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Geographic and Within Tree Variation for Wood Properties in *Acrocarpus fraxinifolius* Wight and Arn. Populations

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The study was conducted to compare the wood parameters among nine populations of *Acrocarpus fraxinifolius* from Southern Karnataka. To understand the variation, three trees from each population were selected and different wood properties, viz., bark-thickness, wood density, specific gravity, fibre parameters and vessel parameters, were analysed. The basic wood density of species was ranged between 0.370 $g \cdot cc^{-1}$ to 0.580 $g \cdot cc^{-1}$. There was a significant difference in fibre length across the populations, with an average fibre length of 1225.49 µm. There was not much difference in fibre width, fibre lumen width and fibre wall thickness. Vessel parameters, except vessel wall thickness varied among the populations. The vessel length varied from 104.78 µm to 124.71 µm. The wood traits varied among the radial portion i.e., from pith to periphery region. Considering the important wood traits, Shreemangala and Balehonnuru populations were found to be better compared to other populations.

Keywords: Pink cedar, Radial variation, Species, Trees, Wood parameter

Introduction

Pink cedar (*Acrocarpus fraxinifolius*) is one of the commercially imperative fast-growing timber yielding tree species belonging to family Fabaceae, which is only one species under genera *Acrocarpus.* It is naturally dispersed in high rainfall ranges in the evergreen forests of Western Ghats, Sikkim, West Bengal and Assam. It is mostly cultivated in Kodagu, Dakshina Kannada and Chikamagaluru as shade-tree in coffee estates.[1–3] Pink cedar, as the name suggests, the heartwood is pinkish and it is also called as Belanji and Havalige (Kannada), Mandane (Bengali), Nelarai (Tamil), Kurangadi (Malayalam), etc. in different parts of the country.[2] Belanji is the most adapted tree species for shade purposes in the coffee plantation among the diverse native shade trees like *Dalbergia*, *Syzygium*, *Lagerstroemia*, etc. with its multipurpose services such as erosion control, fodder, shade, green manure, exudate, fuelwood, etc.[4] It is used in making furniture, doors, windows, beams, rafters, etc. The wood is also used as raw material for pulp and paper making. The pulp is best suitable for Kraft paper.[5] Belanji was termed as the tree for the future because of its multipurpose utility and also recommended as one of the promising species for agroforestry in different parts of the country.[6]

The variability is broad within the species, often sturdily influenced by plant paternity and environmental factor.[2,7] Variation in the environment can result in the variation in wood quality with varying wood properties. The variation among the populations is mainly influenced by the latitude and total site factors.[8] Identification and exploitation of such natural variability is the easiest and faster way of accomplishing gain in forest tree improvement.[9] When the exception is more, there is scope for selection. The evaluation of variation in wood traits is necessary for the delineation of better provenances and the conceptualization of advanced breeding strategies.[10]

In this context, the present study efforts on the evaluation of variation in wood traits of *Acrocarpus fraxinifolius* from different locations of Sothern Karnataka. The literature on the wood properties of *A. fraxinifolius* is minimal when compared to the other monoculture tree species such as eucalyptus, casuarina, etc. The outcomes of the present investigation can be used as baseline data for future tree improvement programme of this species for different end uses with essential details regarding wood properties of the species.

Materials and Methods

Nine populations of *Acrocarpus fraxinifolius* (possibly of local source) located in the coffee-based agro forestry systems of Southern Karnataka were

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selected for study (Fig. 1). The populations were classified based on the moisture content.[8] Populations from Bhagamandala and Totadagadde belonged to the very moist category. Three populations from Mudigere, Shreemangala, Sakleshpura and Vanaguru were classified as moist and remaining populations were considered as slightly moist populations (Table 1). In order to avoid the variation in wood traits as influenced by the age, three trees were selected randomly from each populations falling in the GBH between 120 cm to 150 cm.

