Variation in Growth and Wood Traits Among Nine Populations of Teak in Peninsular India

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Abstract

Growth, wood characteristics and bark thickness were studied in relation to climatic, edaphic and latitudinal factors in seven 60 year old plantations and two natural populations of teak from different ecotypes in Peninsular India. The very moist population (Nilambur, Kerala) had best growth and form but comparatively lower wood density on par with the slightly moist natural stand (Nasik) and the dry teak population (Pandarkawda, Maharashtra). Populations from Kalakkad (natural stand), Topslip and Mudumalai (Tamil Nadu) and Konni (Kerala) had marginally higher wood density values. Sapwood content was negatively correlated with growth rate with significantly lower values for very moist and moist populations (Nilambur, Top slip and Konni). Bark thickness was higher for the very moist populations of Konni and Nilambur and showed a positive correlation with tree girth.

Wood density and sapwood content showed significant negative and positive trends respectively with latitude whereas vessel and fibre traits did not show any consistent trend. The populations varied significantly in vessel characteristics and anatomical indices like Runkel ratio and F/V ratio but not in fibre traits indicating a greater influence of edaphic and site factors than ecotype and latitudinal effects. It is inferred that differences between populations in different traits are influenced by the latitude and total site factors as well as the ecotype of the stand.

Key words: geographic location, India, population, site factors, teak, and wood traits.

Introduction

Teak, a highly commercial timber species is recognised to have distinct ecotypes – namely very dry, dry, semidry, moist and very moist, in India (CHAMPION and SETH, 1968). Several provenances of teak have also been recognised based on the geographical location and the morphological characteristics of stem and leaves and timber properties. Differences are known in the wood obtained from various ecotypes and the good figure of timber from dry areas is valued for panelling and furniture. Teak thrives best and reaches its largest dimensions in moist tropical regions, although it occurs in dry regions marked by hot dry season upto 5 months. An international series of provenance trials in teak coordinated by DANIDA forest seed centre, Denmark across different countries categorised the Indian seedlots into moist west coast, semi moist east coast and dry interior mainly based on the quantum of rainfall received (KJAER *et al.*, 1995).

Growing of teak has been extended to areas beyond its natural range in India with intensive cultivation and reduced rotation by inducing rapid growth and wood production. Very little is known about the differences in wood quality of teak raised from different seed sources and the influence of climate and geographic locations on the wood traits. Studies across few sites and seed sources (PURKAYASTHA *et al.*, 1973) and between dominant and suppressed trees (BHAT *et al.*, 1987) have shown that teak wood responds to the growing conditions. This paper summarises the results of investigations on the growth and wood characteristics of teak plantations and natural stands from markedly differing locations in Peninsular India.

Materials and Methods

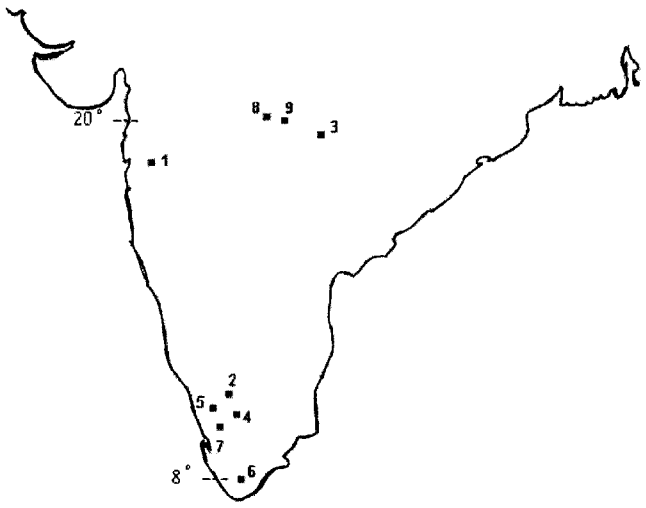
Seven 60 year old teak plantations (probably of local origin) located in the states of Maharashtra, Kerala and Tamil Nadu and two natural stands from Nasik (Maharashtra) and Kalakkad (Tamil Nadu) were selected for the study (*Fig. 1*). Populations from Nilambur and Konni (Kerala) belonged to the very moist category and two populations from Tamil Nadu namely Kalakkad and Topslip were of the moist category. Allapally, Chandrapur, and Nasik (Maharashtra) and Mudumalai (Tamil Nadu) populations belonged to the slightly moist category. The population from Pandarkawda in Maharashtra belonged to the dry category (*Table 1*). The trees in the Kalakkad population were of coppice origin (coppiced in 1968 – SRINIVASAN, 1978) and hence obviously much younger compared to the other plantations. Since the Nasik population was a natural stand the age of the trees was not available.

