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Genetic Diversity and Conservation of Teak-Phase-II

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Kerala Forest Research Institute
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(Final Report of the Project KFRI RP 614/2011)

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ABSTRACT OF THE PROJECT PROPOSAL

a. Project number : KFRI RP 614/ '11

b. Title : Genetic Diversity and Conservation of Teak -Phase II

c. Funding agency : KFRI Plan Fund

d. Duration : July 2011 - June 2012 (1 year)

e. Objectives:

1. to study the genetic diversity with respect to growth and form characters
2. to evaluate the anatomical properties of wood from different ecotypes

f. Investigators : E. P. Indira

P. K. Thulasidas

g. Expected outputs:

- Data on genetic variations in growth, photosynthetic competence and other related characters.
- Information on variations with regard to wood properties in different provenances of teak in India.

ACKNOWLEDGEMENTS

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ABSTRACT

The present project evaluated the genetic diversity in twenty five ecotypes of teak (*Tectona grandis* L.f.) originated from ten natural teak growing States in India (Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Chattisgarh and Orissa) with respect to growth and branch characters. Variability of wood characteristics of 23 Indian teak provenances collected from these 10 States under varied ecological and climatic conditions were studied. These 23 provenances belongs to five age classes, viz., age class I (up to 24 yrs); II (25-34 yrs); III (35-44 yrs); IV (45-54 yrs) and V (55 yrs and above).

Taking in to consideration all the growth and branch characters, best cluster comprises of Konni, Arienkavu (Kerala) and Hudsa (Karnataka) followed by another group containing Mandagadde (Karnataka), Nilambur (Kerala) and Berbera (Orissa). Parambikulam, Tholpetty and Vazhani (Kerala), Asambu (Tamil Nadu), Doddaharve (Karnataka), Adilabad (Andhra Pradesh), Pench Tiger Reserve and Allapalli (Maharashtra) and Basthar (Chhattisgarh) form another cluster with moderate performance. All other North Indian provenances along with Chinnar (Kerala) and Bhadrachalam (Andhra Pradesh) form another cluster with poor performance.

The estimated genetic parameters show high phenotypic and genotypic coefficient of variation and moderate heritability for height, basal girth, number of branches and branch angle. But branch girth has low heritability and genotypic coefficient of variation though it has high phenotypic coefficient of variation. If provenances are selected at 5% selection intensity, high genetic gain is expected except for branch girth.

Latitude has highly significant negative correlation with height, basal girth, number of branches and branch angle while rainfall has highly significant positive correlation with these characters. But latitude and rainfall have no significant relation with branch girth. Height, basal girth, number of branches, branch girth and branch angle have highly significant correlations with each other.

On evaluation of the wood anatomical properties, significant variations were noted between provenances. Higher growth rate was noted in trees grown in southern States like Kerala, Tamilnadu and Karnataka followed by Maharashtra, Gujarat and Andhra Pradesh.

Anatomical investigations of the provenances revealed the reasons for certain significant differences observed in physical properties of Khariar provenance (density 473 kg/m^3) in age class I as reported in Age class 1. The wood was lighter due to faster growth with a wide early wood band, larger vessels/percentage, low fibre percentage and thin walled fibres. However, the same provenance show maturity in density in subsequent age classes and the wood was not affected as evaluated by anatomy.

The present study of anatomical properties of 23 provenances showed significant variations among provenances within each age classes irrespective of the locations. The South Indian teak provenances showed superior wood quality traits as well as growth characteristics suitable for future genetic conservation programmes.

1. INTRODUCTION

Teak (*Tectona grandis* L.f.), belonging to family Verbenaceae, is one of the most important tropical hardwood species of high-quality timber in the international market. In India, teak is distributed naturally in the peninsular region below 25^{o} latitude over a wide range of climatic and geographic conditions. India has the richest genetic resources of teak in the world. Due to anthropogenic disturbances, the natural teak resources declined from 8.9 million ha from 1976-79 (Tewari, 1992) to 6.81 million ha in 2010 as per the recent study by FAO (Kollert and Cherubini, 2012). The total area under teak plantation in India is estimated to be about 1.667 million ha, of which major contribution comes from the States of Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka, Kerala, Tamilnadu, Chattisgarh, Gujarat, Tripura and Mizoram.

Different ecotypes have been evolved in teak since it occurs in different climatic and edaphic zones found over the entire range (Kedharnath and Matthews, 1962). The variations are seen in vigour, tree form, colour and shape of leaves, resistance to insect attack, wood colour, specific gravity, strength, durability and other characters. These may be morphological, physiological or genetical variations. Identification and exploitation of the existing genetic variations are the basic steps in genetic improvement programme. The Indian teak provenances were clearly differentiated from the rest of the world populations by several studies (Shrestha *et al*., 2005; Fofana *et al.,* 2008, 2009; Verhaegen *et al.,* 2010). A study on the genetic variation within and among 10 populations of teak from the Western Ghats and Central India regions showed 78% of variation existing within the population and the rest between populations (Nicodemus *et al.,* 2005). By using AFLP markers, Sreekanth *et al.* (2012) studied nine natural populations of Southern Western Ghats and found higher degree of within population gene diversity. Nilambur had separate identity among the South Indian populations. Similarly, Indira *et al.* (2010) studied 23 Indian provenances of natural teak populations from 10 Indian states to identify distinct and desirable populations for *in situ* and *ex situ* conservation of teak resources.

Teak is known to display wide variations in the wood characteristics among different growing conditions and regions in India (Bhat and Indira, 1997, Indira *et al.*, 2010). It exhibits geographic/provenance variations in the timber characteristics such as wood figure (colour, grain, texture) and also in anatomical and mechanical properties (Bhat and Priya, 2004; Kjaer *et al.,* 1999; Priya and Bhat, 1998, 1999). On evaluation of the physical properties of the wood samples, significant variations were noted between provenances (Indira *et al.*, 2010).

During the first phase of the present project (2005-2010), survey was conducted to all natural teak growing states in India except Manipur and seeds were collected (Indira *et al*, 2010). A provenance trial plot with 25 seed origins was established in Nilambur and was monitored for the early performance as a part of genetic evaluation. In addition, morphological variations of the trees in their original sites were evaluated and wood samples were collected from 23 provenances. Physical and anatomical properties of the wood discs collected were analysed during the first phase and report published (KFRI Research Report No. 384). For the successive evaluation of the provenances for genetic diversity and also for completing the wood anatomical studies of the increment core samples collected in the first phase, 2nd phase of the project was taken up with the following objectives.

1. to study the genetic diversity with respect to growth and form characters
2. to evaluate the anatomical properties of wood from different ecotypes

2. MATERIALS AND METHODS

2.1 Growth and branching pattern

During the first phase of this project (2005-2010), seeds were collected from 26 natural teak populations and wood samples (from 23 provenances) belonging to different states of India (Table 1). A provenance trial was also established at Nilambur, Kerala in the year 2008 with 25 seed origins (provenances) following randomized block design (RBD). Twelve seedlings of each of the 25 provenances were field planted in each of the three blocks at spacing of 2 x 2 M. Since enough seedlings were not available, Chinnar provenance could be planted only in two blocks and Hudsa provenance from Dandeli in another one block. Growth measurements on height and basal girth and also number of branches, branch girth and angle of branching were taken at the age of 3.5 years after field planting. Angle of branching was measured using a protractor.

2.1.1 *Statistical analysis*

Statistical analysis was carried out using the computer software packages SPSS/PC+ advanced statistics V 10.0 (Norusis, 2002). The ANOVA provides the basic information for the calculation of provenance heritability and other genetic estimates. Phenotypic and Genotypic coefficient of variation (PCV and GCV respectively), heritability and genetic gain were computed following Singh & Chaudhary (1985). Correlation coefficients between different parameters were estimated following Goulden (1952). Cluster analysis was carried out to understand the overall similarity between the provenances and by using average linkage between groups algorithm. This corresponds to the "Group average method" reported by Everitt (1974). The values of genetic parameters were classified as given below:

Genetic parameter	**Low**	**Moderate**	**High**
GCV, PCV & Genetic gain	0 - 10 %	11 - 20 %	More than 20%
Heritability	0 - 30 %	31 - 60 %	More than 60 %

Table 1. Location of Teak populations selected from different States

State	Forest Divisions	Provenance locations	Geo position		Elevation (M)	Rain fall (mm)
			Latitude (N)	Longitude (E)		
Kerala	Wynad	Tholpetty	11^o 54’	76^o 05’	752	2137
	Nilambur	Karulai	11^o 20'	75^o 21'	68	2353
	Peechi-Vazhani W.L.S., Thrissur	Vazhani (Machad Range)	10^o 46’	76^o13’	58	2730
	Peechi-Vazhani W.L.S., Thrissur	Thamaravellachal (Peechi Range)	10^o 35’	76^o 25’	80	2730
	Parambikulam	Parambikulam	10^o 21'	76^o 48'	560	1890
	Konni	Konni	9^o 10'	76^o 57'	220	2229
	Thenmala	Arienkavu	8^o 59'	77^o 07'	381	1694
	Chinnar	Chinnar	10^o 32’	77^o 19’	968	1431
Tamil Nadu	Kanyakumari	Asambu	8^o 22’	77^o 18’	200	1226
Karnataka	Hunsur	Doddaharve (Periyapatna)	12^o 24’	75^o 57’	877	1258
	Shimoga (Thirthahalli)	Mandagadde	13^o 46’	75^o 29’	592	1536
	Haliyal (Dandeli)	Hudsa (Virnoli) (Teli variety)	15^o 15’	74^o 37’	531	1860
Andhra Pradesh	Adilabad	Adilabad (Echoda)	19^o 18'	78^o 34'	356	1061
	Bhadrachalam N.	Bhadrachalam (Dhummagudam)	18^o 31'	80^o 57'	181	1453
Maharashtra	Allappalli	Allapalli	19^o 25'	80^o 05'	157	1451
	Nagpur	Pench Tiger Reserve (Pipariya)	21^o 34'	79^o 17'	425	1060
Chhattisgarh	Rajnandagaon	Chouki	20^o 41'	80^o 43'	382	1449
	Basthar	Basthar (Machkot)	18^o 51'	82^o 08'	489	1493
Orissa	Khariar	Khariar (Sinnapally)	20^o 06'	82^o 24'	300	1333
	Khurda	Berbera (Balugaon)	19^o 52'	85^o 02'	213	1287
Madhya Pradesh	Jabalpur	Burgi	22^o 57'	79^o 47'	376	1195
	Dewas	Dewas (Punjapura)	22^o 25'	76^o 21'	227	928
Gujarat	Valsad North	Valsad (Vasda)	20^o 45'	73^o 28'	164	2100
	Rajpipla East	Rajpipla (Sagbara)	21^o 36'	73^o 44'	403	1213
Rajasthan	Banaswara	Banaswara (Ghatol)	23^o 44'	74^o 30'	225	853
	Baran	Baran (Nahargarh)	24^o 51'	76^o 46'	308	869

2.2 Wood samples

A total of 150 samples from 82 trees of various ages were collected from the 23 provenances, of which 57 were wood cross-sectional discs (5.0 cm thick) belonging to 9 provenances obtained by destructive sampling. For the remaining trees from 14 localities, increment core samples (size 4 mm) were withdrawn from the outermost growth increment to the inner core near pith at breast height (BH) using increment borer. After determining the age of the tree by counting the annual rings, the samples were grouped into five age classes (I–V) as shown below for studying various wood properties. For a given age class, each provenance represents three trees, sometimes the same provenance may occur more than 2 times in different age classes (see Table 1 above).