Bark thickness of the selected trees was measured at breast height level by using Swedish bark gauge. The wood core samples were collected with the help Pressler's increment borer by inserting up to half of the diameter at the breast height level (Fig. 2a). The collected samples were transported as such in sealed containers to the laboratory for assessment of wood

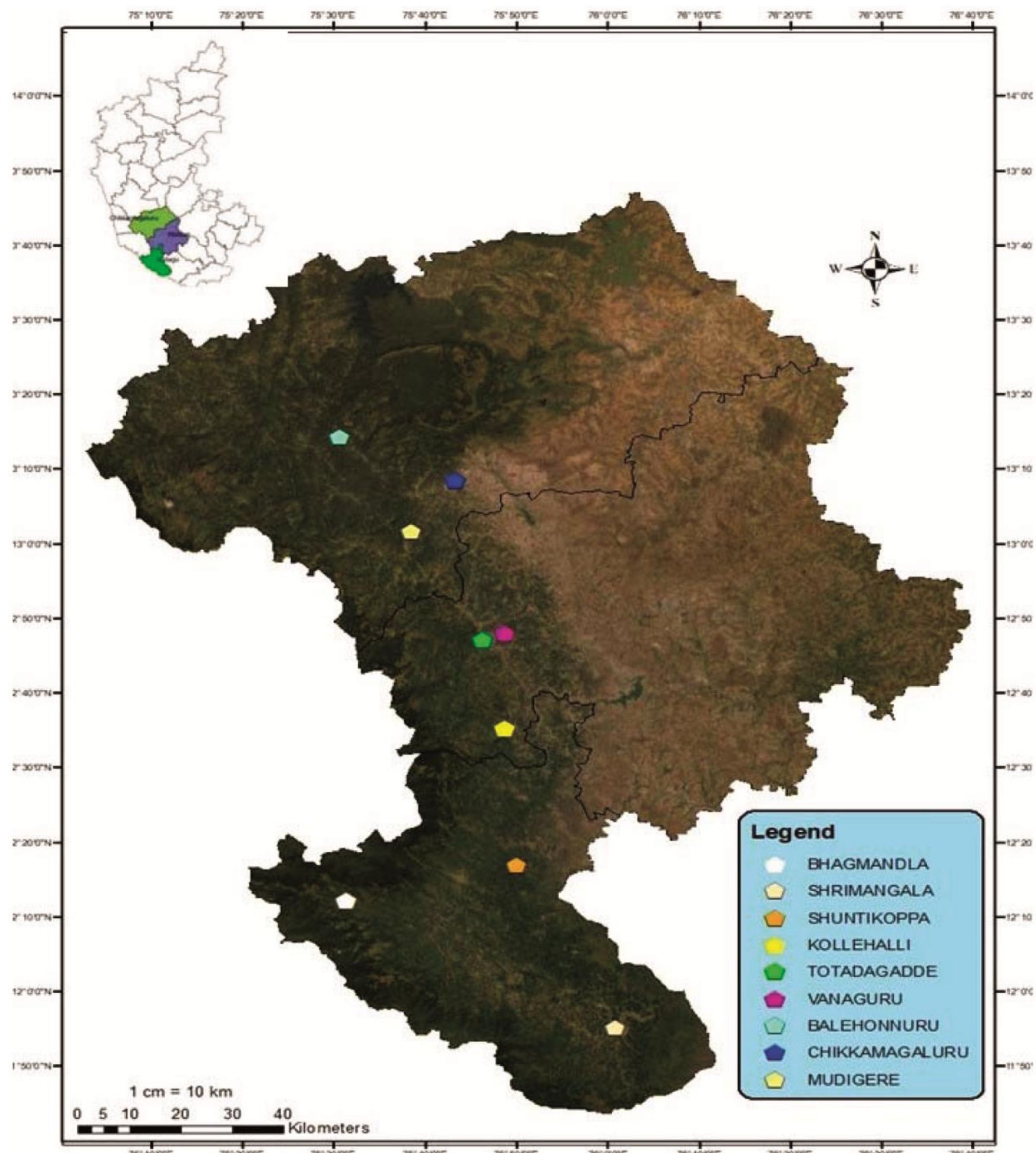

Fig. 1 — Map showing locations of *Acrocarpus fraxinifolius populations*

parameters (Fig. 2b). Core samples divided into three parts along the radial portion representing periphery, middle and near to pith, and the same was used for estimating the wood traits.

