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Variation in wood fibre traits among eight populations of *Dipterocarpus indicus* in Western Ghats, India

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Abstract

Wood elements and anatomical ratio of *Dipterocarpus indicus* were studied to evaluate variation among populations and to recommend for end selection. The variation of wood element [fibre length (FL), fibre diameter (FD), lumen diameter (LD), cell wall thickness (CWT), double wall thickness (DWT), and lumen volume (LV)] and anatomical ratio [fibre lumen area (FLA), slenderness ratio (SR) and runkel ratio (RR)] were investigated in a girth class of 100 - 120 cm among eight populations of *Dipterocarpus indicus* in Western Ghats, India. The study revealed a significant variations in FL (0.2426), FD (4.7019), LD (3.1689), CWT (2.7104), DWT and (5.4298) among populations. The variations in anatomical ratios were significant among populations except in case of LV. The causes of variations among populations in their wood traits were attributed to the site factors. The interaction between genetic makeup of wood traits combined with effects of edaphic, local and regional climatic conditions reflect the amount of variation among populations. The highest coefficient of variation (CV %) for FL, FD, CWT and DWT was recorded in population of Gundya whereas low coefficient of variation were recorded in the population of Makuta (FL), Devimane (FD, CWT and DWT), and Sampaje (LD). The wood of *Dipterocarpus indicus* was found undesirable for pulp wood but can be utilized for plywood timbers.

Key words

Anatomical ratio, *Dipterocarpus indicus*, Fibre properties, Locality factors, Population variation

Introduction

Western Ghats are among the major tropical evergreen forest regions in India that are characterized by the presence of many economically important plants. These plants are being used as timber, medicines, fodder, food and other purposes. Dipterocarp forests are dominant and major source of timber in the tropical forests of Southeast Asia. *Dipterocarpus indicus* is endemic to the Southern Western Ghats of India and found distributed in the tropical lowland forest areas of Karnataka, Kerala and Tamil Nadu. In Karnataka, the tree species are abundant in the wet evergreen forest of Coorg, Hassan, Uttara Kannada, Dakshina Kannada, Chikmagalore and Shimoga (Ravikumar et al., 2000). At present the dipterocarp dominates the international tropical timber market due to its wood quality. Tree to tree variability is especially wide, with difference within species, often being strongly influenced by plant's genetic and environmental factors (Zobel and Van Buijtenen, 1989). A difference in environmental condition can result in the production of wood with varying properties. Wood properties were influenced by a few physical and chemical soil properties (Moya and Perez, 2008). The physical and chemical soil properties are associated to the cell division and differentiation of cambial cells, and this interaction is influenced as well by environmental or ecological conditions (Aguilar-Rodriguez *et al.*, 2006).

The differences between populations in different traits are influenced by the latitude and total site factors as well as the ecotype of the stand (Varghese *et al*., 2000). Roque and Tomazello (2007) found that wood density parameters and fibre dimensions were related to growth rates. The minimum and mean wood density, cell wall thickness, fibre width and lumen diameter decreased with increase in growth rate. In addition, fibre length is directly connected to the strength of inter-fibre bonding and tear strength (Perez and Fauchon, 2003). Fibre length exhibited significant variation among