Age classes	**Age (Yr)**	**No. of provenances**
I	Up to 24	5
II	25-34	8
III	35-44	13
IV	45-54	12
V	> 55 yrs	12
	Total	**50**

Results of the physical properties of wood like colour, heartwood proportion, ring width, basic density, extractive content and lignin etc were reported for all the 23 provenances in the 1st phase of the project (Indira *et al.,* 2010).

2.2.1 *Anatomy and microscopy*

Of the 23 provenances, anatomical investigations were completed for the 57 disc samples belonging to 9 provenances (Khariar, Konni, Baran, Burgin, Basthar in Age Class I and Khariar, Basthar, Berbera, Dandeli in Age Class II). In the 2nd phase, remaining 14 provenances were studied for the anatomical properties (increment core samples of 82 trees). However, in order to obtain a complete picture of provenance variation, anatomical properties of all the 150 samples were analyzed statistically and results are presented in this report. The standard microtechnique procedure as described in the 1st phase of the project (Indira *et al.,* 2010) was followed for anatomical investigations. Important anatomical properties studied in a growth ring were early- and late wood percent, vessel diameter/ frequency, proportion of vessels, fibres and parenchyma (both ray and axial parenchyma combined). Vessel diameter of 25 cells was measured at random to obtain mean values per ring. Fibre dimensions of the 57 wood disc samples of 9 provenances were completed in the 1st phase and for the increment core samples the same has not been studied due to small core samples.

2.2.2 ***Statistical analysis***

The data on wood anatomical properties *viz.,* percentage of early- and late wood, vessel diameter and vessel percentage, its frequency, percentage of fibres and parenchyma were subjected to statistical analyses after applying appropriate data transformation. Pair-wise comparison tests on mean values were done through Duncan Multiple Range Test (DMRT) wherever required. Age group comparison was not attempted due to non-availability of adequate representative samples from each provenance.

3. RESULTS AND DISCUSSION

3.1 Growth and branch pattern

The provenances were evaluated only for growth and branching pattern as other characters were not expressed fully. Highly significant differences between provenances were noted for all the characters. Mean growth performance of different provenances is given in Table 2.

In general, Konni, Arienkavu and Nilambur (Kerala), Hudsa and Mandagadde (Karnataka) Berbera (Orissa) showed very good performance. Parambikulam, Vazhani and Tholpetty (Kerala), Adilabad (Andhra Pradesh), Doddaharve (Mysore, Karnataka), Asambu (Tamil Nadu), Allapalli and Pench Tiger reserve (Maharashtra) and Basthar (Chhattisgarh) also showed good performance. Konni is the best performer for growth as well as wide branch angle followed by Arienkavu (Figs.1 & 2). More number of branches, higher girth for branches and narrow branch angle are not desirable for timber species like teak.

All other provenances, especially from Northern India have poor growth and branching pattern. Baran from Rajasthan showed very poor performance.

Table 2. Provenances with highest to least mean values for different characters

Provenance	Height (cm)	Provenance	Basal girth in (cm)	Provenance	No. of branches	Provenance	Branch girth in (cm)	Provenance	Branch angle (^{o})
Konni	**241.53**	Konni	**14.75**	Konni	5.87	Khrr	5.76	Kni	**48.19**
Arien	**225.08**	Berber	**12.39**	Nlmbr	5.71	Brbra	5.23	Akv	**47.27**
Nlmbr	**189.78**	Mndgd	**11.74**	Mgd	5.59	Kni	5.22	Mdg	**41.67**
Mgd	**178.09**	Arienk	**11.54**	Asmbu	4.99	Vzni	4.54	Nbr	**39.82**
Brbra	**168.57**	Nlambr	**11.36**	Arien	4.35	Prmbi	4.22	Asb	**38.25**
Vzhani	**152.89**	Vzhani	**10.47**	Drve	4.00	Mdg	4.20	Brbra	**38.02**
Pench	**152.00**	Asamb	**9.94**	Vzhani	3.79	Nbr	4.18	Wynd	**35.40**
Asmbu	**134.08**	Bastar	**9.78**	Brbra	3.35	Bstr	4.14	Prmbi	**34.98**
Adlbd	**132.58**	Adilbd	**9.59**	Prmbi	3.28	Akv	4.07	Drv	**34.76**
Drve	**130.52**	Chinar	**9.32**	Tholpe	3.21	Adb	4.04	Vzni	**34.75**
Bstar	**130.01**	Param	8.86	Khrrr	**2.63**	Drv	3.95	Cnr	**34.22**
Alpali	124.51	Chouki	8.79	Adlbd	**2.39**	Asb	3.91	Bstr	**34.01**
Prmbi	120.14	Khariar	8.57	Pench	**2.37**	Cnr	**3.68**	Alpli	**32.35**
Tholpe	117.77	Dodarv	8.49	Chnar	**2.35**	Pnch	**3.43**	Pnch	**31.56**
Vlsd	109.19	Pench	8.30	Bstar	**2.34**	Alpli	**3.41**	Adb	30.30
Chnar	106.61	Tholpe	8.04	Dewas	**2.32**	Bnsra	**3.36**	Barn	27.68
Bhdrch	98.99	Allapali	7.97	Alpali	**2.26**	Vlds	**3.35**	Chki	27.66
Bnsra	98.13	Bhadra	7.81	Rjpipl	**2.26**	Barn	**3.28**	Bcm	25.33
Khrrr	90.30	Valsad	7.77	Vlsd	**2.10**	Rjpla	**3.16**	Rjpla	24.79
Choki	81.16	Rjpipla	7.09	Baran	**1.65**	Bcm	**3.12**	Dws	23.93
Baran	76.35	Bnsar	7.03	Choki	**1.63**	Chki	**3.10**	Vlds	23.77
Dewas	76.34	Dewas	7.00	Bhdrch	**1.52**	Dws	**3.00**	Khrr	21.79
Rjpipl	67.25	Burgi	6.52	Bnsra	**1.44**	Wynd	**2.93**	Bnsra	20.42
Burgi	66.84	Baran	6.43	Burgi	**1.26**	Brgi	**2.42**	Brgi	14.04
Mean	127.86		9.06		3.06		3.76		31.44
Hudsa*****	219.58		14.58		4.00		4.54		41.67
Maximum value	345.42		18.75		10.45		9.10		55.45

*Mean values above the average is given in bold letters; * only 1 replication*

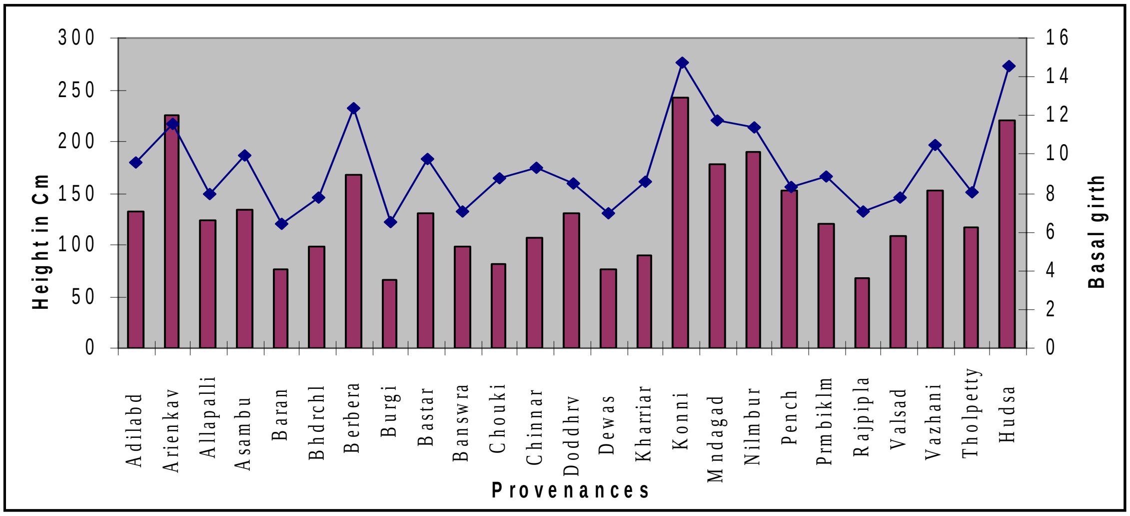


Fig.1. Comparative growth performance in teak

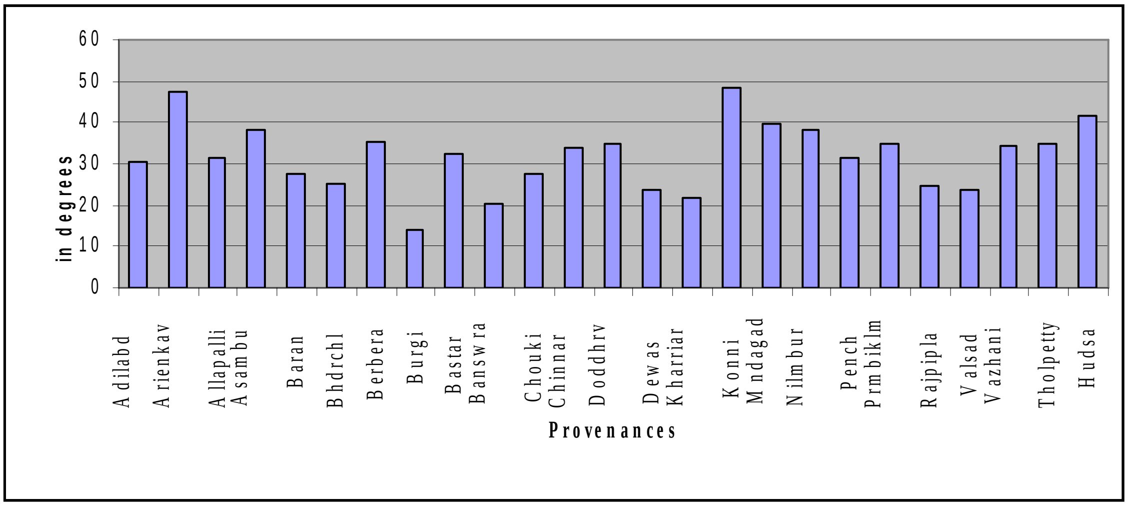


Fig.2. Branch angle in different teak provenances

Hierarchical clustering with respect to height shows that 25 provenances can be classified into four homogeneous groups, on allowing 20 percent variability within a group (Fig. 3). The best cluster contains Konni, Arienkavu and Hudsa followed by second cluster with Nilambur, Mandagadde and Berbera. Almost all the North Indian provenances along with Chinnar from Kerala form the cluster with poor height performance.