Basic wood density was estimated on an oven-dry basis. The specific gravity of the core samples was determined by the maximum moisture content method.[11] Maceration was done by using Jeffrey's

Table 1 — Geographic and climatic details of the Belanji populations studied

Rainfall zone	Populations	Latitude (ºN)	Longitude (ºE)	Altitude (m)	MAR (mm)
Very moist	Bhagamandala	12º23'	75º31'	946	4255
	Totadagadde	12°47'	75°45'	929	3559
Moist	Vanaguru	12°56'	75°46'	932	2305
	Sakleshpura	12°57'	75°48'	945	2103
	Shreemangala	12°06'	76°00'	832	2086
	Mudigere	13º10'	75º39'	1030	2064
Slightly moist	Balehonnuru	13º22'	75º31'	727	1985
	Shuntikoppa	12°27'	75°50'	981	1659
	Chikamagaluru	13º16'	75º43'	1084	1705

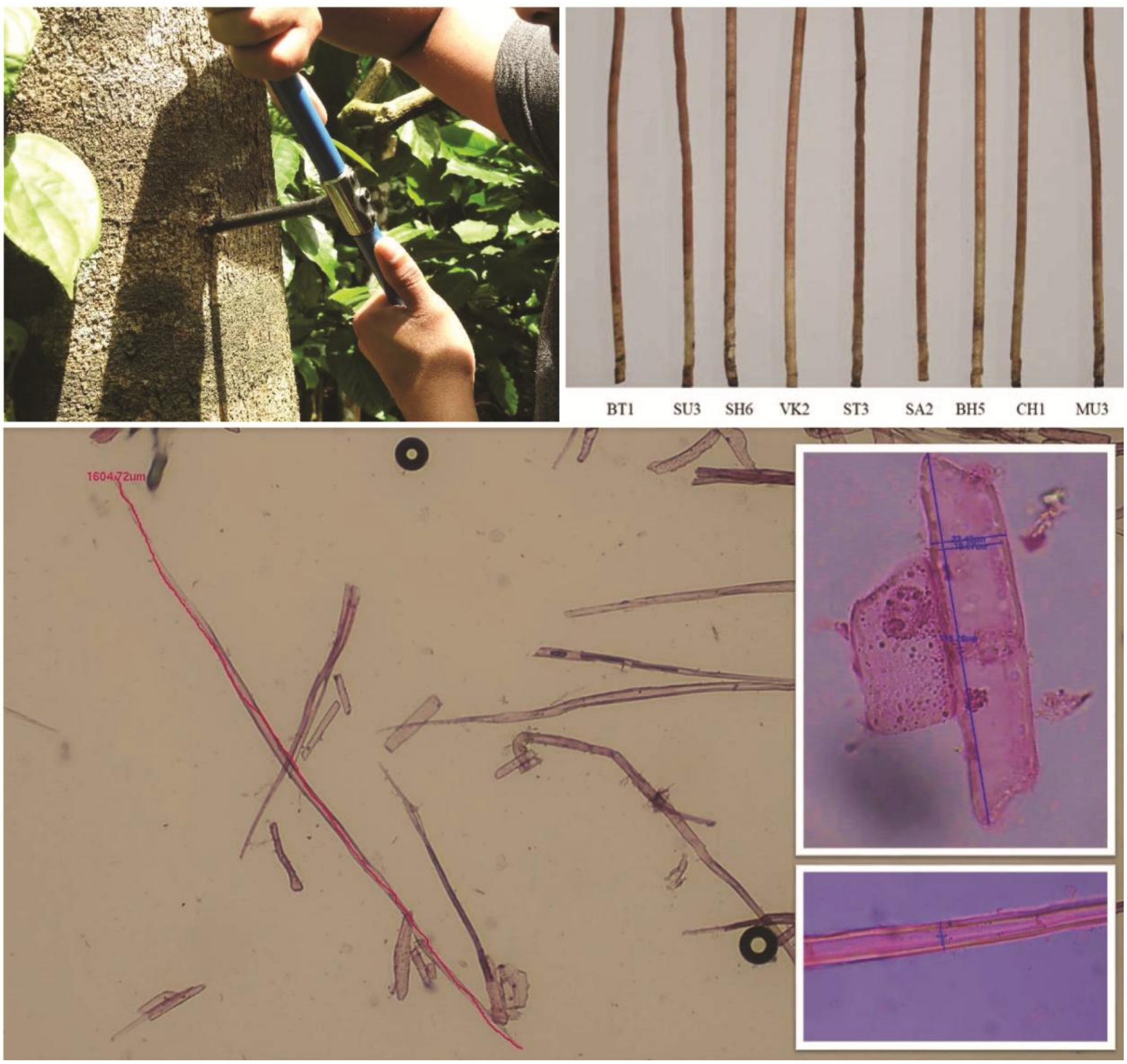

Fig. 2 — Glimpse of study; (a) collection of wood samples (b) wood core samples with tree identity (c) wood fibre and vessel parameters

