054
T4	Juvenile	20	3.99 ± 1.32	81.29 ± 6.54	0.685 ± 0.023
	Mature	110	1.05 ± 0.76	58.65 ± 14.65	0.595 ± 0.065
T5	Juvenile	20	3.48 ± 1.34	78.89 ± 5.59	0.645 ± 0.029
	Mature	100	1.51 ± 0.91	64.46 ± 11.95	0.620 ± 0.065

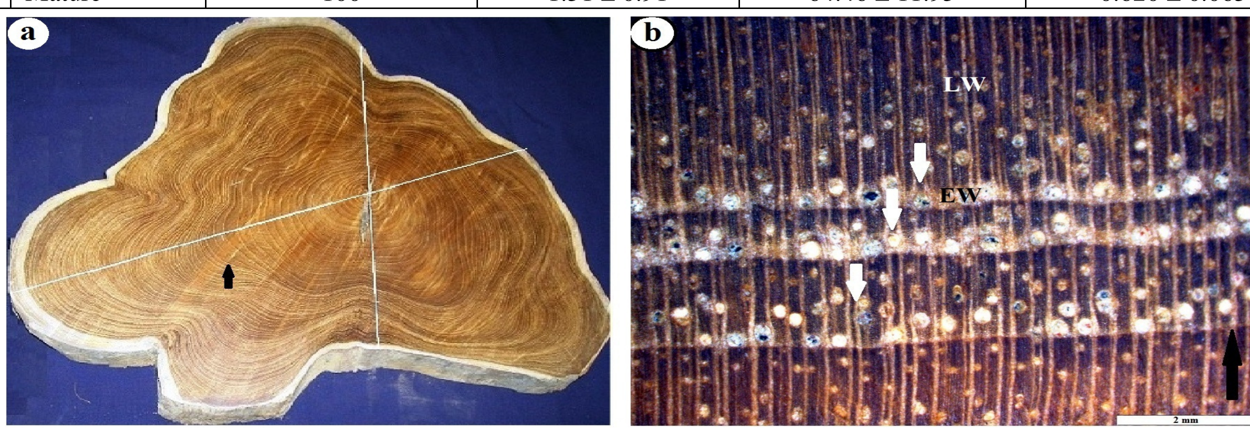


Figure-1
(a) Macroscopic picture of a polished *Tectona grandis* wood cross-section showing distinct annual growth rings; the black arrow indicates the boundary between juvenile and mature wood (b) Microscopic photograph showing gradual transition from earlywood (EW) to latewood (LW) within an annual growth ring; white arrows indicate the arbitrary demarcation between EW and LW; black arrow indicates the direction of growth