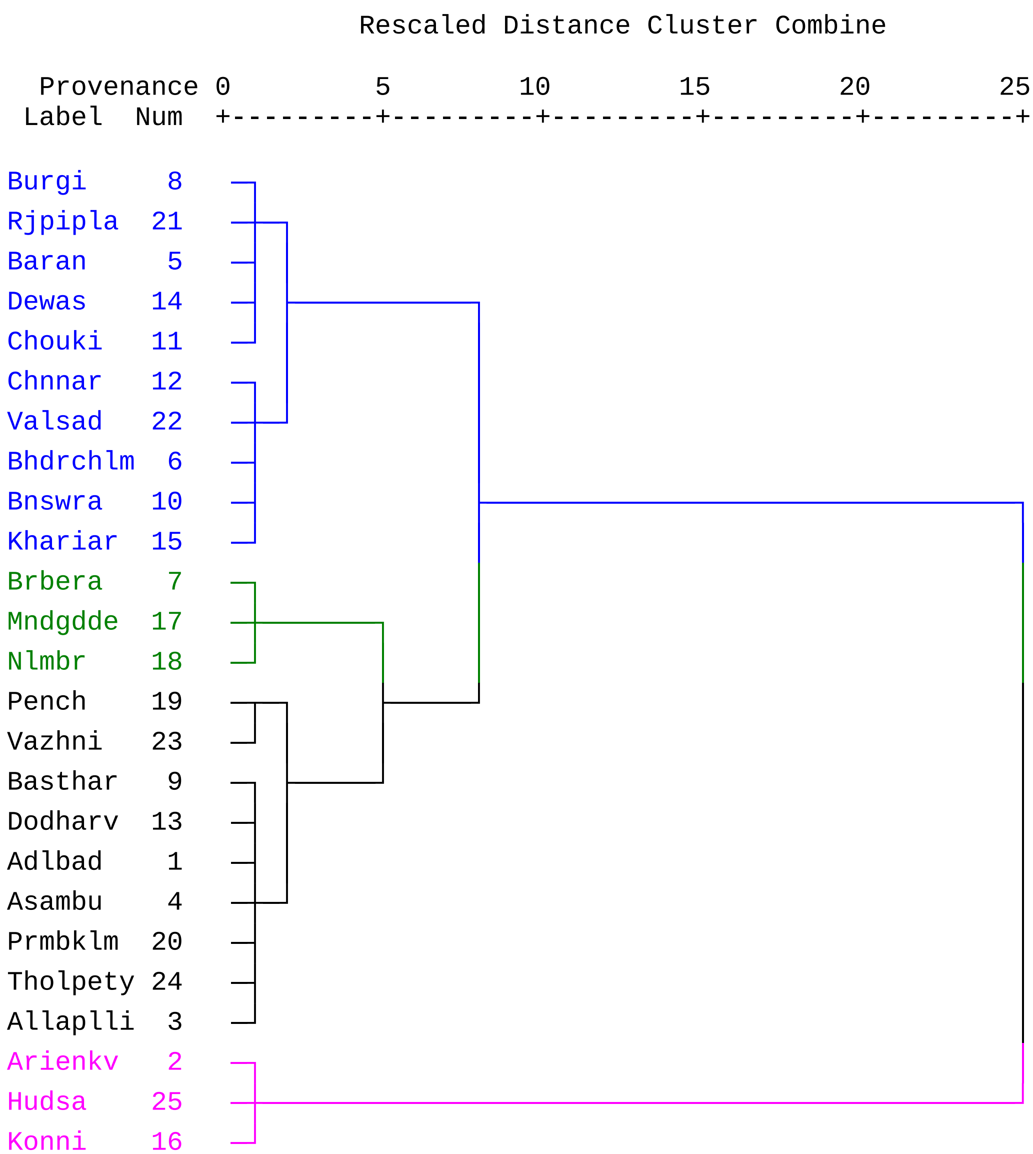


Fig. 3. Clusters showing similarity between provenances based on height

Grouping based on basal girth shows three homogeneous groups, on allowing 30 percent variability within a group (Fig. 4). The best cluster consists of Konni and Hudsa. On allowing 10% variability within a group, Nilambur, Mandagadde, Arienkavu and Berbera form the second best cluster. Almost all North Indian provenances along with Tholpetty and Parambikulam from Kerala form the cluster with poor performance.

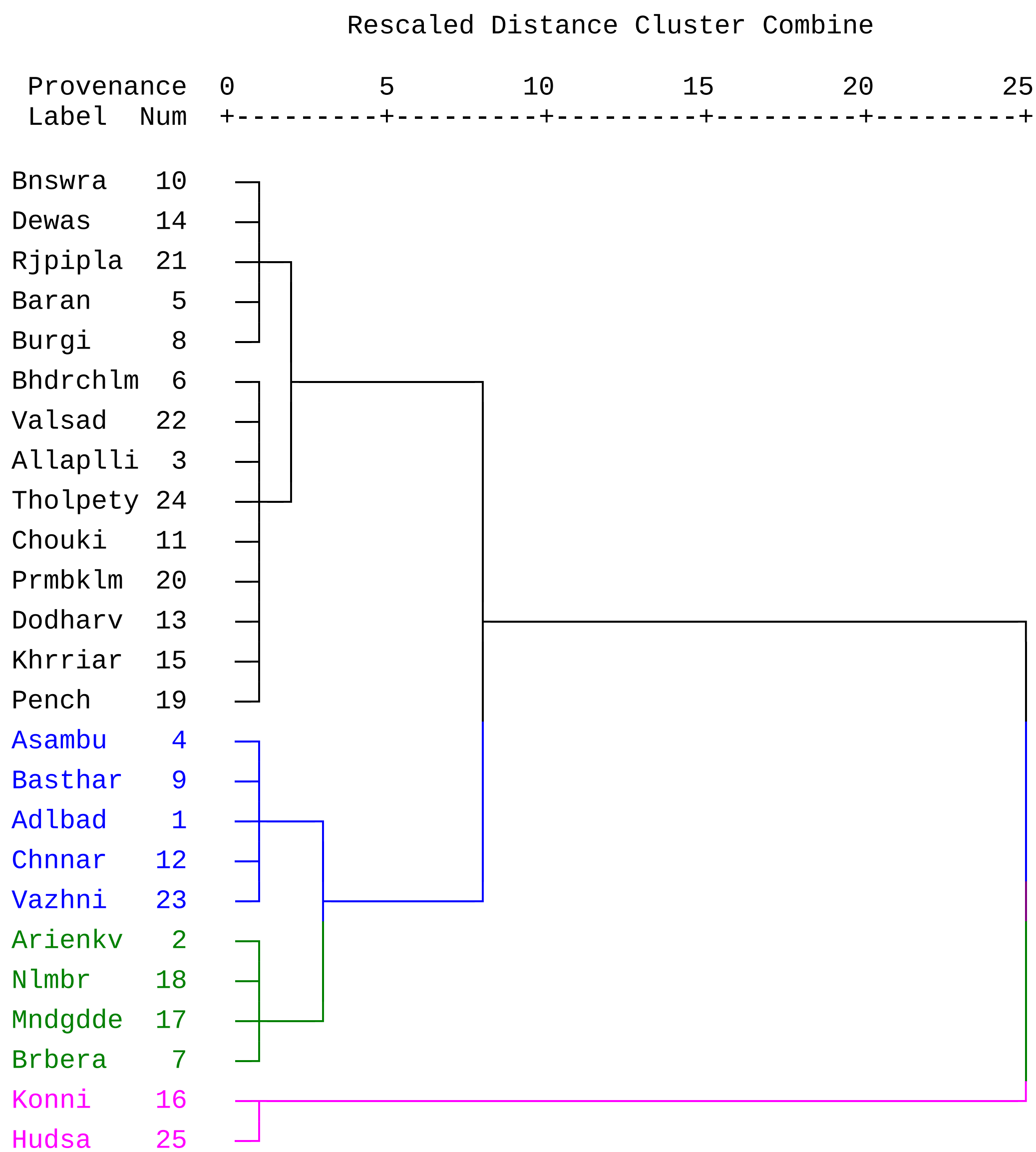


Fig. 4. Clusters showing similarity between provenances based on basal girth

Hierarchical clustering with respect to number of branches shows three homogeneous groups, on allowing 20 percent variability within a group (Fig.5). One cluster with maximum number of branches contains Konni, Arienkavu, Nilambur, Mandagadde and Asambu. The second cluster has provenances from South India and Berbera from Orissa. Another group consists of provenances from North and Central India and Chinnar, Bhadrachalam and Allapally from South India which have low number of branches.