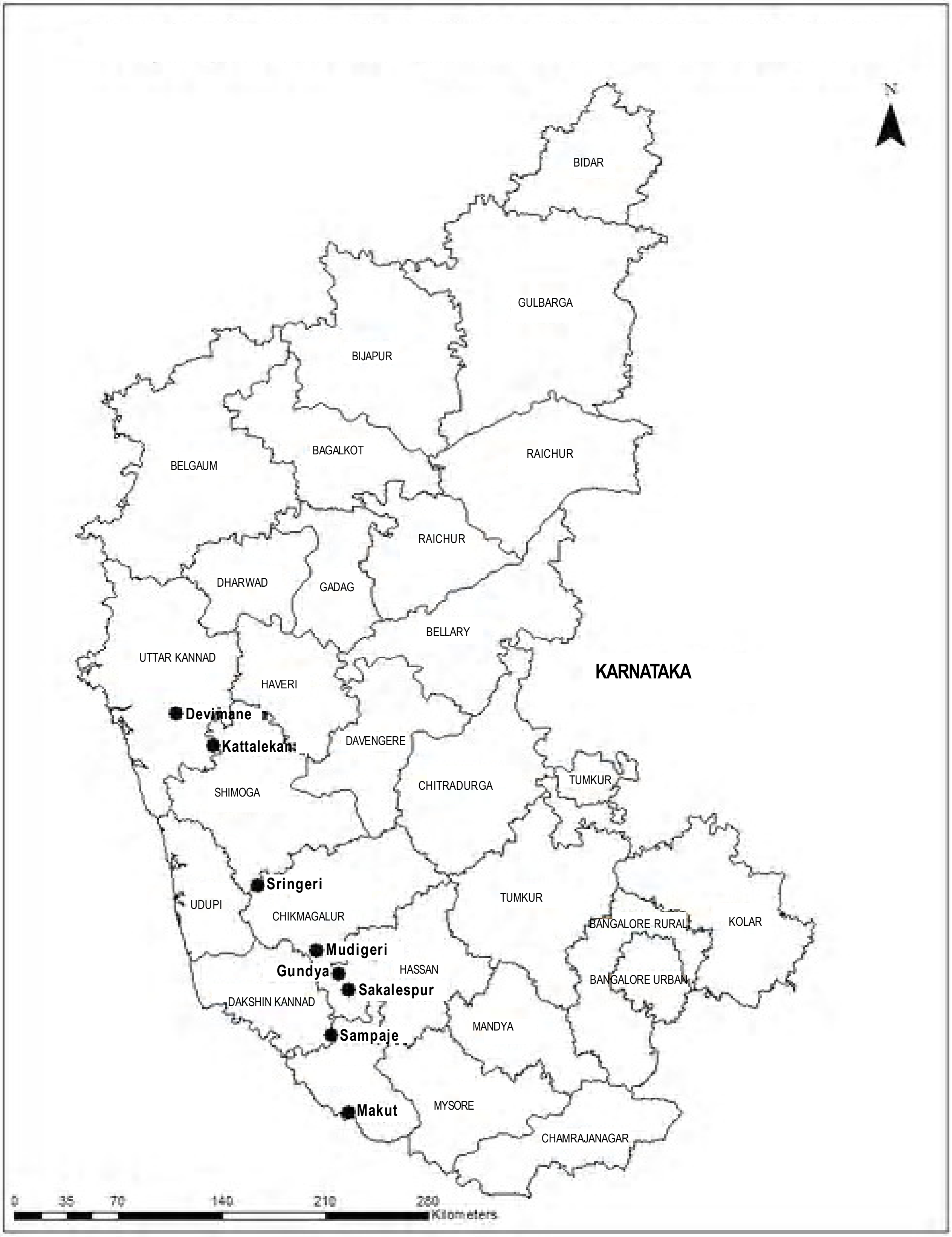

Fig. 1: Map of the study areas in Dipterocarp forests of Western Ghats, India, showing sampling locations (eight)

sites in juvenile *Pinus radiata*, strongest significant relationships with stem slenderness and average air temperature. The average air temperature is found to be the major environmental determinant of fibre length while soil fertility, phosphorus, total nitrogen and pH had little influence on fibre length (Watt *et al*., 2008). Juvenile wood is generally characterised by low density, thin cell walls, and short fibres with small lumens, high grain angle, and high fibre angle. These characters result in low strength and stiffness and poor dimensional stability compared to mature wood (Macdonald and Hubert, 2002). Watt *et al*. (2008) inferred that there was no effect of fertilization on fibre length despite the significant effects of this treatment on growth rate. It is reported that rotation age, especially juvenile and adult woods (Haygreen and Bowyer, 1994), growth accelerating treatments such as fertilization and irrigation have an effect on average fibre dimensional sizes in stem.