solution.[12] Temporary slides prepared from macerated wood samples were used to observe under a stereomicroscope with inbuilt Image Analyzer. Fifty measurements on fibre parameters (Fig. 2) and fifteen measurements on vessel parameter were recorded for each samples. Observations recorded on wood traits were subjected to the Two-way ANOVA to understand the variation in wood traits among different populations and among the radial portions across the population as described by Panse and Sukhatme (1978)[(13)] using SPSS 16.0 software. To know the association between the different wood traits, Karl Pearson's correlation coefficient were estimated as per the standard method.[13] Hierarchical grouping and dendrogram was done by cluster analysis method of Average Linkage (between groups) with the measure of Squared Euclidean Distance using SPSS 16.0 software as suggested by Pande *et al*., (2013).[(14)]

Results and Discussion

Variation in Wood Traits across the Populations

The wood parameters studied across the population showed a considerable variation from different rainfall zones (Table 2). The mean annual rainfall and total site factors are always considered as the most crucial elements influencing the growth and wood parameters. The bark thickness varied significantly across the populations. Highest bark thickness was recorded in Vanaguru population (0.86 cm) and lowest was recorded in Shreemangala population (0.66 cm). Such site-to-site variation in bark thickness was reported in *Dipterocarpus indicus* populations[15], where the less moist areas had lower bark thickness. The provenance effect on wood density and specific gravity was not found to be significant. The mean basic wood density values ranged from 0.460 $g{\cdot}cc^{-1}$ (Bhagamandala) to 0.513 $g{\cdot}cc^{-1}$ (Balehonnuru). Among nine populations, maximum specific gravity was recorded in Balehonnuru population (0.513) followed by Mudigere (0.507), Vanaguru (0.498), Chikamagaluru (0.491), Shuntikoppa (0.481), Shreemangala (0.474), Sakleshpura (0.473), Totadagadde (0.471) and the minimum was observed in Bhagamandala population (0.468). It is evident from the earlier studies that the wood density is mainly controlled by rainfall and the altitude in additional to other site factors. Though values for basic wood density and specific gravity were not significant, it was marked that higher rainfall regions had low density than the low moist regions. Similar findings were reported in *Acacia melanoxylon* of Portugal, in *Tectona grandis* and *Melia dubia*.[16]

Mean values of wood fibre and vessel traits are depicted in Table 2. Significant population variation was noticed for fibre parameters *viz.*, Fibre Length (FL), Fibre Lumen Width (FLW), Fibre Wall Thickness (FWT) except Fibre Width (FW). The average FL of populations varied significantly between 1141.15 µm (Vanaguru) and 1348.14 µm (Shreemangala). The fibre length reduced with increasing rainfall. Yang *et al.*, (2009)[(10)] reported a reduction in fibre length from a higher elevation to lower elevation. The highest value for FW was recorded in Bhagamandala (21.54 µm), followed by Totadagadde (20.84 µm), Shuntikoppa (20.74 µm), Sakleshpura (20.64 µm), Balehonnuru (20.03 µm), Vanaguru (19.87 µm), Shreemangala (19.77 µm), Chikamagaluru (19.27 µm), and Mudigere (19.13) populations. FWT found to be significant across the populations, ranged from 3.09 µm (Chikamagaluru) to 4.16 µm (Shreemangala). Fibre wall thickness was