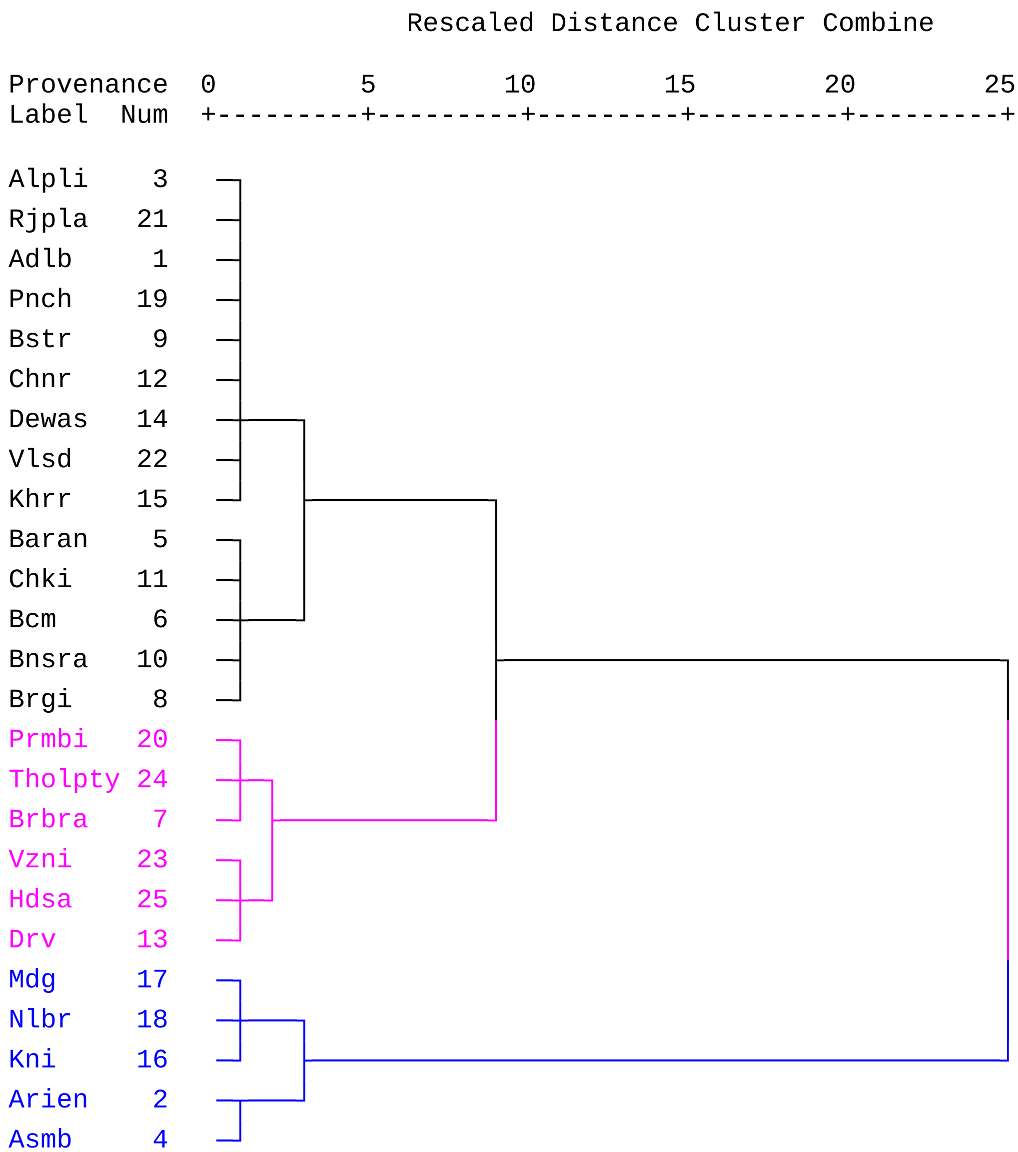


Fig. 5. Clusters showing similarity between provenances based on number of branches

Grouping of provenances with respect to branch girth shows four homogeneous groups, on allowing 20 percent variability within a group (Fig. 6). The first cluster with highest branch girth consists of Konni from Kerala and Berbera and Khariar from Orissa. Almost all South Indian provenances and Basthar from Chhattisgarh form the group with second highest branch girth. Almost all North Indian provenances along with Tholpetty and Chinnar from Kerala and Bhadrachalam from Andhra Pradesh form another cluster. Burgi from Jabalpur Division (Madhya Pradesh) stands separately with least branch girth.

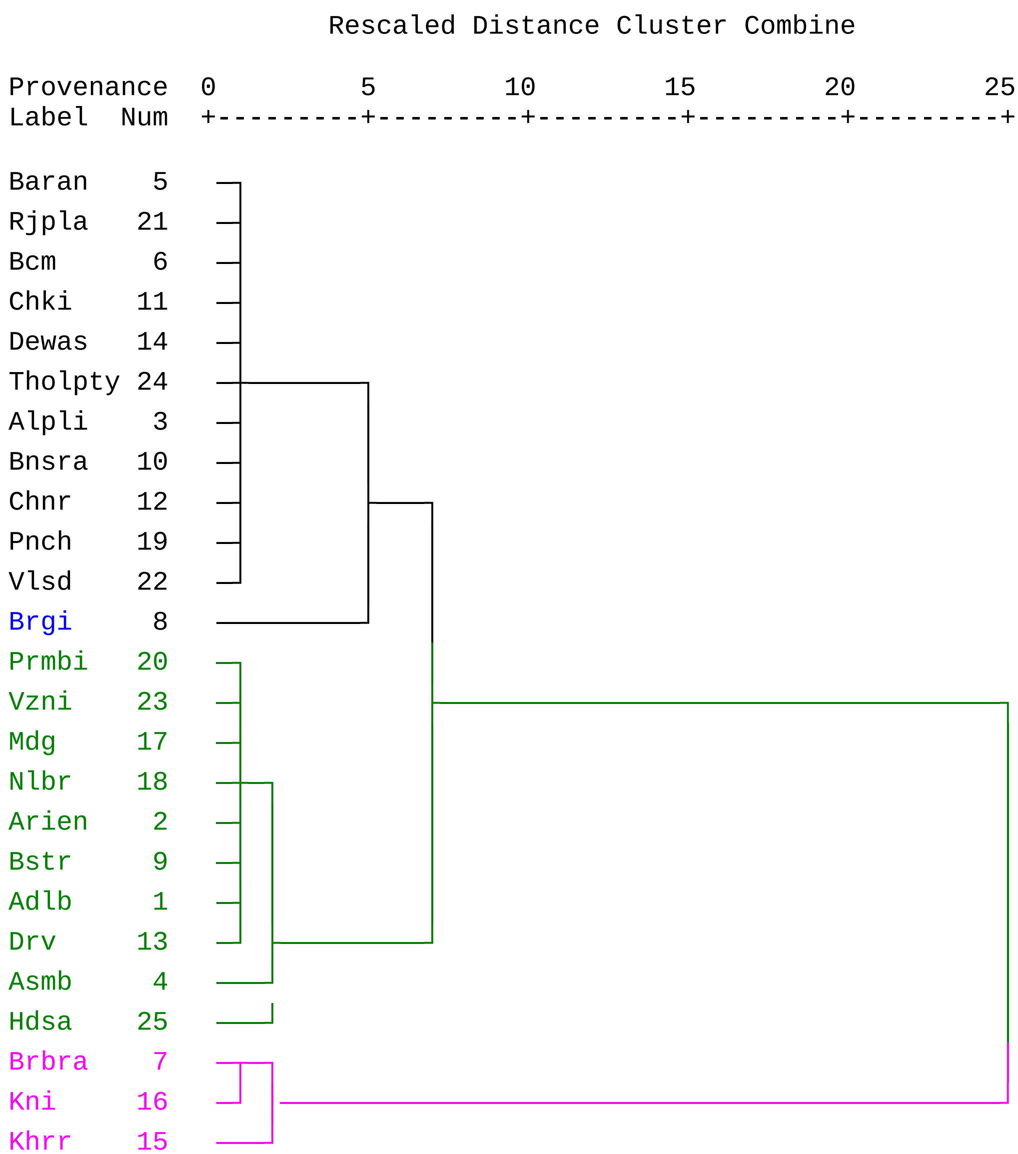


Fig. 6. Clusters showing similarity between provenances based on branch girth

Hierarchical clustering with regard to branch angle shows four homogeneous groups, on allowing 20 percent variability within a group (Fig. 7). Best cluster with wider branch angle consists of Konni and Arienkavu. Provenances of Asambu, Mandagadde, Nilambur and Hudsa also showed wide branch angle and they stand as a single cluster if 15% variability within a group is allowed. Burgi with the least branch angle stands separately. Provenances from North India also have low branch angle.