In view of high commercial value of wood, in the present study an attempt was made to know the variation among wood traits of individuals of *D. indicus* as influenced by environment and locality factors in different bioregions.

Materials and Methods

Study areas and analysis of soil: The present study was undertaken in eight sites within Western Ghats of Karnataka state in latitude range from 12° 10' N (Makuta) to 14° 57' N (Devimane) and longitude range from 74° 70' E (Devimane) to 75° 77' E (Sampaje). Gundya represented the lowest elevation (153 m a.m.s.l) while Mudigere was located at the highest elevation (846 m a.m.s.l) among the study sites. Sites average day temperature was between 34.10°C in Sringeri and 31.22°C in Makuta. The average rainfall recorded over a period of ten years (1998 -2008) was highest for Sampaje site (2575.98 mm) and lowest was at Kattalekan site (1976.52 mm). The study area fall under tropical climate with April – May being the hottest and December – January being the coldest periods and maximum rainfall during July – August months. The soil is lateritic, shallow to medium in depth and reddish brown to dark yellowish brown and in some places black in colour, usually leachable, poor in base saturation, cation exchange capacity and water holding capacity. Eight samples of soil were collected from each site for physico- chemical analysis. These soil samples were powdered and passed through 2 mm sieve for further analysis. For organic carbon and zinc, soil was passed through 0.2 mm sieve. The analysis carried out includes soil pH, available phosphorus, calcium and zinc (Jackson, 1973), organic matter (Walkley and Black, 1934), potassium, magnesium and sulphur (Page *et al*., 1982), total nitrogen (Subbaiah, 1956). The soil texture and percentage of clay, silt and sand were determined using hydrometer and pipette method.

Wood samples and measurements: Twenty four wood samples of *Dipterocarpus indicus* were collected from eight sites of Western Ghats, Karnataka, India (Fig. 1). The sampling sites covered the natural distribution range of the Dipterocarpaceae species. In each site, three trees were selected randomly within a girth class ranging from 100 to 120 cm. From each tree, with the help of Hagloff increment borer, one core sample was extracted at 1.37 m height and 15 cm depth inside tree's trunk. Wood cores were preserved in 5% formaldehyde. Wood cores were then chopped and macerated in standard jeffrey's solution (mixture of 10% of nitric acid and 10% of chromic acid) for 20 hrs (Pandey *et al.,* 1968). The samples were then rinsed three times with de-ionised water and stained with an aqueous solution of safranin. The stained macerated samples were mounted in 10% glycerine and observation under the microscope. Fibre length, fibre diameter, cell wall thickness and lumen area were measured with the help of image analyzer (Rasband, 1996). A minimum of 40 to 50 fibres were measured in each slide resulting in at least 1080 measured fibres for each population. Wood elements like fibre length (FL), fibre diameter (FD), lumen diemeter (LD), cell wall thickness (CWT), lumen volume (LV), double wall thickness (DWT) were measured. Anatomical ratio such as fibre lumen area (FLA), slenderness ratio (SR) and runkel ratio (RR) were calculated. The anatomical indices were calculated to assess wood quality and utilization using the formulae (Varghese *et al*., 2000; Hegde and Varghese, 2008; Rana *et al.*, 2009).

Statistical analysis: Analysis of variance (ANOVA) and Co-efficient of variance (CV) were calculated following the method of Panse and Sukhatme (1961). Pearson correlation coefficients were calculated between population means for the fibre traits and locality factors. Analysis of variance was carried out following the method of Williams and Matheson (1994). The FORTRAN software 5.4 and Microsoft Excel sheet were used to assess the critical differences (CD) among different geographical areas.