Table 2 — Variation in wood traits across the populations

Populations	Bark thickness (cm)	Basic wood density ($g{\cdot}cc^{-1}$)	Specific gravity	Fibre length (µm)	Fibre width (µm)	Fibre lumen width (µm)	Fibre wall thickness (µm)	Vessel length (µm)	Vessel width (µm)	Vessel lumen width (µm)	Vessel wall thickness (µm)
Shreemangala	0.66^{a}	0.484^{ab}	0.474^{ab}	1348.14^{d}	19.77^{ab}	11.45^{a}	4.16^{c}	121.25^{b}	32.18^{bc}	27.65^{cd}	2.27^{a}
Shuntikoppa	0.71^{ab}	0.476^{ab}	0.481^{ab}	1216.34^{abc}	20.74^{ab}	13.76^{cd}	3.49^{ab}	114.66^{ab}	26.17^{a}	21.33^{ab}	2.42^{ab}
Bhagamandala	0.77^{abc}	0.460^{a}	0.468^{a}	1167.39^{ab}	21.54^{b}	14.06^{d}	3.74^{bc}	124.71^{b}	28.65^{ab}	24.16^{bc}	2.24^{a}
Chikamagaluru	0.80^{bcd}	0.491^{ab}	0.491^{ab}	1209.83^{abc}	19.27^{a}	12.20^{abcd}	3.09^{a}	113.24^{ab}	29.77^{bc}	25.32^{cd}	2.22^{a}
Balehonnuru	0.80^{cd}	0.513^{b}	0.513^{b}	1289.20^{cd}	20.03^{ab}	12.10^{abc}	3.96^{bc}	113.12^{ab}	25.97^{a}	19.73^{a}	2.56^{b}
Mudigere	0.82^{cd}	0.507^{b}	0.507^{b}	1242.62^{bc}	19.13^{a}	11.76^{ab}	3.52^{ab}	104.78^{a}	30.99^{bc}	26.35^{cd}	2.32^{ab}
Sakleshpura	0.87^{d}	0.471^{ab}	0.473^{ab}	1205.17^{ab}	20.64^{ab}	12.64^{abcd}	4.00^{bc}	121.74^{b}	33.33^{c}	28.71^{d}	2.31^{ab}
Totadagadde	0.83^{cd}	0.471^{ab}	0.471^{ab}	1209.31^{abc}	20.84^{ab}	13.39^{bcd}	3.73^{bc}	123.02^{b}	32.83^{c}	28.20^{d}	2.31^{ab}
Vanaguru	0.86^{d}	0.496^{ab}	0.498^{b}	1141.15^{a}	19.87^{ab}	12.32^{abcd}	3.77^{bc}	114.60^{ab}	31.60^{bc}	27.12^{cd}	2.24^{a}
Mean	0.79	0.485	0.486	1225.49	20.20	12.63	3.72	116.79	30.16	25.40	2.32
SEm (±)	0.03	0.014	0.014	25.67	0.57	0.58	0.19	3.66	1.19	1.16	0.08
CD (0.05)	0.08	NS	NS	72.78	NS	1.66	0.53	10.36	3.39	3.29	NS

Values sharing common alphabets do not differ significantly
NS = Not significant

supreme in the moist region than the very moist and slightly moist zones. The Shreemangala population exhibited greater fibre length, fibre lumen width and fibre wall thickness than other populations. The Bhagamandala population recorded the least fibre length, whereas fibre width and fibre lumen width were maximum. The results of the present study are supported by the findings in teak[8], where the fibre dimensions varied among the different rainfall zones. Pande *et al.*, (2013)[(14)] explain such variation in fibre traits among 24 populations of *Leucaena leucocephala* from Andra Pradesh, Tamil Nadu and Orissa. Except for Vessel Wall Thickness (VWT), all the vessel traits such as Vessel Length (VL), Vessel Width (VW) and Vessel Lumen Width (VLW) had shown significant variation across the populations. The vessel length varied significantly across the populations with the highest vessel length of 124.71 µm from the trees of Bhagamandala population and least vessel length was recorded from Mudigere (104.78 µm) population. The mean vessel parameters were highest in a very moist area. Sahoo *et al.*, (2017)[(17)] revealed a significant variation among the populations of *Artocarpus hirsutus* from the different agro-climatic zones of Kerala, where most of the vessel parameter were greater in Malayoram zone.