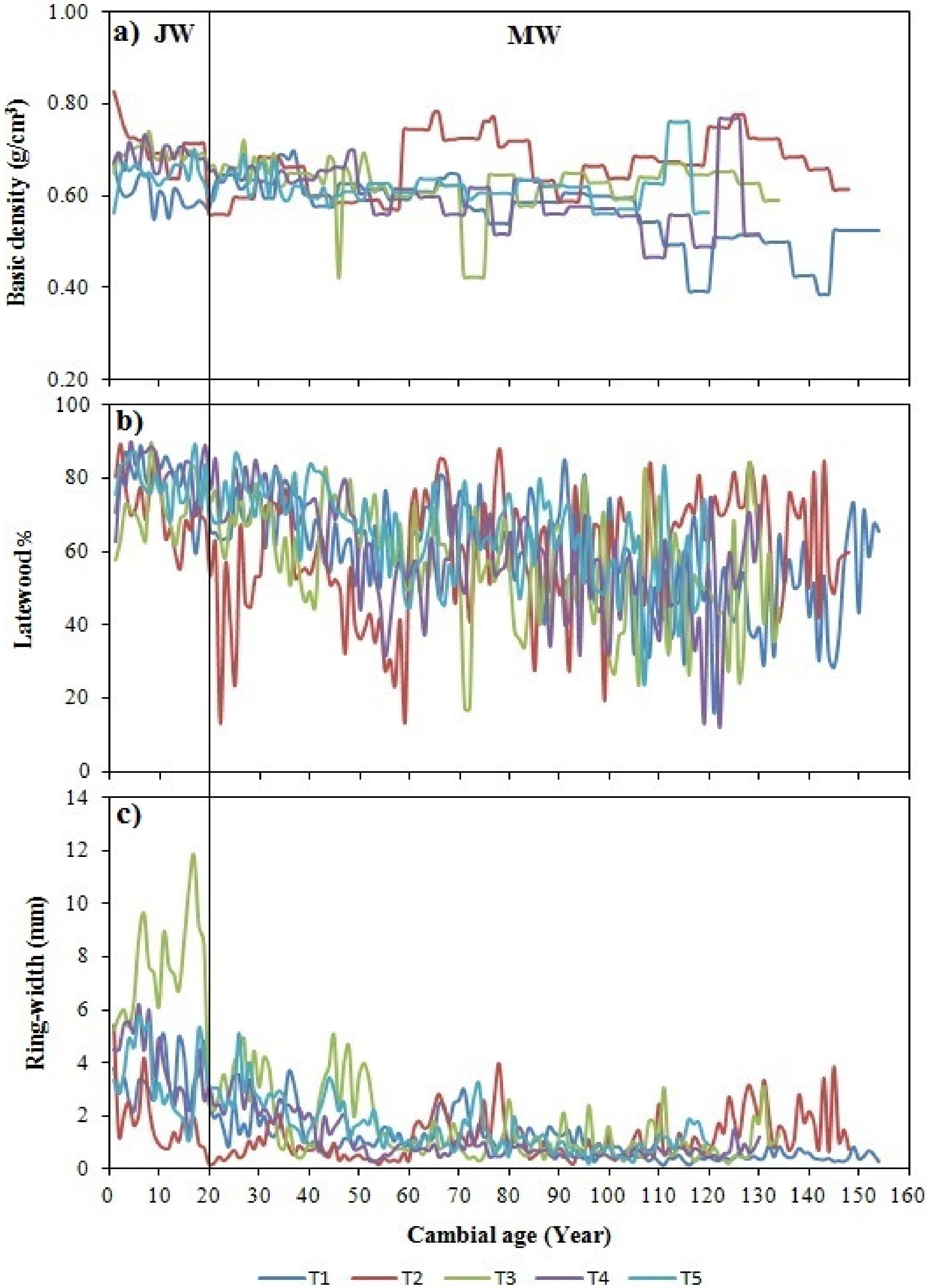
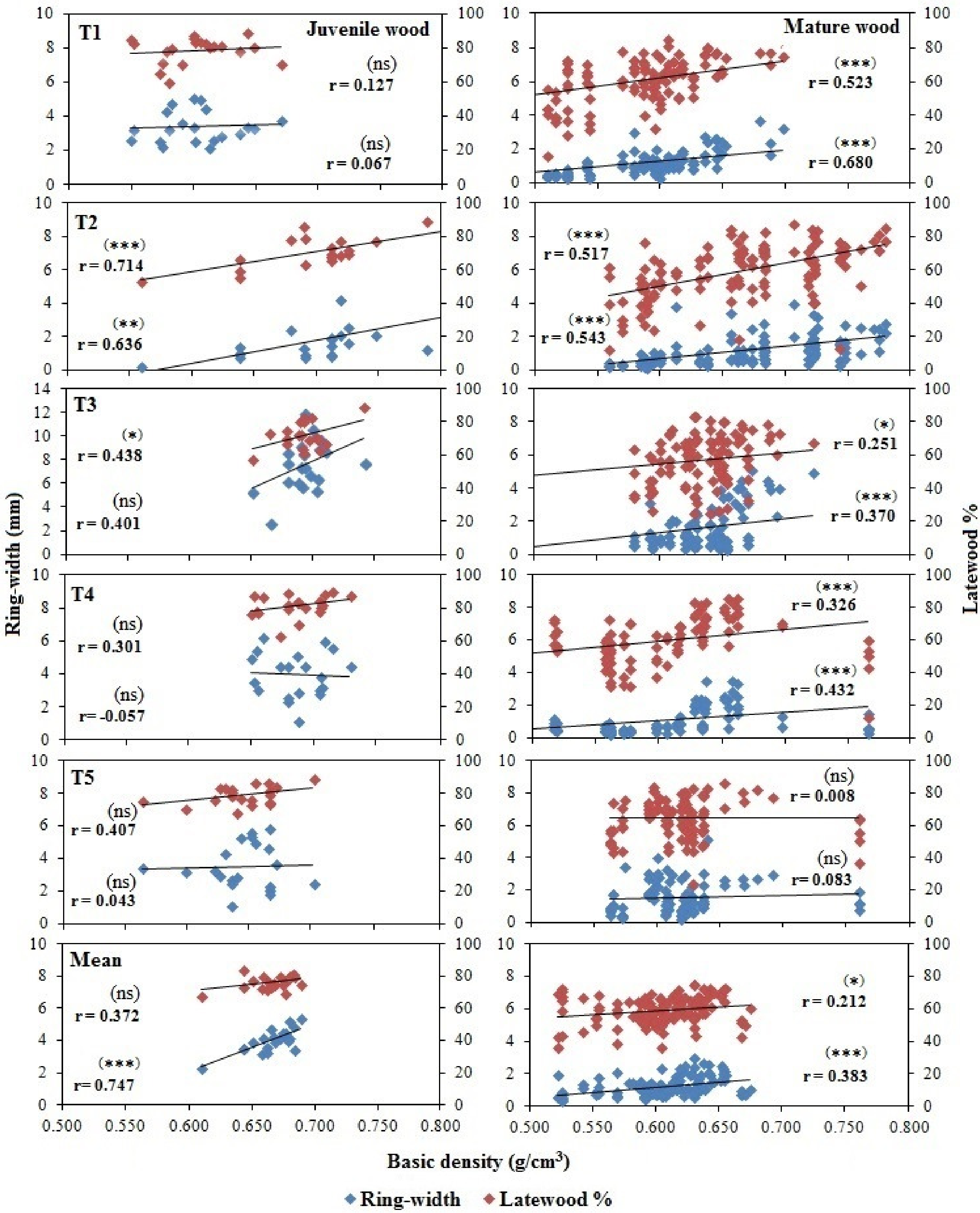