Ten trees, representative of the diameter range were selected from two sample plots (50 m x 50 m size) randomly laid out at each site and increment core samples (6 mm internal diameter) were extracted from pith to periphery of each tree at breast height. The tree height and girth as well as bark thickness at breast height were measured for all the sampled trees. The

Table 1. – Geographic and climatic details of the teak populations studied.

Location	Latitude(°N)	Longitude(°E)	Annual rainfall (mm)	Category
1. Nasik*	19°47'	73°26'	1562	Slightly moist
2. Mudumalai	11°34'	73°38'	1429	Slightly moist
3. Allapally	19°27'	80°	1520	Slightly moist
4. Topslip	10°33'	76°50'	2080	Moist
5. Nilambur	11°18'	76°18'	2580	Very moist
6. Kalakkad*	8°29'	77°30'	1864	Moist
7. Konni	9°21'	76°51'	2560	Very moist
8. Pandarkawda	20°	78°33'	1081	Dry
9. Chandrapur	19°59'	79°15'	1348	Slightly moist

*) natural stand



1 – Nasik; 2 – Mudumalai; 3 – Allapally; 4 – Topslip; 5 – Nilambur; 6 – Kalakkad; 7 – Konni; 8 – Pandarkawda; 9 – Chandrapur

Fig. 1. – Map showing location of teak populations in Peninsular India.

core samples were carefully transported as such in sealed test tubes to the laboratory for estimating other wood parameters. In the laboratory the cores were saturated in distilled water for 24 hours to regain the original volume.

Width of sapwood was measured based on colour differences and recorded as percentage of the tree radius. Wood density was estimated by oven dry method. Core samples were macerated to record the vessel and fibre dimensions. Two anatomical indices namely Runkel ratio (ratio of double wall thickness to lumen width of fibre) and F/V ratio (fibre length to vessel element length) were computed for each sample. Data were subjected to analysis of variance and DUNCAN's Multiple Range Test to compare the differences between populations.

Results

Tree growth

The Kalakkad trees were the smallest followed by the dry teak population of Pandarkawda and slightly moist population from Nasik (*Table 2*). In terms of tree height, Nilambur and Topslip trees had the highest values followed by Konni, Mudumalai and Chandrapur trees. Tree girth also followed a similar pattern with Nilambur trees having the largest values followed by Konni, Top slip and Mudumalai trees. There was a significant phenotypic correlation of 0.60 between the two traits (*Table 4*).

Bark and wood traits

Bark thickness varied significantly between populations. There was a positive correlation (0.41) between tree girth and bark thickness as evidenced by the high values for Konni and Nilambur populations followed by the Chandrapur stand. Two populations did not conform to the trend; Kalakkad trees with a low mean girth of 96.6 cm had a mean bark thickness of 1.22 cm and Mudumalai trees with intermediate girth had the lowest bark thickness. Slightly moist and dry teak populations of Nasik and Pandarkawda with lower girth had low bark thickness.

Mean wood density values ranged from 0.542 g/cm^3 (Pandarkawda) to 0.624 g/cm^3 (Kalakkad). Only the Pandarkawda population had a significantly lower wood density than most populations. Wood density did not show any correlation with tree growth parameters like height and girth (*Table 4*). A regression of wood density on stand latitude showed significant ($P = 0.0003$; $r = -0.473$) negative relationship. Wood density showed a decreasing trend with latitude of location of trees sampled (*Fig. 2A*).