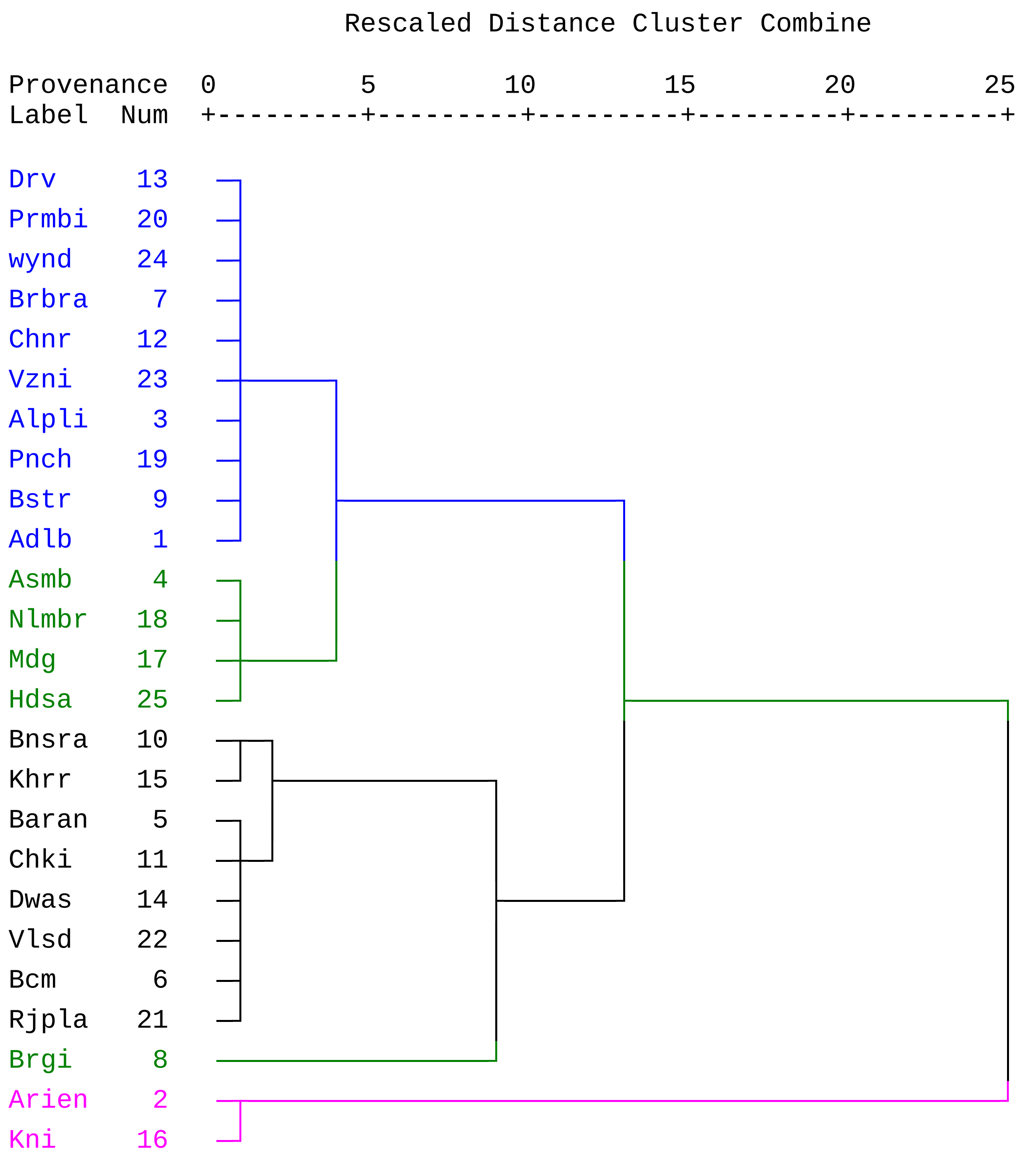


Fig. 7. Clusters showing similarity between provenances based on branch angle

3.1.1 *Correlations between characters and geo-climatic factors*

Analysis of correlation among growth and branching characters and these characters with geo-climatic factors showed that latitude has highly significant negative correlation with height, basal girth, number of branches and branch angle (Table 3). But it has no significant relation with branch girth. On the other hand, rainfall has highly significant positive correlation with all the characters except branch girth. The significant influence of latitude and rainfall on the early growth of teak provenances was reported in the 1st phase of the project (Indira *et al.*, 2010). Height, basal girth, number of branches, branch girth and branch angle have highly significant correlations with each other. Since some of the provenances have very poor growth, the development of branches might not have initiated in these. Hence, this has to be monitored for half the rotation or at least one third of the rotation period.

Table 3. Correlations between characters and geo-climatic factors

	Height	Basal girth	No. of branches	Branch girth	Branch angle
Latitude	-0.626**	-0.591**	-0.791**	-0.347	-0.794**
Longitude	-0.095	0.022	-0.267	0.276	-0.137
Altitude	-0.054	-0.022	0.022	-0.107	0.166
Rainfall	0.520**	0.508**	0.521**	0.300	0.492*
Height		0.911**	0.806**	0.599**	0.884**
Basal girth			0.762**	0.714**	0.827**
No. of branches				0.555**	0.840**
Branch girth					0.499*

** *Significant at 0.01 level*; * *Significant at 0.05 level*

As all the characters are significantly and positively correlated, hierarchical grouping was attempted taking all the characters into consideration so as to classify the Indian provenances. On accepting 20 percent variability within a group, four clusters are formed (Fig. 8). Best cluster is having Konni, Arienkavu and Hudsa followed by another cluster containing Mandagadde, Nilambur and Berbera. All the North Indian provenances along with Chinnar (Kerala) and Bhadrachalam (Andhra Pradesh) form another cluster with poor performance. Nine provenances *viz.,* Parambikulam, Tholpetty and Vazhani (Kerala), Asambu (Tamil Nadu), Doddaharve (Karnataka), Adilabad (Andhra Pradesh), Pench Tiger Reserve and Allapalli (Maharashtra) and Basthar (Chhattisgarh) form another cluster with moderate performance.

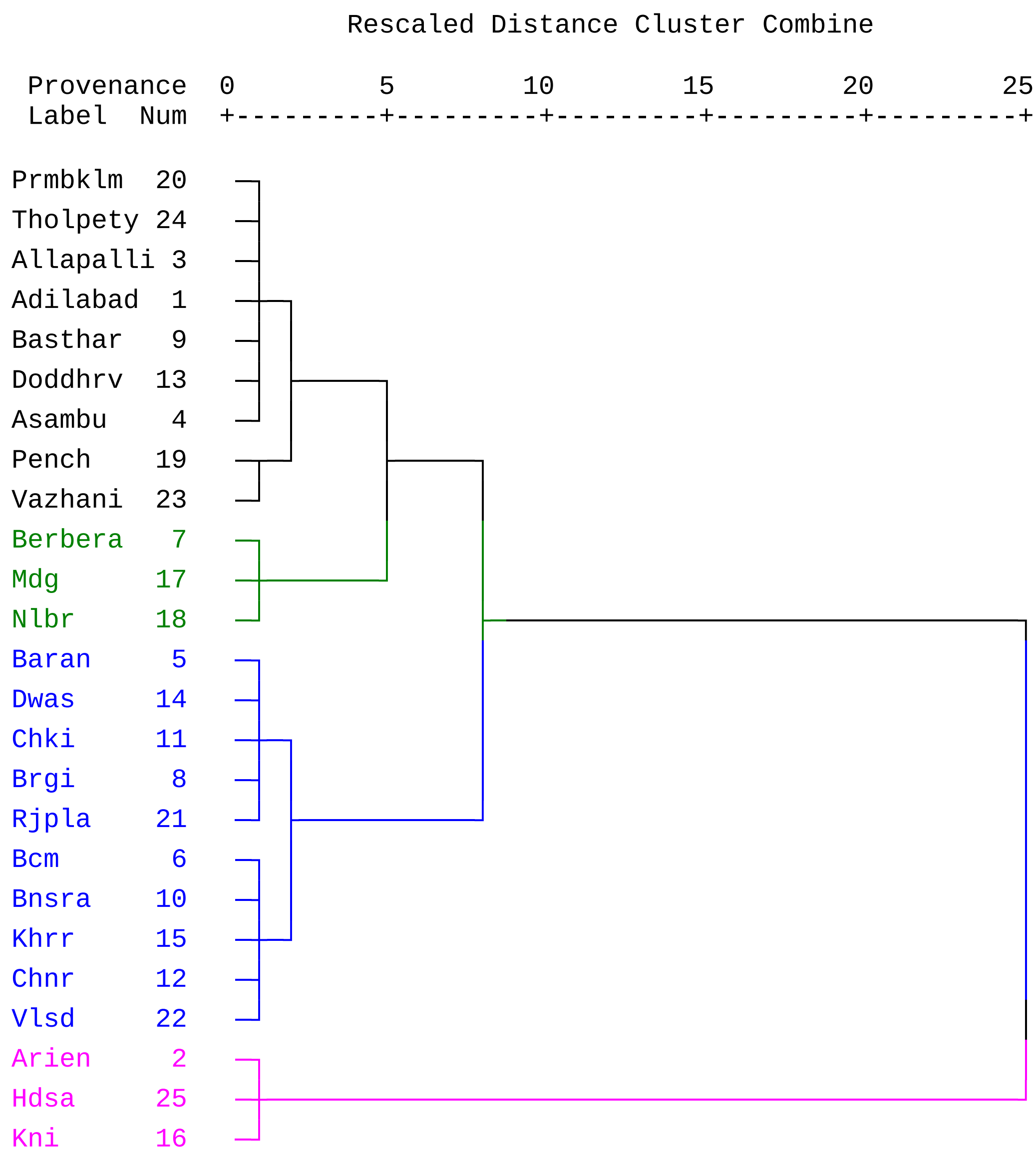


Fig. 8. Clusters showing similarity between provenances based on all the characters- Growth and branching

3.1.2 *Genetic parameters*

The estimated genetic parameters show high phenotypic and genotypic coefficient of variation (PCV and GCV) and moderate heritability for height, basal girth, number of branches and branch angle (Table 4). But branch girth has low heritability and genotypic coefficient of variation though it has high phenotypic coefficient of variation. If provenances are selected at 5% selection intensity, high genetic gain is expected except for branch girth. Earlier reports in teak showed high heritability at provenance level for diameter growth, stem straightness, clear bole and persistence of axis (Harahap and Soerinegara, 1977; Keiding *et al.,* 1986; Kaosa-ard, 1993). However, heritability is strongly influenced by provenances, site factors and age of the crop.

Table 4. Genetic parameters for 3.5 year growth and branch characters

Variable	**PCV**	**GCV**	**Heritability %**	**Genetic gain* as % of mean**
Height	40.81	31.42	47.8	59.71
Basal girth	28.26	20.48	52.5	35.65
No. of branches	57.84	40.20	48.1	59.15
Branch girth	31.62	9.68	30.6	20.21
Branch angle	31.98	21.87	46.8	33.54

***** *Genetic gain estimated with 5 % selection intensity*

3.2 Variations in the wood anatomical properties

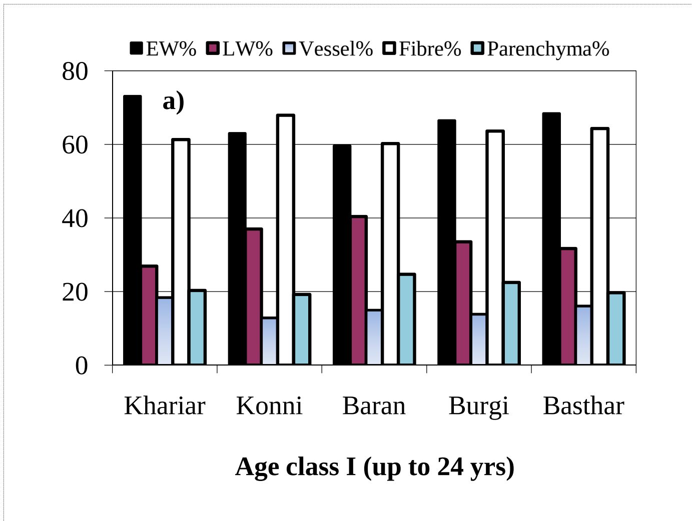
In the 1st phase of the project (Indira *et al.,* 2010), anatomical properties of 9 provenances (Khariar, Konni, Baran, Burgi, Bastar- in Age class-1 and Khariar, Bastar, Berbera, Dandeli- in Age class II) were studied and conclusions were drawn leaving behind the properties of 14 provenances unexplained and study was completed in the 2nd phase (Appendix- 1). The ANOVA of the anatomical properties of 23 provenances are presented in Table 5 and Figs. 9, 10 and 11.