Results and Discussion

Variation of locality factors among populations: There was considerable variation in geography and climate gradient at different sites. Mean annual rainfall ranged from 2039.12 mm at Sakleshpura up to 2576.52 mm at Kattalekan. The altitude ranged from 153 m a.m.s.l (above main see level) at Gundya to 846 m a.m.s.l at Mudigere. There was a significant variation in humidity among sites (p= 0.000145), the annual average ranging from 83.75% at Mudigere to 93.75% at Sringeri. Temperature also showed significant variations among studied sites (p=0.00596). It ranged from 31.22°C at Makuta to 34.01°C at Sringeri. Though the soil texture in all the sites was sandy loam texture, considerable variations was observed in their physical properties as shown in Table 1. Rigatto *et al*. (2004) found that the wood quality was affected by soil chemical properties, while physical properties affecting the production of cellulose in *Pinus tadea*, as evidenced by the low wood density, short fibre, wide cellular wall, high contents of extractives and lignin, and low contents of cellulose. The possibility of significant climate change on a global scale is becoming increasingly apparent (Crowley, 2000). The lower and upper distributional limits, for example of long-lived, dominant tree along an elevation gradient are often determined by the combined effects of physiological tolerances and ecological constraints on that species. (Gworek *et al*., 2007). The variations in wood fibre properties among sites

Table - 1: Physico-chemical properties of soil from eight sampling sites of Dipterocarp populations in Western Ghats

Parameters	Makuta	Sakleshpura	Mudigere	Sringeri	Devimane	Kattalekan	Gundya	Sampaje
Sand %	67.90	73.97	96.97	68.13	68.90	69.13	70.97	74.97
Silt %	9.97	7.90	7.13	8.97	9.97	6.97	8.13	6.00
Clay %	22.13	18.13	22.90	23.90	21.13	24.90	20.90	19.03
pH	6.96	7.12	6.42	6.56	7.26	6.96	6.62	6.56
EC (DSm^{-1} at 25°C)	1.02	1.27	0.97	0.92	1.37	0.82	1.07	0.87
Organic carbon %	1.19	1.19	0.79	0.90	1.49	1.18	0.82	1.20
Nitrogen (kg ha^{-1})	593.80	565.80	495.80	523.80	665.80	583.80	554.80	656.80
Phosphors (kg ha^{-1})	144.80	122.80	103.80	99.80	152.80	109.80	123.80	153.80
Potassium (kg ha^{-1})	391.80	413.80	343.80	341.60	513.80	396.60	383.80	420.80
Sulphur (ppm)	16.24	16.54	14.54	14.84	18.64	15.64	13.57	16.57
Calcium (Cmol. (P+) kg^{-1})	6.55	5.85	6.85	6.25	8.25	6.35	7.85	8.80
Magnesium (Cmol. (P+) kg^{-1})	2.93	2.93	3.93	2.53	5.33	2.22	3.93	4.30
Zinc (ppm)	1.98	2.18	1.93	2.38	2.48	2.32	2.33	2.53
Copper (ppm)	1.62	2.12	1.72	2.32	2.32	2.10	2.02	2.47
Manganese (ppm)	33.60	32.50	30.20	34.32	36.50	29.96	36.00	32.00
Iron (ppm)	0.96	1.26	0.96	1.26	1.56	0.86	1.21	1.71

The study areas have soil with sandy loam structure

Table - 2: Performance of wood fibre parameters across locations in Girth range from 100 to 120 cm