Sapwood % varied significantly among populations with Kalakkad and Allapally trees showing highest values. Dry teak population of Pandarkawda and slightly moist teak popula-

Table 2. – Growth and wood traits of teak populations.

Population	Tree height (m)	Tree girth (cm)	Sapwood (%)	Wood density (g\cm^3)	Bark thickness (cm)
1. Nasik	19.60 b	109.8 a	8.14 bc	0.582 ab	0.62 a
2. Mudumalai	25.55 cd	150.0 b	5.57 ab	0.609 b	0.54 a
3. Allapally	22.76 bc	91.32 a	13.36 dc	0.601 b	0.82 ab
4. Top slip	31.90 e	152.20 b	4.89 a	0.622 b	1.04 bc
5. Nilambur	31.96 e	194.0 c	2.73 a	0.576 ab	1.56 de
6. Kalakkad	15.60 a	96.60 a	14.03 e	0.624 b	1.22 cd
7. Konni	25.60 cd	158.20 b	5.15 ab	0.611 b	1.80 e
8. Pandarkawda	22.20 bc	107.0 a	9.42 c	0.542 a	0.78 ab
9. Chandrapur	23.60 cd	119.20 a	10.83 cd	0.611 b	1.22 cd

Values followed by the same letter do not differ significanty by DUNCAN's multiple range test

Table 3. – Fibre and vessel characteristics in teak.

Population	FL (μm)	VL (μm)	VD (μm)	FW (μm)	LW (μm)	DWT (μm)	RR	F/V ratio
1. Nasik	1403 b	317 ab	160 ab	24.3ns	13.7ns	10.6ns	0.81 ab	4.5 b
2. Mudumalai	1473 b	339 abc	182 bc	23.7ns	13.7ns	10.1ns	0.78 a	4.4 b
3. Allapally	1444 b	370 c	156 ab	24.8ns	14.4ns	10.7ns	0.77 a	3.9 a
4. Top slip	1435 b	347 bc	153 ab	24.2ns	14.5ns	9.7ns	0.69 a	4.2 ab
5. Nilambur	1472 b	324 ab	199 cd	24.3ns	14.0ns	10.4ns	0.82 ab	4.6 b
6. Kalakkad	1203 a	309 a	144 a	22.7ns	12.8ns	10.7ns	1.01 b	3.9 a
7. Konni	1451 b	320 ab	200cd	23.8ns	13.5ns	10.3ns	0.83 ab	4.6 b
8. Pand'awda	1435 b	336 abc	160 ab	25.1ns	14.9ns	10.2ns	0.71 a	4.3 b
9. Chandrapur	1373 b	306 a	225 d	23.9ns	13.1ns	10.8ns	0.89 ab	4.5 b

FL-Fibre length; VL-Vessel element length; VD-Vessel diameter; FW-Fibre width; LW-Lumen width; DWT-Double wall thickness; RR-Runkel ratio. Values followed by the same letter do not differ significantly by DUNCAN's multiple range test

Table 4. – Phenotypic correlation coefficients of growth and wood traits.

	Tree girth	Tree height	Wood density	Sap wood %
Tree girth	–			
Tree height	0.60 **	–		
Wood density	-0.03 ns	0.11 ns	–	
Sap wood %	-0.67 **	-0.52 **	-0.07 ns	–
Bark thickness	0.41 **	0.21 ns	0.12 ns	-0.16 ns