Figure-2
Radial variation of (a) basic density (b) latewood proportion and (c) ring-width in juvenile (JW) and mature wood (MW) of five teak trees



Note: *** significant at 0.1% level; ** significant at 1% level; * significant at 5% level; ns non significant

Figure-3

Scatter plots illustrating the relationships between growth-ring features (ring-width, latewood content) and basic density in juvenile and mature wood of teak trees (T1-T5) and their mean value

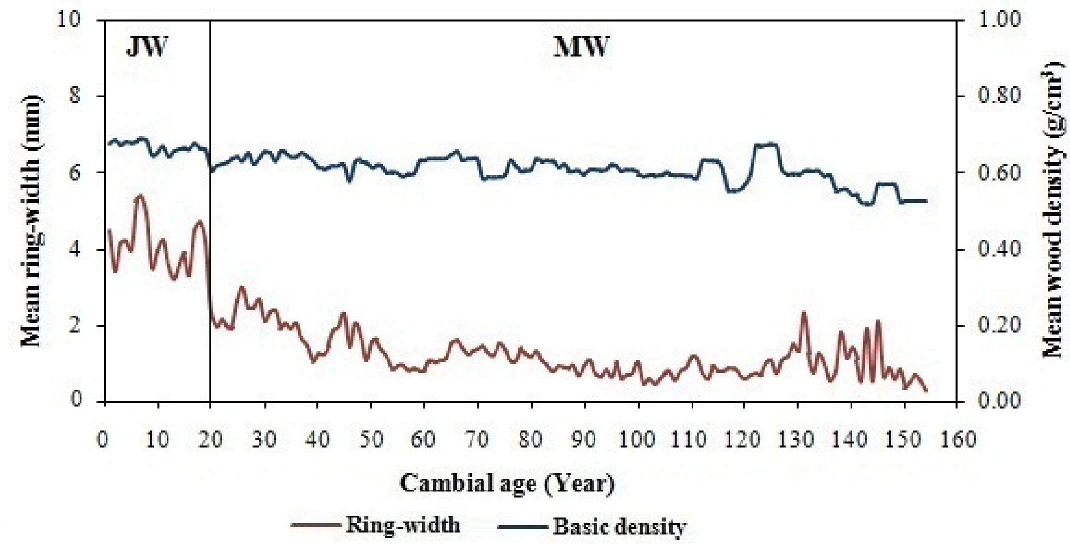


Figure-4
Radial variation of mean wood density with ring-width in juvenile (JW) and mature wood (MW)