Locations		FL (mm)	FD (µm)	LD (µm)	CWT (µm)	FLA (%)	LV $(µm)^3$	DWT (µm)	SR	RR
Devimane	M	1.67	25.48	7.16	9.16	28.05	109.60	18.32	65.50	2.64
	R	1.55-1.80	24.33-27.29	5.61-8.01	8.41-9.72	23.08-32.26	87.04-137.58	16.81-19.43	62.35-68.13	2.10-3.33
	CV	7.64	6.24	18.73	7.39	16.54	23.45	7.39	4.47	24.01
Kattalekan	M	1.74	26.67	4.37	11.15	16.43	83.72	22.30	66.33	5.17
	R	1.59-1.96	24.32-30.63	3.56-4.81	10.12-12.95	14.65-19.21	72.39-97.48	20.25-25.90	51.96-80.47	4.21-5.83
	CV	11.09	12.93	16.01	14.02	14.84	15.20	14.02	21.50	16.50
Mudigere	M	1.55	25.39	10.09	7.65	40.90	115.11	15.30	63.15	1.58
	R	1.46-1.73	20.52-28.53	8.48-11.12	4.93-10.03	29.73-51.97	90.86-130.77	9.85-20.05	50.99-84.32	0.92-2.36
	CV	9.98	16.86	13.98	33.55	27.20	18.50	33.55	29.14	46.29
Sringeri	M	1.74	21.90	9.25	6.33	41.73	97.11	12.65	80.47	1.53
	R	1.39-1.97	19.30-23.80	5.99-12.41	5.07-7.23	31.01-54.91	78.63-124.75	10.19-14.46	61.55-102.23	0.82"2.23
	CV	17.63	10.64	34.75	17.45	29.09	25.11	17.45	25.46	45.84
Gundya	M	1.21	29.73	13.46	8.13	46.90	135.39	16.26	41.21	1.23
	R	1.01-1.36	23.83-36.78	12.47-14.91	5.40-12.15	33.90-54.64	70.95-206.08	10.81-24.31	36.98-44.34	0.83-1.95
	CV	15.03	22.03	9.50	43.73	24.14	50.06	43.73	9.22	15.52
Sakleshpura	M	1.61	24.98	11.56	6.71	46.29	124.63	13.42	64.49	1.17
	R	1.56-1.67	23.62-26.7	10.31-12.45	6.05-7.42	43.64-50.7	106.726-141.70	12.11-14.85	59.84-67.7	0.97-1.29
	CV	3.41	76.46	9.65	10.25	18.32	14.04	10.25	96.43	14.77
Makuta	M	1.67	32.15	9.11	11.52	28.41	175.13	23.03	52.49	2.56
	R	1.62-1.7	29.23"35.49	7.85-10.32	10.69-13.16	25.82-32.55	43.93-195.11	21.39-26.33	5.58"58.67	2.07-2.87
	CV	23.00	9.80	13.59	12.39	12.77	15.63	12.39	12.53	16.68
Sampaje	M	1.71	22.74	10.78	5.98	47.54	113.03	11.95	74.90	1.11
	R	1.42"1.85	19.99"25.17	9.92-11.80	5.04"6.68	46.11-49.61	70.69-146.18	10.07-13.36	70.80-80.25	1.02-1.17
	CV	14.78	11.45	8.83	14.18	3.86	34.13	14.18	6.47	7.23
Grand Total	M	1.61	26.13	9.47	8.33	37.03	119.22	16.66	63.57	2.12
	R	1.01-1.97	19.3-36.776	3.56"14.91	4.93"13.16	4.65"54.91	70.69-206.08	9.85-26.33	36.98"102.23	0.82"5.83
	CV	10.32	12.05	15.63	19.12	17.09	24.52	19.12	14.40	27.73
CD	@0.05	0.2426*	4.7019*	3.1689*	2.7104*	13.4718*	NS	5.4298*	16.2175*	1.4945*
SED		0.1134	2.1972	1.4808	1.2666	6.2952		2.5331	7.5783	0.6984
P-Value		0.050362	0.0434	0.000	0.0096	0.0007		0.009	0.021	0.000

Critical differences (CD), Standard error of difference (SED), P-value at 0.05, Means (M), Range (R), Coefficient of variance (CV%), Fiber length (FL), Fiber diameter (FD), Lumen diameter (LD), Cell wall thickness (CWT), Fiber lumen area (FLA), Lumen volume (LV), Double wall thickness (DWT), Slenderness ratio (SR), Runkel ratio (RR).