**) Significant at p <0.01; ns = not significant.

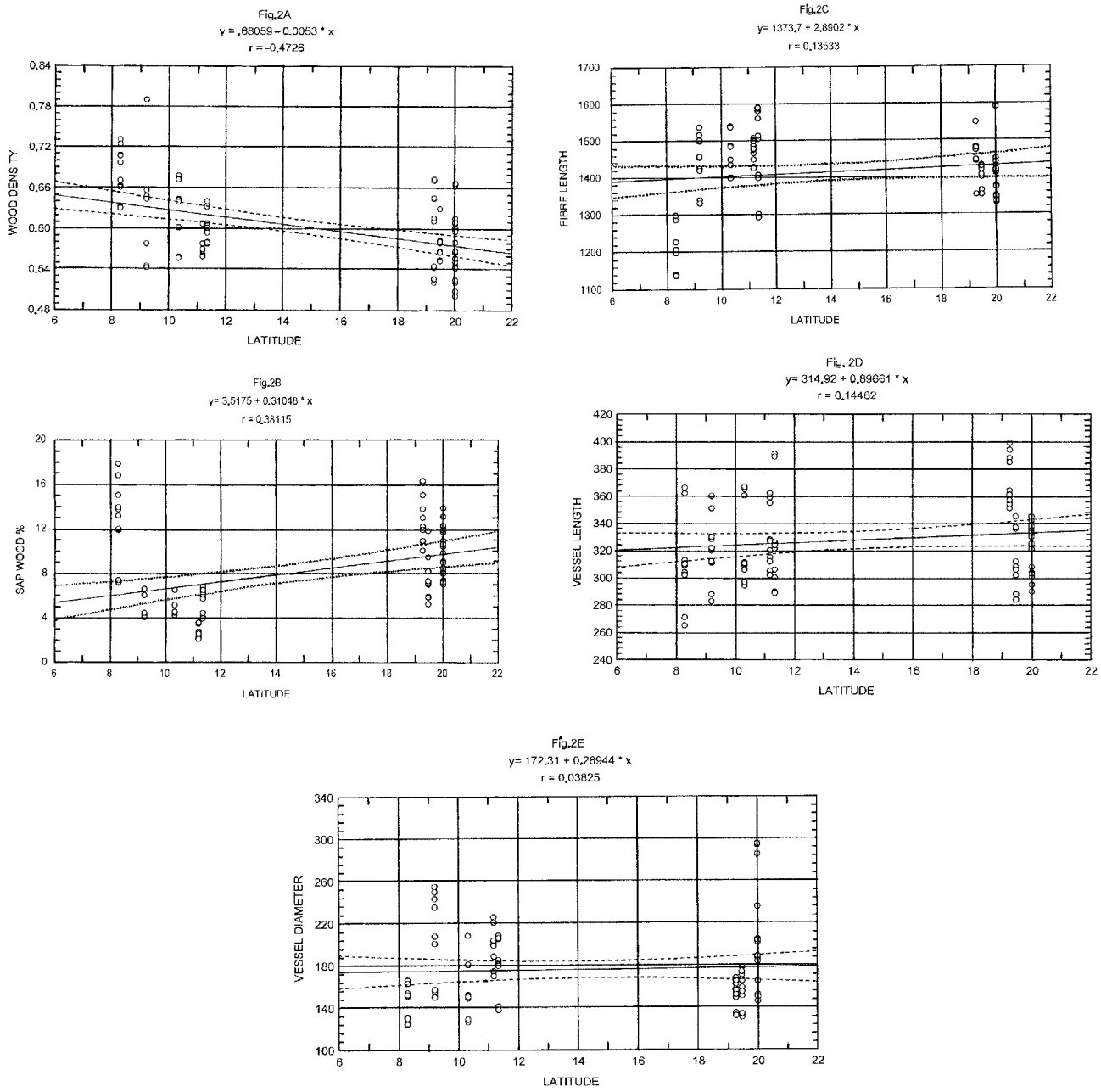


Fig. 2. – Relationship of latitude with (2A) wood density (g/cm^3), (2B) sapwood percentage, (2C) fibre length (µm), (2D) vessel element length (µm) and (2E) vessel diameter (µm) of teak in Peninsular India.

tions of Nasik, Chandrapur and Allapally had high sapwood content compared to the very moist (Nilambur and Konni) and moist (Topslip) populations. Sapwood % showed significant negative correlation with both tree height and girth (*Table 4*). A regression of sapwood % on latitude of stand showed a positive trend (P = 0.002; r = 0.381); higher values with increasing latitude (*Fig. 2B*).