Variation in Wood Traits among the Radial Portions across the Population

To know the extent of variation in wood traits among the radial portions, mean value across the different populations were compared. Most of the traits showed an increasing trend from near to pith portion to periphery region (Table 3). The wood parameters vary in sapwood and heartwood based on the moisture content, extractive present, etc. The vessel and fibre parameters such as area and frequency chiefly affect the density of the wood. Basic wood density and specific gravity had shown a significant variation between the radial portions with highest value observed in the periphery portion (0.522 $g\cdot cc^{-1}$) and with least in near to pith portion (0.452 $g\cdot cc^{-1}$). Anoop *et al.*, (2014)[(18)] reported significant variation in wood density and specific gravity in the radial portion with an increasing pattern from pith to periphery due to its lesser vessel diameter and vessel area besides high vessel frequency.

Among the radial portions, FL and FWT were shown a significant variation, whereas the FW and FLW were not significant. The maximum average FL was recorded in the periphery (1339.99 µm) and lowest near to pith (1045.06 µm). Between the radial portions, the FWT showed a significant variation, maximum fibre wall thickness was recorded in the periphery (3.93 µm) and least was recorded near to pith (3.48 µm). Though the FW and FLW are not significant, values showed an increasing trend from near to pith portion to periphery region. Jahan *et al.*, (2019)[19] revealed such variation among the radial portions in *Acacia auriculiformis*.

The vessel parameters were stable across the radial portions and showed a non-significant variation except the vessel wall thickness. Maximum vessel length was recorded in the periphery (118.77 µm) and the lowest was recorded in the middle (113.20 µm) portion. The

Table 3 — Variation in wood traits among the radial portions across the populations

Parameters \ Portions	Periphery	Middle	Near to pith	Mean	CD (0.05)
BWD ($g\cdot cc^{-1}$)	0.522 ± 0.008^{c}	0.482 ± 0.008^{b}	0.452 ± 0.008^{a}	0.485	0.022
SG	0.524 ± 0.008^{c}	0.483 ± 0.008^{b}	0.451 ± 0.008^{a}	0.486	0.022
Fibre parameters (µm)					
FL	1339.99 ± 14.82^{c}	1291.41 ± 14.82^{b}	1045.06 ± 14.82^{a}	1225.49	42.02
FW	20.34 ± 0.33^{a}	20.12 ± 0.33^{a}	20.15 ± 0.33^{a}	20.20	NS
FLW	12.97 ± 0.34^{a}	12.44 ± 0.34^{a}	12.49 ± 0.34^{a}	12.632	NS
FWT	3.93 ± 0.11^{b}	3.75 ± 0.11^{ab}	3.48 ± 0.11^{a}	3.72	0.30
Vessel parameters (µm)					
VL	118.77 ± 2.11^{a}	113.20 ± 2.11^{a}	118.40 ± 2.11^{a}	116.79	NS
VW	30.86 ± 0.69^{a}	30.26 ± 0.69^{a}	29.38 ± 0.69^{a}	30.16	NS
VLW	25.89 ± 0.67^{a}	25.83 ± 0.67^{a}	24.47 ± 0.67^{a}	25.40	NS
VWT	2.30 ± 0.05^{a}	2.21 ± 0.05^{a}	2.45 ± 0.05^{b}	2.32	0.14

Values sharing common alphabets do not differ significantly
NS= Not significant
BWD = Basic Wood Density, SG = Specific Gravity, FL = Fibre Length, FW = Fibre width, FLW = Fibre Lumen Width, FWT = Fibre Wall Thickness, VL = Vessel Length, VW = Vessel Width, VLW = Vessel Lumen Width, VWT = Vessel Wall Thickness

Similar results were found in hybrid clones of *Populus deltoids*[20], *Artocarpus hirsutus* in different agro-climatic zones of Kerala.[17]

Relationship between Wood Traits

The correlation study gives the degree and magnitude of the relationships among the different traits. The study revealed a significant or non-significant relationship, either positive or negative, between the wood parameters (Table 4). Among the studied wood traits, basic wood density showed a significant positive association with the specific gravity (r = 0.971) and negatively correlated with fibre lumen width (r =−0.449). Wood density decreased with an increase in fibre lumen width. Fibre width showed a significant positive correlation with fibre lumen width (r = 0.904), fibre wall thickness (r = 0.588) and vessel length (r = 0.517). Fibre wall thickness and vessel length have shown a significant positive correlation (r = 0.576). Interestingly, the relationship between vessel lengths was positively correlated with fibre width and fibre wall thickness. Vessel width and vessel lumen width was positively correlated (r = 0.996). Similar observations were reported in *Bambusa chungii*[10], *Swietenia macrophylla*[18], *Dalbergia latifolia*[21], for different wood parameters with the weather parameters. Different authors stated that wood density is positively associated with specific gravity and negatively associated with moisture content. Fibre diameter and fibre lumen diameter are found to be positively associated.