Table - 3: Correlation matrix for wood properties with geoclimatic factors of *Dipterocarpus indicus* in girth classes 100 -120 cm

Fibre parameters	Latitude	Longitude	Altitude	Rainfall	Temperature
FL	-0.570*	-0.305	-0.548*	0.637*	0.485*
FD	-0.535*	0.214	-0.226	-0.190	-0.369
LD	-0.613*	0.706*	-0.452*	0.694*	-0.295
CWT	0.155	-0.227	0.068	-0.241	-0.147
FLA	-0.482*	0.568*	-0.291	0.559*	-0.097
LV	-0.518*	0.450*	-0.253	0.489*	-0.386
DWT	0.155	-0.227	0.068	-0.241	-0.147
SR	0.224	-0.292	0.364	-0.246	0.395
RR	0.553*	-0.588*	0.257	-0.630*	0.095

* Significant association @ 0.05 P level, r= ± 0.404

could be attributed to physical and chemical properties of soil, variation in growth rate and geoclimatic factor. It was evident that, increased clay percentage reduces the fibre diameter as observed in core samples extracted from populations of Sringeri and Kattalekan. Varghese *et al.* (2000) reported that physical and chemical properties of soil influence to a large extent tree growth and cell characteristics. Thus edaphic and climatic factors may have a greater impact on wood quality than cultural and silvicultural operations.

Variation in wood traits among populations: Wood elements showed significant variation among wood core samples collected from different populations except in the case of lumen volume as shown in Table 2. The cores collected from the populations of Makuta had the maximum mean value of FD (32.15 µm), CWT (11.52 µm), LV (175.13 µm) and DWT (23.03 µm) whereas the cores collected from the populations of Kattalekan and Gundya had the maximum mean values of FL (1.74 mm) and LD (13.46 µm), respectively. The minimum mean values of FL, FD, LD, CWT, and DWT were obtained from the core samples collected from the populations of Gundya (1.21 mm), Sringeri (21.90 µm), Kattalekan (4.37 µm) and Sampaje (5.98 and 11.95), respectively. The maximum variation (CV %) for wood elements was observed in the core samples collected from population of Gundya with 15.03% FL, 22.03% FD, 43.73% for CWT and DWT. The core samples of Sringeri had the highest variance in LD (34.75%). The minimum variation of FD,CWT and DWT were found in core samples obtained from the population of Devimane 6.24, 7.39 and 7.39%, respectively. Ram´irez *et al*., (2009) and Miranda *et al*., (2001) studied the chemical composition and wood anatomy of *Eucalyptus globulus* clones and found that there was no variation in fiber wall thickness and it remained constant in all the clones.

The maximum average value of FLA, SR and RR were observed in the core samples of Sampaje (47.54), Makuta (23.03) and Kattalekan (5.17) while it was minimum in sample of Kattalekan (16.43), Gundya (41.21) and Sampaje populations (1.11). The maximum coefficient of variation (CV) in FLA and SR was found to be 27.20% and 29.14% in population of Mudigere and minimum of 3.86% and 7.23% was observed in wood cores of Sampaje .

The FL was positively correlated with rainfall (r=-0.637), temperature (r=-0.485), sulphur (r=0.42) and SR (r=0.764). However, FL was negatively correlated with latitude (r=-0.570), altitude (r=-0.548), LD (r=-0.551) and FLA (r=-0.420). The FD was positively correlated with CWT (r=0.813), LV(r=0.825) and CWT (r= 813). The negative relationships of FD were found to be with available copper (r=0.550) and SR (r=-0.769). The LD positively correlated with FLA (r=0.877) and negatively with latitude (r=-0.613), altitude (r=-0.452), clay (r=-0.579), organic carbon (r=-0.442), CWT (r=-0.504), DWT (r=-0.504) and RR (r=-0.869). The CWT was negatively correlated with copper (r=-0.440), iron (r=-0.484), FLA (r=-0.844) and SR (r=-0.439) and positive correlation with LV (r=0.504), DWT (r=1.00) and RR (r=0.736). The LV was negatively associated with latitude (r=-0.518) and availability of copper (r=-0.429), SR (r=-0.499) and positively with longitude (r=0.450), rainfall (r=0.489) and DWT(r=0.504). The DWT was negatively correlated with copper (r=-0.440), iron (r=-0.484) and SR (r=-0.439) and positively with RR (r=0.736). The FLA was negatively correlated with clay (r=-0.56), pH (r=-0.451), FL (r=-0420), CWT (r=-844) and organic carbon (r=-0.406) and positively with iron (r=0.407) and LD (r=0.877). The SR was positively correlated with copper (r=0.475), FL (r=0.764) and negatively with FD (r=-0.769), CWT (r=-0.439), LV (r=-0.499) and DWT (r=-0.439). The RR was negatively correlated with LD (r=-0.896) and FLA (r=-0.926) and positively correlated with CWT (r=0.736) and DWT (r=0.736) as shown in Tables 3,4 and 5.