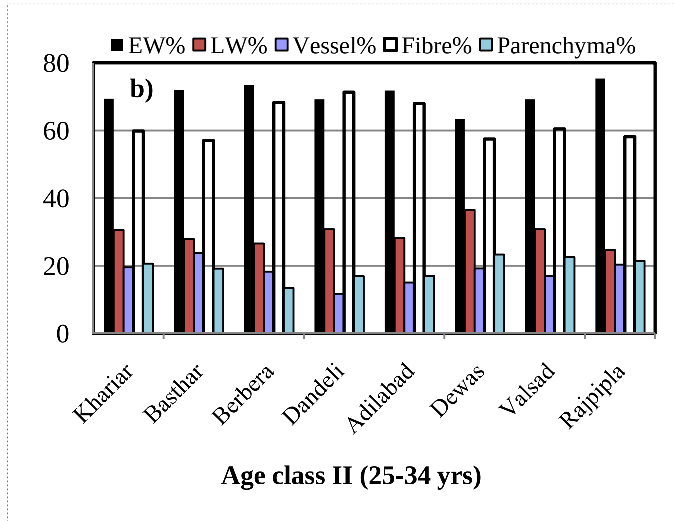
Mean values are shown separately in the APPENDIX-1. The interrelationships of various anatomical properties are revealed through the correlation matrix shown in APPENDIX – II. Variations observed in the anatomical studies of 23 provenances were correlated with results of wood physical properties completed in the 1st phase of the project (Indira *et al.,* 2010) for drawing definitive conclusions in this report. The results of ANOVA showed that the teak provenances in a given age class differed significantly for the anatomical properties studied (Table 5).

Table 5. ANOVA on anatomical properties

Age Classes	**Source of variation**	**d.f**	**F-values**						
			Early wood	Late wood	Vessel diameter	Vessel frequency	Vessel	Fibre	Parenchyma
I	Provenance	4	4.63*	4.63*	3.88*	4.84*	8.36**	7.2**	6.32**
	Error	55	25.79	25.79	0.016	0.029	4.03	5.32	4.63
II	Provenance	7	4.55**	4.55**	91.75**	19.13**	32.66**	39.05**	29.06**
	Error	136	20.66	20.66	0.007	0.017	4.24	5.33	3.82
III	Provenance	12	18.31**	18.31**	73.27**	22.11**	17.19**	18.83**	20.16**
	Error	298	24.09	24.09	0.010	0.036	6.33	6.85	3.02
IV	Provenance	11	12.82**	12.82**	42.34**	36.81**	22.18**	7.49**	40.95**
	Error	347	20.76	20.76	0.015	0.022	7.00	8.73	3.28
V	Provenance	11	33.24**	33.24**	40.10**	20.60**	16.55**	14.60**	13.84**
	Error	420	15.70	15.70	0.017	0.027	6.60	7.60	3.12

*d.f- degrees of freedom; ** significant at $P \leq 0.01$; * significant at $P \leq 0.05$*





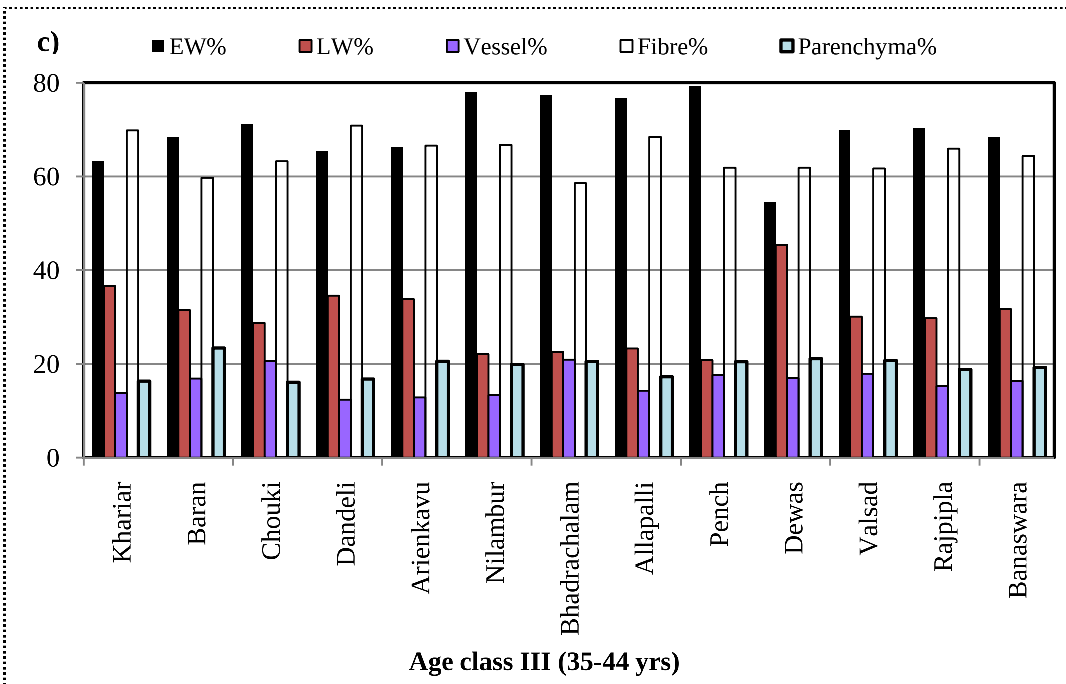
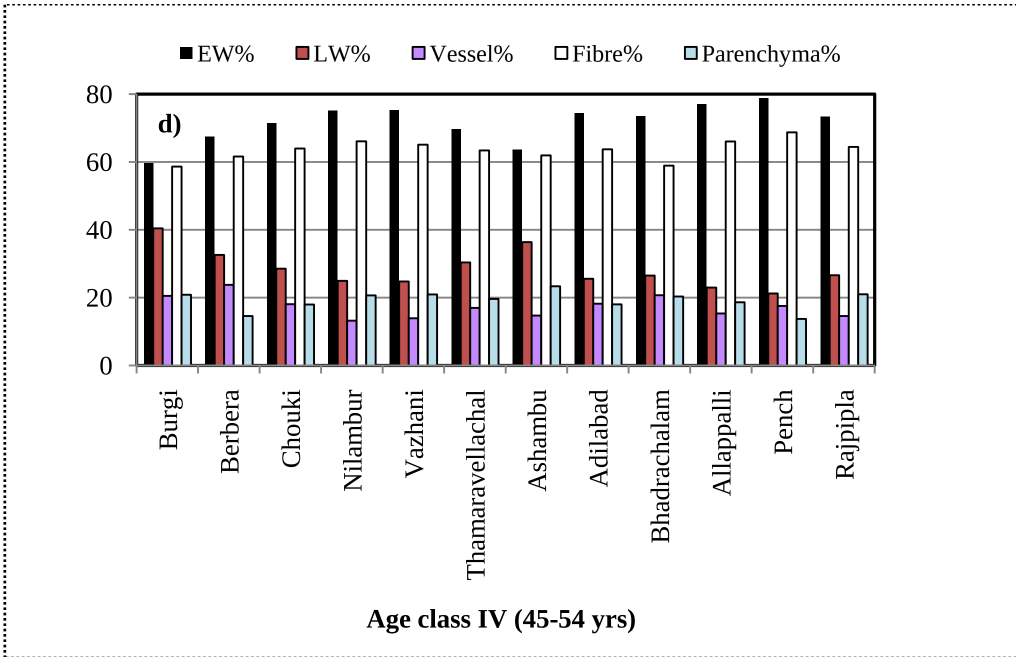