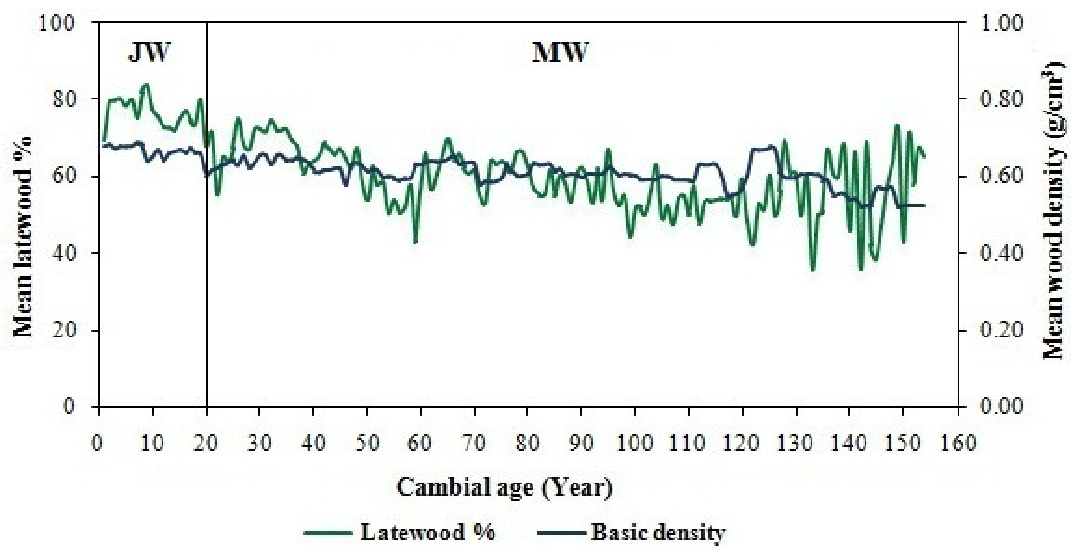


Figure-5
Radial variation of mean wood density with latewood content in juvenile (JW) and mature wood (MW)

The effect of growth rate in terms of ring width on wood density has been subjected to many investigations and much controversy. For instance, Bhat and Indira reported significant positive correlation between ring width and basic density[7], while many authors found non-significant or negative correlation between these traits[8-11].

Relationship between latewood content and basic density: Association of radial variations in mean latewood proportion and basic density of five individuals (T1-T5) with cambial age from pith are illustrated in figure-5. The relationship between latewood proportion and basic density was similar to that of trend recorded between ring width and basic density. Correlation coefficients between latewood proportion and basic density of five individuals and their mean values in juvenile and mature wood are shown in figure-3. It is clear from scatter plots that there was no significant correlation between latewood proportion and basic density in juvenile wood of trees bearing no. T1, T4, T5. However, this relationship was significant at 0.1% and 5% in T2 and T3, respectively. Interestingly, a significant positive correlation was found in mature wood of all sampled trees, except T5, which show non-significant relationship. This result is supported by Zobel and van Buijtenen, where latewood proportion with fewer vessels increases as ring width increases and vice-versa[3]. However, this influences the variation in basic density of both juvenile and mature wood of a ring-porous hardwood.

Based on the results of the present study, it was observed that the basic density of five individuals showed non-significant relationship with ring width and latewood content in juvenile wood. However, the relationship was significantly positive in mature wood of most of the studied individuals. The mean ring width value of all studied trees showed a strong relationship with basic density in both juvenile and mature wood. However, mean latewood content showed a non-significant or weak relationship.

Conclusion

The mean ring width, latewood content and basic density values are found more in juvenile wood than mature wood of all teak trees. The patterns of radial variation of ring width, latewood content and basic density are more inherent in the juvenile wood than mature wood resulting from cambial ageing. This study shows that there is no relationship between growth ring features and basic density in juvenile wood, while a strong relationship is found in mature wood of most of individual trees within the site. It is important to consider individual tree variation while breeding for high wood density rather than mean variation of all the trees of a site.

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