Wood elements like fibre length, fibre diameter, lumen diameter, cell wall thickness, lumen volumetric and double wall thickness are important parameters to be considered for improving pulp wood quality. Makinen *et al.* (2002) found a significant negative correlation of latitude and altitude on fibre length found in conifers. Watt *et al.* (2008) stated that fibre exhibited significant variation between sites in *Pinus radiata*. Many studies report significant variation in fibre length between different geographical localities often as a function of latitude and altitude.

The strongest environmental determinant was found to be mean annual temperature which exhibited a significant positive relationship with fibre length. The strong positive relationship between stem slenderness and fibre length was evident in Table 5. This could be resulted from the strong competition for light and nutrients. Watt *et al.* (2008) reported that the relationship between fibre length and stem slenderness may therefore be an adaptation to ensure

Table - 4: Correlation matrix for wood properties of *Dipterocarpus indicus* with soil properties in girth classes 100-120 cm

Soil properties	FL (mm)	FD (μm)	LD (μm)	CWT (μm)	LV $(\mu m)^3$	DWT (μm)	FLA (%)	SR	RR
Sand %	-0.131	-0.135	0.206	-0.238	-0.051	-0.238	0.268	0.013	-0.276
Silt %	0.015	0.301	-0.099	0.319	0.307	0.319	-0.249	-0.187	0.044
Clay %	0.179	-0.664*	-0.579*	0.394	-0.235	0.394	-0.555*	0.093	0.613*
pH	0.191	0.187	-0.374	0.381	0.070	0.381	-0.451*	-0.081	0.396
EC (DSm^{-1} at 25°C)	-0.157	0.085	0.174	-0.028	0.170	-0.028	0.087	-0.193	-0.240
Organic carbon %	0.385	-0.706*	-0.442*	0.253	-0.008	0.253	-0.406*	0.159	0.341
Nitrogen (kg ha^{-1})	0.221	-0.003	-0.227	0.130	0.026	0.130	-0.207	0.081	0.163
Phosphors (kg ha^{-1})	0.061	0.165	0.058	0.110	0.297	0.110	-0.019	-0.113	-0.104
Potassium (kg ha^{-1})	0.112	0.011	-0.232	0.145	-0.015	0.145	-0.238	-0.009	0.162
Sulphur (ppm)	0.421*	-0.116	-0.380	0.122	-0.017	0.122	-0.296	0.253	0.183
Calcium (Cmol. (P+) kg^{-1})	-0.163	-0.067	0.173	-0.160	-0.002	-0.160	0.189	-0.056	-0.229
Magnesium (Cmol. (P+) kg^{-1})	-0.194	-0.061	0.202	-0.171	0.050	-0.171	0.201	-0.098	-0.331
Zinc (ppm)	0.098	-0.372	-0.100	-0.264	-0.359	-0.264	0.063	0.299	0.010
Copper (ppm)	0.204	-0.550*	-0.064	-0.440*	-0.429*	-0.440*	0.183	0.475*	-0.113
Manganese (ppm)	-0.274	0.139	0.280	-0.043	0.207	-0.043	0.159	-0.235	-0.306
Iron (ppm)	0.058	-0.385	0.257	-0.484*	-0.093	-0.484*	0.407*	0.276	-0.473*