Fig. 9a, b & c. Provenance variation of tissue percentage with age



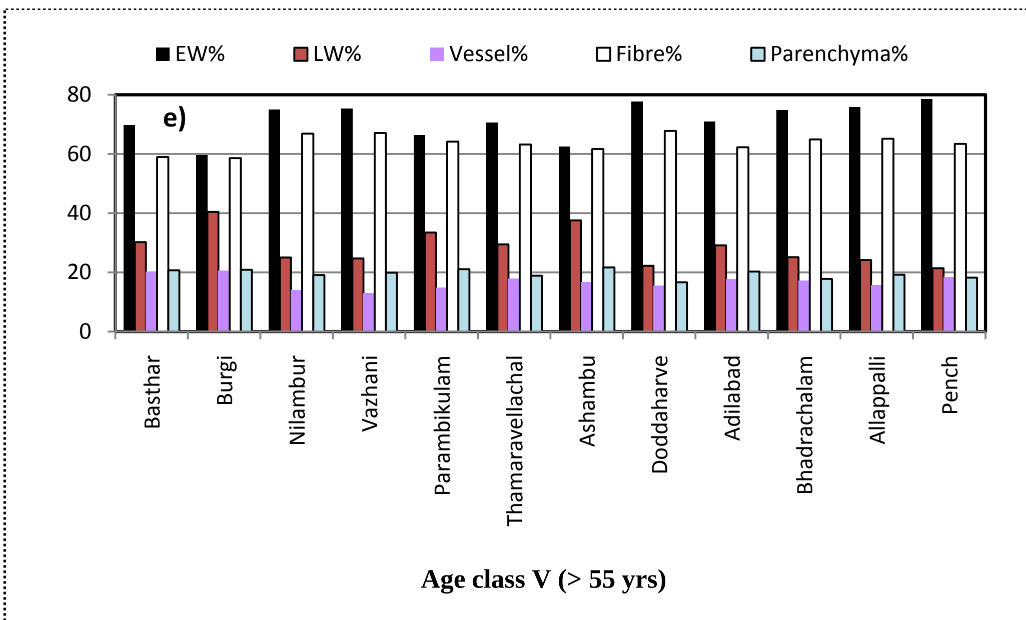


Fig. 9d & e. Provenance variation of tissue percentage with age

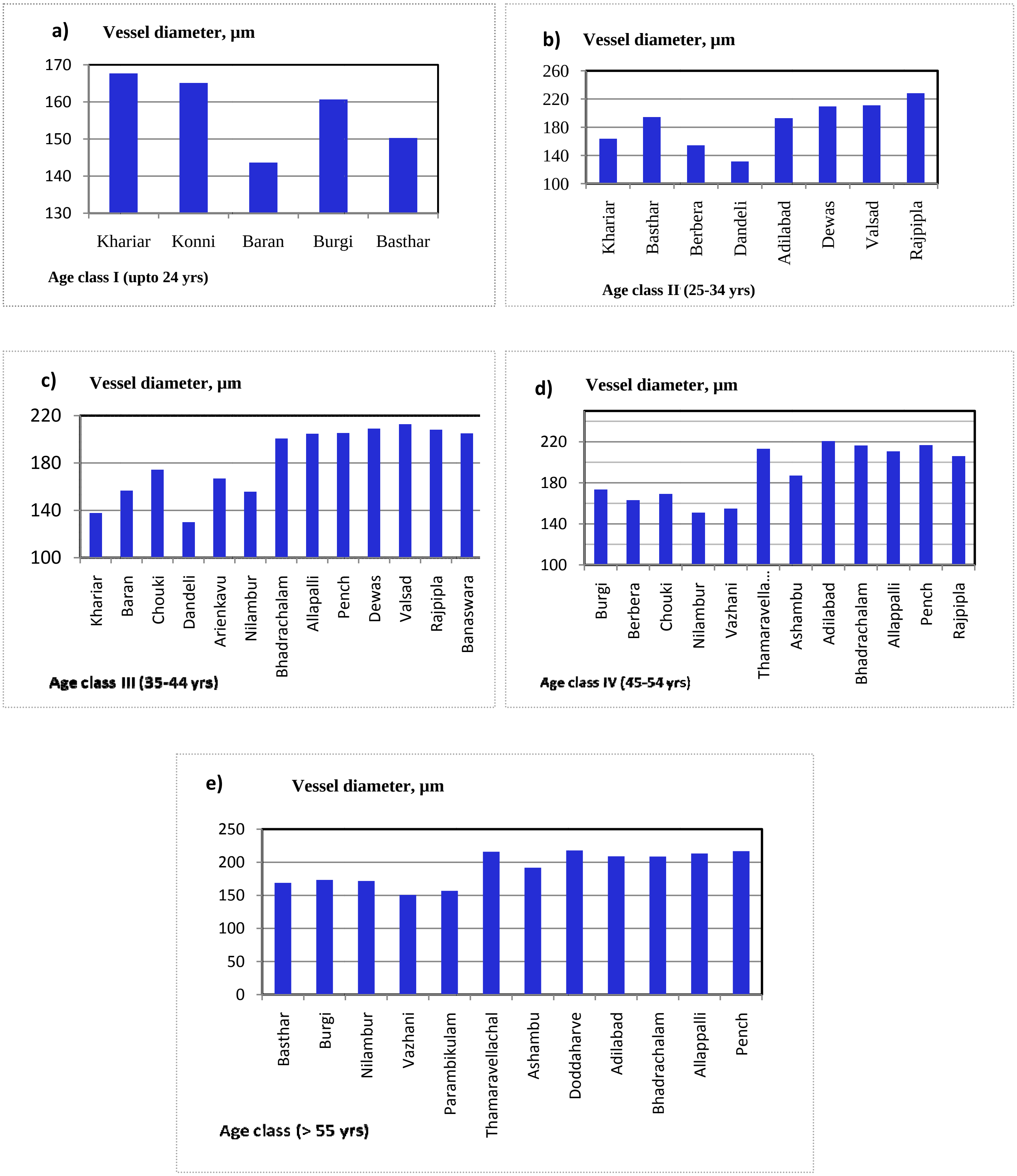


Fig.10a, b, c, d & e. Provenance variation of vessel diameter with age

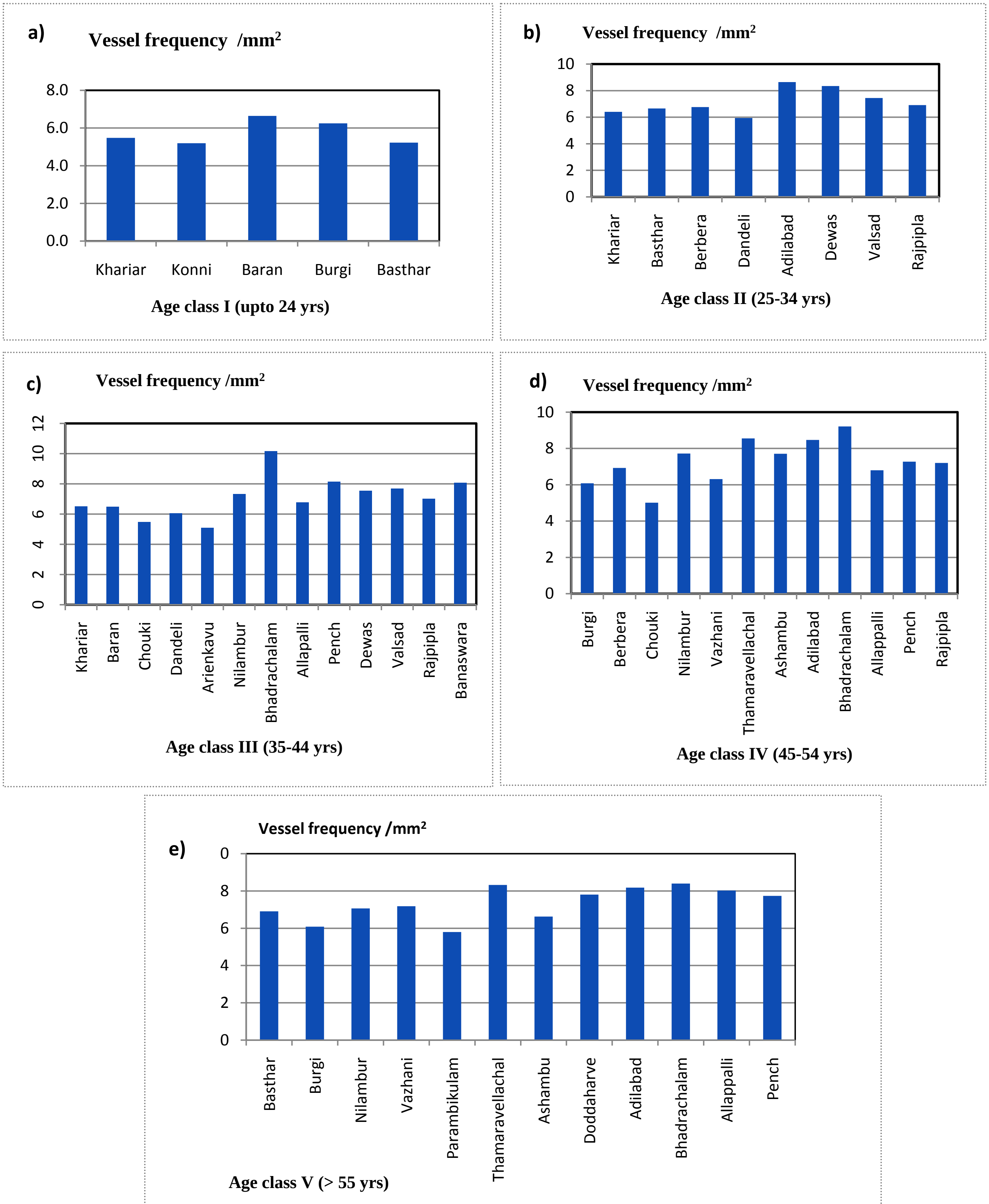


Fig.11a, b, c, d & e. Provenance variation of vessel frequency with age

The lighter wood of Khariar provenance (Odisha) (Density 473 kg/m^3 reported in KFRI Res. Report No. 384) in Age class 1 was due to faster growth rate with a wide early wood band, large vessels/percentage, followed by low fibre percentage and thin walled fibres (Table in Appendix-1, Fig. 9). However, the fibre length showed maturity (1.2 mm) as in all other age classes. The same provenance showed a decreasing trend for all the above anatomical properties in age class II and the wood became dense in age class III (density 665 kg/m^3) accompanied by reduced vessel diameter/percentage with high proportion of fires and low percentage of parenchyma (Appendix- 1, Figs.9a,b,c & 10a,b,c).

The Teli variety teak (Dandeli) provenance from the Western Ghat region of Karnataka (age class II & III) had significantly low vessel percentage/ diameter and high proportion of fibres (71%) with comparatively low amount of parenchyma (16.8%) in the narrow rings, while the early wood and late showed non-significant variation (Appendix-1). The result is contradictory to the findings of Bhat and Indira (2005) that the slow growing North Kanara provenance (21-years) exhibited significantly higher proportion of parenchyma and a low proportion of fibre tissue in the narrow rings, and the wood was found inferior in mechanical properties, and the reverse was noted for another slow growing Konni provenance (65- year-old) teak. They subscribe this as a possible adaptation with the higher amount of storage tissue possibly being related to soil rich conditions. In the present study also, the Konni provenance in age class 1 showed a similar trend (Appendix-1). The Burgi and Basthar provenances in age class V displays non-significant variation in terms of anatomical properties (*P=0.01*). Irrespective of the age classes, all the central provenances teak showed significant variation in tissue percentages while the vessel diameter continue to vary even after age class III and somewhat stabilized in age class V (Appendix-1, Figs. 9 & 10) with a slight insignificant variation. Larger vessels were noticed in Rajapipla provenance in age class II with high growth rate (ring width). However, in the subsequent age class III and IV, the diameter tends to decrease with low vessel percentage and high amount of fibres like other provenances in the same age class. Vessel frequency also showed an inconsistent relationship upto age class IV and got stabilized in age class V (Fig.11). The interrelationships of various anatomical properties are clearer in the correlation matrix as depicted in Appendix-II.

Although fibre dimensions were measured only for 9 provenances and found that the maximum fibre length obtained was 1.4 mm for Konni provenance, it exceeded 1.00 mm irrespective of the age class. The maturity age of fibres in teak was found to be around 20-25 years (Bhat *et al.,* 2001) and the present results for the 9 provenances are in conformity with their report. The fibre proportions of all the 23 provenances exceeded 60% in age class III and above and showed its strong positive influence on the density which also exceeded 610 kg/m^3 in age class III and above as reported in the 1st phase of the project (Indira *et al.,* 2010). However, it is to be noted that fibre wall thickness and lumen width shall contribute more to wood density rather than tissue percentage alone. Density being a heritable trait, once it is stabilized, only age related structural changes can occur and is independent of growth rate.

The present study of anatomical properties of 23 provenances showed significant variations among provenances within each age classes irrespective of the locations.

4. SUMMARY AND CONCLUSIONS

The genetic diversity in teak (*Tectona grandis* L.f.) with respect to growth and branching characters was analysed at an early age of 3.5 years. 25 different ecotypes from ten Indian States (Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Chattisgarh and Orissa) were compared.

Wood samples in the form of disc or core samples taken from 23 populations (provenances) were analysed for the anatomical properties to explain some of the variations observed in wood physical properties.