Fibre traits

Fibre traits were found to be uniform in all the populations studied. The only exception was Kalakkad natural population which had short fibres. Though the other fibre characteristics like lumen width and wall thickness were also slightly lower in the latter population, they were not significantly different in any of the populations. Fibre length did not show any relationship with latitude of tree stand (*Fig. 2C*).

Vessel dimensions

Vessel elements were significantly short in Chandrapur and Kalakkad populations and long in Allapally trees. The other stands did not differ significantly for this trait. Vessel diameter was also low in the Kalakkad population whereas it was significantly high in the Chandrapur stand. Konni and Nilambur populations had comparatively higher values though not significantly different from the Mudumalai trees with intermediate values. Vessel element length and vessel diameter were not influenced by latitude of tree stand (*Figs. 2D* and *E*).

Anatomical indices

Runkel ratio was high (1.01) for the Kalakkad trees. Other populations did not differ much for this parameter. F/V ratio was low in Kalakkad and Allapally populations whereas the other stands had comparatively uniform values.

Discussion

Growth rate and wood density

Total annual rainfall which is used to classify a category of teak forest is the most important factor influencing the growth of teak. Populations in very moist and moist regions had better growth compared to the inland regions receiving less rainfall. Physical and chemical properties of soil also influence the quality of plantation grown teak. Rate of growth may influence wood properties differently in various species. There may also be geographic trends in wood density variation for different species. Slow rate of growth is reported to be associated with reduced wood density in teak (BHAT *et al.*, 1987) and in other ring porous hard woods (FIELDING, 1967). However in a study like the present one where several environments and seed sources are involved, the relationship may not be that straightforward. PURKAYASTHA *et al.* (1973), in a study of four seedlots across two sites observed greater differences between locations in wood density and ring width than between seedlots. BHAT (1998) reported no significant difference in wood density between six geographically separated seedlots tested in a provenance trial in Kerala. A similar trend is observed in the present study where most of the sampled trees did not vary much in wood density.

The trees sampled at three locations namely Pandarkawda (16%), Nilambur and Nasik (7%) showed comparatively lower wood density. PURKAYASTHA and SATHYAMURTHY (1975) also observed lower wood density values for Nilambur grown trees than Topslip plantations. It is interesting to note that coppice origin trees at Kalakkad which were almost half the age of other sampled trees had the highest wood density indicating that once mature wood was formed wood density was less influenced by age. This observation is in line with the conclusion drawn by BHAT (1995) that wood density of 8 year old teak wood was only 5% lower to that of 50 year old trees. Thus latitude of the stand has greater influence on wood density than age of the tree or ecotype of the stand. An opposite trend in latitudinal variation of wood density was reported in *Larix laricina* (YANG and HAZENBERG, 1987). As there was no significant relationship between growth rate and wood density, this study does not reveal any annual precipitation influenced difference in wood density known to occur in pines (TROVATI and FERRAZ, 1984; ZOBEL *et al.*, 1960) and other conifers (SIDDIQUI *et al.*, 1989).

Differences in wood density observed between adjacent populations like Chandrapur and Pandarkawda could be the effect of edaphic factors as reported by PURKAYASTHA and SATHYAMURTHY (1975) or probably the interaction of several locality factors than the influence of a single factor like annual rainfall. Number of dry months and rainfall received in summer months is reported to influence wood density in Pines (TROVATI and FERRAZ, 1984; WILKES, 1989).

Bark thickness and sapwood content

Bark thickness and sapwood % are two traits that were different in Kalakkad population. These trees being of coppice origin were young and thin and had high sapwood content (14%). Nilambur and Konni trees of the very moist category in lower latitudes had greater girth and hence the lowest sapwood content. A similar correlation of increased heartwood volume with growth rate at 5 years and 8 years of age was reported in earlier studies in teak (BHAT, 1995; BHAT and INDIRA, 1997). Significant difference in heart wood percent, positively correlated to tree size, was reported between provenances of teak (KJAER *et al.*, 1999) with higher heart wood content in larger trees of superior provenances. This is in contrast to the observation in *Pinus sylvestris* that stand density has a greater influence than provenance and latitudinal transfer on heart wood content (FRIES, 1999).