*Significant association at 0.05 P level, r= ± 0.404, Fibre length (FL), Fiber diameter (FD), Lumen diameter (LD), Cell wall thickness (CWT), Fiber lumen area (FLA), Lumen volume (LV), Double wall thickness (DWT), Slenderness ratio (SR), Runkel ratio (RR)

Table - 5: Correlation matrix for wood properties of *Dipterocarpus indicus* in girth classes 100 -120 cm

	FL	FD	LD	CWT	FLA	LV	DWT	SLR	RR
FL	1								
FD	-0.219	1							
LD	-0.551*	0.093	1						
CWT	0.132	0.813*	-0.504*	1					
FLA	-0.420*	-0.383	0.877	-0.844*	1				
Lv	0.012	0.825*	0.362	0.504*	-0.060	1			
DWT	0.132	0.813*	-0.504*	1.000*	-0.844*	0.504*	1		
SR	0.764*	-0.769*	-0.390	-0.439*	-0.007	-0.499*	-0.439*	1	
RR	0.358	0.263	-0.869*	0.736*	-0.926*	-0.150	0.736*	0.031	1

* Significant association at 0.05 P level, r= ± 0.404, Fibre length (FL), Fiber diameter (FD), Lumen diameter (LD), Cell wall thickness (CWT), Fiber lumen area (FLA), Lumen volume (LV), Double wall thickness (DWT), Slenderness ratio (SR), Runkel ratio (RR)

adequate water flow in slender trees where path length is high relative to the stem basal cross sectional area. The populations that have long fibre are preferred for pulp wood production. Hegde and Varghese (2008) reported that provenance or families with long fibre are suitable for pulp wood production. Interestingly, the values observed of FD, CWT, and DWT were much lower in Sringeri and Sampaje compared to other populations. This variation in wood elements could be attributed to the variation in environmental gradients. It was evident that FD negatively correlated with latitude and copper whereas CWT and DWT did not show any correlations with geoclimatic factors. Fibre diameter positively correlated with CWT, LV and DWT. Thus we can infer that wood elements are associated with each other. Furthermore, FL, FD, CWT and DWT have positive relationship with each other and negatively correlated with LD and the data are presented in Table 5.

The RR, SR and FLA influence the paper making properties of wood such as tensile strength, burst strength and resistance to tearing. High RR and low flexibility coefficient make poor quality pulp (Ververis *et al*. 2004). In the present study, all populations showed undesirable RR for pulp wood (>1) and slenderness ratio (>50). Hegde and Varghese (2008) studied the genetic of wood traits in *Eucalyptus camaldulensis* and found that few provenances showed desirable Runkel ratio (<1) coupled with high flexibility coefficient (> 0.5) and high slenderness (>50). Provenances like Ord river, Laura river and Setumadai can make good quality pulp. In this study, we found that the variation in wood elements and anatomical ratio of *Dipterocarpus indicus* among populations were not desirable for pulp wood but could be suitable for plywood. The populations of Sampaje and Sakleshpura had low RR and high SR with contrast to entire populations as shown in Table 2. The variation in RR may result from the variation in geo-climatic factors, which is negatively correlated with longitude and rainfall and positively correlated with latitude as shown in Table 3. It may be concluded that the variation in wood elements and anatomical ratio of *Dipterocarpus indicus* was significant in overall populations except in the case of LV. The causes of variations in wood fibre properties are attributed to the variation in environmental gradients among different populations. Less variation was found among the cores extracted from the populations of Sringeri, Sampaje and Sakleshpura compared to the rest of the populations. This study suggested that wood elements and anatomical ratio of *Dipterocarpus indicus* are the main traits to be considered in clone selection for wood quality improvement in natural populations. The study also revealed that this type of wood is undesirable for pulp making as evident from the anatomical ratio of wood properties. Therefore, we are suggesting that the wood of *Dipterocarpus indicus* can be best used for the manufacture of plywood.

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