Hierarchical Grouping

Data collected on wood traits from nine populations were subjected to Hierarchical cluster analysis to categorize populations based on the degree of similarity. Based on Squared Euclidean distances, nine populations were grouped into three clusters based on the wood properties that indicating, that the selected populations had sufficient amount of variability (Table 5). Cluster I had five populations (Sakleshpura, Totadagadde, Shuntikoppa, Chikamagaluru, Mudigere), followed by cluster II with two populations (Bhagamandala, Vanaguru) and cluster III with two populations (Shreemangala, Balehonnuru). The dendrogram (Fig. 3) was prepared using the Between—groups linkage method to reveal a

Table 4 — Pearson Correlations among the growth and wood traits

	BT	BWD	SG	FL	FW	FLW	FWT	VL	VW	VLW	VWT
BT	1										
BWD	0.291	1									
SG	0.305	0.971**	1								
FL	−0.261	0.185	0.048	1							
FW	−0.035	−0.310	-0.257	−0.195	1						
FLW	−0.124	−0.449*	−0.341	−0.364	0.904**	1					
FWT	0.153	0.135	0.053	0.240	0.588**	0.185	1				
VL	−0.144	−0.115	−0.116	0.010	0.517**	0.324	0.576**	1			
VW	0.210	−0.112	−0.167	−0.184	0.055	−0.080	0.279	0.357	1		
VLW	0.210	−0.128	−0.175	−0.207	0.061	−0.062	0.259	0.344	0.996**	1	
VWT	−0.058	0.204	0.132	0.315	−0.080	−0.184	0.167	0.072	−0.203	−0.288	1

** Correlation is significant at the 0.01 level (2—tailed)
* Correlation is significant at the 0.05 level (2—tailed)
BT = Bark thickness, BWD = Basic Wood Density, SG = specific gravity, FL = fibre length, FW = fibre width, FLW = fibre lumen width, FWT = fibre wall thickness, VL = vessel length, VW = vessel width, VLW = vessel lumen width, VWT =vessel wall thickness

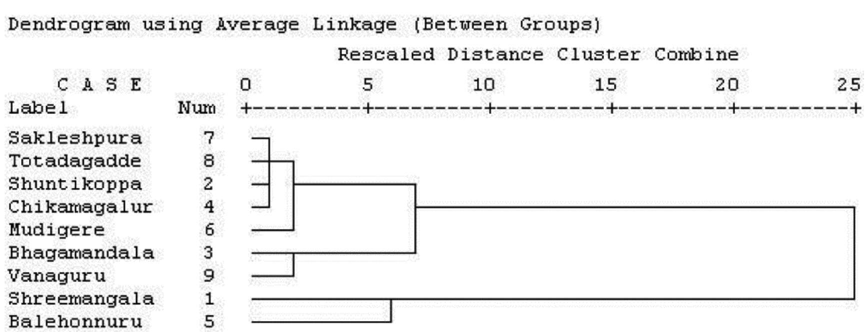

Fig. 3 — Dendrogram showing clusters of selected populations

Table 5 — Population composition of different clusters

Cluster number	No. of populations	Populations
I	5	Sakleshpura, Totadagadde, Shuntikoppa, Chikamagaluru, Mudigere
II	2	Bhagamandala, Vanaguru
III	2	Shreemangala, Balehonnuru

similar pattern of information. Similar pattern of classification and pattern of genetic divergence was revealed by Pande *et al*., (2013)[14] in *Leucaena leucocephala*, where 24 populations were clustered into six groups.

Conclusions

Complete knowledge of geographic variation within a species is essential for developing effective tree improvement programmes. It gives an idea about the species range, amount of diversity encountered within the species in its natural range and also its pattern of variation. In anatomical properties, the variation is related to age as well as locality factor. Based on the variation studied, further selection can be made for identifying superior genotypes for mass multiplication and in the future breeding program. Considering the vital wood traits, Shreemangala and Balehonnuru populations were found to be better compared to other populations and future selections (candidate plus trees) could be made from these populations.

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