Bark thickness varied within population and was found to increase with tree girth. Thus most of the trees sampled from the very moist regions had thick bark compared to the other regions. A similar increase in bark thickness with tree height was reported in rubber trees by BHAT *et al.* (1984). The Kalakkad trees of coppice origin were an exception which though quite small had comparatively thick bark. Differences in wood density and bark thickness were reported between seedlots sampled from wide geographical regions tested in multi locational provenance trials of teak (KJAER *et al.*, 1995).

Anatomical characteristics

Growth conditions and silvicultural practices like spacing and thinning generally influence the rate of tree growth which in turn influence the anatomical characteristics. Management of teak plantations in India follows a uniform practice of an initial spacing of 2 m x 2 m followed by two mechanical thinnings and then by two silvicultural thinnings. Teak is however reported to respond to cultural operations and fertiliser application only in younger stages with no significant improvement in volume increment in older plantations (BALAGOPALAN *et al.*, 1998). Edaphic characters mainly the parent material or the nature of underlying rocks from which soils are formed influence the quality and distribution of natural teak. In plantations, the physical and chemical properties of soil influence to a large extent tree growth and cell characteristics. Thus edpahic and climatic factors may have a greater impact on wood quality than cultural and silvicultural operations.

In general the younger Kalakkad trees had short and narrow fibres and vessel elements. Vessel dimensions varied between populations but did not show any consistent relationship with growth rate or category of teak forest. This trend is similar to the observation by RAO *et al.* (1966) that factors other than growth rate are of great importance in determining the proportion of tissues in teak.

Fibre traits were very stable and not influenced by either latitude, site or ecotype effects. Vessel dimensions on the other hand were more influenced by the individual edaphic effects than latitudinal or ecotype effect. BAMBER *et al.* (1982) observed such a trend in *Eucalyptus grandis* where fast growth affected the physiologically active cells but not the fibres that offer mechanical strength. The trend may differ with species as in *Leucaena leucocephala* (SHIOKURA *et al.*, 1985) where faster grown trees had longer fibres and vessel elements. Though not significantly different, the Kalakkad samples with high wood density had narrow fibre lumen and thick walls which is in agreement with an earlier observation (PURKAYASTHA *et al.*, 1972) that wall thickness was positively correlated with wood density in teak.

Fibre lumen and wall thickness may respond differently to the growing conditions as reported in four species of eucalypts (WILKES and ABBOTT, 1983) where larger trees had greater wall thickness, but not fibre diameter leading to greater Runkel ratios. No such consistent trend was observed in the present study. Plant groups with primitive features have low F/V ratio and the average dicotyledon has a ratio around 2.0 (CARLQUIST, 1988). Trees with specialised wood have higher values as reported in *Casuarina equisetifolia* (VARGHESE and SIVARAMAKRISHNA, 1996) and the higher values observed in teak may be an adaptation for long fibres.

Conclusion

Teak wood is fairly stable across different populations and locations and the properties are not altered to the extent reported in some hardwoods and conifers. Combined influence of edaphic and latitudinal factors on wood properties does not indicate any consistent ecotype effect. Wood density and heart wood content are higher in lower latitudes of Peninsular India. Site factors have an influence on wood density and heartwood content that are decisive in determining the utility of wood. Better growth seen in very moist climates in southern latitudes is associated with improved wood characteristics. Short rotation does not affect wood density drastically as it is mainly influenced by latitude of the site. Longer rotation fetches timber with higher proportion of heartwood which can also be improved with accelerated growth. Suitable packages can be developed to produce quality timber with more heartwood in the high rainfall moist regions in southern India.

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