The results of the present study lead to the following conclusions:

1. With regard to growth, Konni, Arienkavu (Kerala) and Hudsa (Karnataka) have shown highest growth.

2. Taking into consideration of the growth and branch angle monitored, best cluster comprises of Konni, Arienkavu and Hudsa followed by another group containing Mandagadde (Karnataka), Nilambur (Kerala) and Berbera (Orissa).
3. Parambikulam, Tholpetty and Vazhani (Kerala), Asambu (Tamil Nadu), Doddaharve (Karnataka), Adilabad (Andhra Pradesh), Pench Tiger Reserve and Allapalli (Maharashtra) and Basthar (Chhattisgarh) are the ecotypes with moderate performance.
4. Most of the North Indian ecotypes along with Chinnar (Kerala) and Bhadrachalam (Andhra Pradesh) form another cluster with poor performance.
5. There is high genetic coefficient of variation and moderate heritability for growth, which will help in exploiting the genetic gain through the selection of good provenances.
6. The estimated genetic parameters show high phenotypic and genotypic coefficient of variation and moderate heritability for height, basal girth, number of branches and branch angle.
7. Latitude has highly significant negative correlation with height, basal girth, number of branches and branch angle and rainfall has highly significant positive correlation with these characters.
8. Higher growth rate was noted in trees grown in southern states like Kerala, Tamilnadu and Karnataka followed by Maharashtra, Gujarat and Andhra Pradesh.
9. Anatomical investigations of the provenances revealed the reasons for certain significant differences observed in physical properties of Khariar provenance (lighter wood-density 473kg/m^3) in Age class I as reported in the 1st phase of the project. The wood was lighter due to faster growth with a wide early wood band, larger vessels/percentage, low fibre percentage and thin walled fibres. However, the same provenance show maturity in density in subsequent age classes and the wood was not affected as evaluated by anatomy.
10. The present study of anatomical properties of 23 provenances showed significant variations among provenances within each age classes irrespective of the locations.

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APPENDIX-1

Mean values (SD in parenthesis) of wood anatomical properties between 23 teak provenances belonging to different age classes

(Note: Statistical comparison was made between provenances within each Age Class. Cell values differing by a letter in the superscript in each row, under each age class corresponding to each property are significantly different at P≤0.05)

Properties	**Age Class 1**					**Age Class II**							
	Mean					**Mean**							
	Khariar	**Konni**	**Baran**	**Burgi**	**Basthar**	**Khariar**	**Basthar**	**Berbera**	**Dandeli**	**Adilabad**	**Dewas**	**Valsad**	**Rajpipla**
Early wood (EW) %	73.1^{c} (5.9)	63.0^{ab} (8.0)	59.6^{a} (10.2)	66.5^{abc} (8.2)	68.4^{bc} (8.7)	69.4^{b} (7.1)	72.1^{bc} (6.2)	73.4^{bc} (7.9)	69.2^{b} (9.1)	71.8^{bc} (5.9)	63.4^{a} (6.9)	69.2^{b} (5.3)	75.4^{c} (7.8)
Late wood (LW) %	26.9^{a} (5.9)	37.0^{bc} (8.0)	40.4^{c} (10.2)	33.5^{abc} (8.2)	31.7^{ab} (8.7)	30.6^{b} (7.1)	27.9^{ab} (6.2)	26.6^{ab} (7.9)	30.8^{b} (9.1)	28.2^{ab} (5.9)	36.6^{c} (6.9)	30.8^{b} (5.3)	24.6^{a} (7.8)
Vessel diameter, µm	167.7^{c} (5.7)	165.1^{bc} (12.9)	143.6^{a} (22.7)	160.7^{bc} (19.8)	150.3^{ab} (22.9)	163.8^{c} (10.8)	194.3^{de} (19.4)	154.2^{b} (11.2)	131.5^{a} (17.7)	192.8^{d} (14.0)	209.8^{f} (15.5)	211.2^{f} (5.2)	228.3^{g} (19.2)
Vessel frequency /mm^{2}	5.5^{abc} (0.7)	5.2^{ab} (0.7)	6.6^{c} (1.4)	6.3^{bc} (0.7)	5.2^{a} (0.9)	6.4^{ab} (0.9)	6.7^{b} (0.9)	6.8^{b} (0.9)	5.9^{a} (1.1)	8.7^{d} (0.8)	8.4^{d} (0.9)	7.5^{c} (0.8)	6.9^{bc} (0.5)
Vessel %	18.4^{c} (2.8)	12.9^{ab} (3.1)	15.0^{b} (2.8)	13.9^{ab} (1.9)	16.1^{b} (1.5)	19.5^{de} (3.5)	23.8^{f} (4.1)	18.3^{cd} (2.1)	11.7^{a} (3.2)	15.0^{b} (0.8)	19.2^{de} (3.0)	17.0^{c} (1.3)	20.4^{e} (2.9)
Fibre %	61.3^{ab} (1.8)	67.9^{c} (4.6)	60.2^{a} (3.6)	63.6^{b} (5.1)	64.3^{b} (3.2)	59.9^{ab} (4.1)	57.0^{a} (5.2)	68.3^{c} (2.8)	71.3^{d} (2.8)	67.9^{c} (2.4)	57.5^{a} (4.6)	60.4^{b} (1.8)	58.2^{ab} (5.9)
Parenchyma %	20.3^{ab} (1.5)	19.2^{a} (2.2)	24.7^{c} (4.6)	22.5^{bc} (3.7)	19.7^{a} (2.3)	20.6^{cd} (2.4)	19.2^{c} (2.2)	13.5^{a} (2.8)	16.9^{b} (2.6)	17.1^{b} (2.0)	23.3^{e} (3.0)	22.6^{e} (1.3)	21.5^{de} (3.8)
Fibre length, mm	1.2^{c} (0.06)	1.4^{d} (0.1)	1.0^{a} (0.1)	1.0^{a} (0.1)	1.1^{b} (0.1)	1.1^{b} (0.1)	1.0^{a} (0.2)	1.1^{b} (0.2)	1.2^{c} (0.1)	Fibre dimensions were not measured due to small core samples			
Fibre diameter, µm	24.9^{b} (1.0)	26.7^{c} (1.7)	23.0^{a} (1.7)	24.9^{b} (1.9)	22.4^{a} (0.9)	25.9^{c} (3.1)	22.2^{a} (2.8)	25.9^{c} (2.1)	24.6^{b} (3.2)				
Lumen width, µm	17.5^{d} (0.75)	18.2^{e} (1.0)	14.1^{b} (1.5)	15.7^{c} (1.7)	12.2^{a} (1.0)	16.9^{c} (2.2)	13.5^{a} (1.5)	16.9^{c} (1.4)	15.6^{b} (2.6)				
Double wall thickness, µm	7.84^{a} (0.5)	8.5^{b} (0.9)	8.9^{b} (0.6)	9.2^{b} (1.1)	10.2^{c} (0.6)	8.9^{b} (0.9)	8.7^{a} (1.4)	8.9^{b} (0.8)	8.9^{b} (0.9)				

Properties	Age Class III												
	Mean												
	Khariar	**Baran**	**Chouki**	**Dandeli**	**Arienkavu**	**Nilambur**	**Bhadrachalam**	**Allapalli**	**Pench**	**Dewas**	**Valsad**	**Rajpipla**	**Banaswara**
Early wood (EW) %	63.4^{b} (9.9)	68.9^{cd} (9.7)	71.3^{d} (5.8)	65.4^{bc} (6.5)	66.2^{bcd} (13.2)	77.9^{e} (5.7)	77.4^{e} (5.8)	76.7^{e} (3.6)	79.2^{e} (3.4)	54.6^{a} (9.1)	69.9^{cd} (7.3)	70.3^{cd} (6.0)	68.3^{cd} (9.9)
Late wood (LW) %	36.6^{d} (9.9)	31.5^{bc} (9.7)	28.8^{b} (5.8)	34.6^{cd} (6.5)	33.8^{bcd} (13.2)	22.1^{a} (5.7)	22.6^{a} (5.8)	23.3^{a} (3.6)	20.8^{a} (3.4)	45.4^{e} (9.1)	30.1^{bc} (7.3)	29.7^{bc} (6.0)	31.7^{bc} (9.9)
Vessel diameter, µm	137.8^{b} (14.4)	156.6^{c} (19.6)	174.3^{d} (13.3)	129.8^{a} (16.1)	166.8^{d} (23.3)	155.8^{c} (14.1)	200.4^{e} (11.0)	204.5^{e} (22.3)	205.3^{e} (8.8)	208.9^{e} (8.1)	212.6^{e} (14.3)	207.9^{e} (17.5)	204.8^{e} (27.9)
Vessel frequency /mm^{2}	6.5^{cde} (0.9)	6.48^{cd} (1.7)	5.5^{ab} (0.8)	6.0^{bc} (1.1)	5.1^{a} (1.3)	7.3^{efgh} (1.4)	10.2^{i} (2.6)	6.8^{cdef} (1.7)	8.1^{h} (0.9)	7.5^{fgh} (1.2)	7.7^{gh} (1.3)	7.0^{defg} (1.1)	8.1^{h} (1.1)
Vessel %	13.8^{abc} (2.2)	16.9^{de} (3.8)	20.6^{f} (3.2)	12.4^{a} (3.7)	12.9^{ab} (2.6)	13.4^{abc} (1.4)	20.9^{f} (7.6)	14.3^{bc} (3.0)	17.6^{e} (2.3)	17.0^{de} (1.4)	17.9^{e} (3.2)	15.3^{cd} (2.3)	16.4^{de} (3.1)
Fibre %	69.8^{f} (3.7)	59.7^{ab} (4.5)	63.3^{c} (3.5)	70.9^{f} (3.8)	66.6^{de} (4.0)	66.8d^{e} (2.6)	58.6^{a} (10.1)	68.5^{ef} (4.8)	61.9^{bc} (1.7)	61.9^{bc} (1.5)	61.7^{bc} (3.8)	65.9^{de} (3.7)	64.4^{cd} (3.2)
Parenchyma %	16.3^{a} (2.1)	23.4^{e} (2.6)	16.1^{a} (1.9)	16.8^{a} (3.1)	20.6^{cd} (2.7)	19.9^{bcd} (1.6)	20.5^{cd} (3.5)	17.3^{a} (2.6)	20.5^{cd} (2.2)	21.1^{d} (1.6)	20.7^{cd} (2.0)	18.8^{b} (2.3)	19.2^{bc} (1.8)
Fibre length, mm	1.1^{a} (0.1)	1.2^{b} (0.1)	1.1^{a} (0.1)	1.1^{a} (0.1)	1.3^{c} (0.1)	Fibre dimensions were not measured due to small core samples							
Fibre diameter, µm	27.4^{c} (2.6)	24.4^{a} (1.6)	23.9^{a} (1.3)	25.8^{b} (1.2)	27.0^{c} (1.8)								
Lumen width, µm	19.2^{d} (3.0)	15.1^{a} (1.3)	14.5^{a} (0.8)	16.6^{b} (0.3)	18.5^{c} (2.0)								
Double wall thickness, µm	8.2^{a} (0.4)	9.2^{c} (0.6)	9.4^{d} (0.5)	9.1^{c} (1.0)	8.5^{b} (0.8)								

Properties	Age Class IV											
	Mean											
	Burgi	**Berbera**	**Chouki**	**Nilambur**	**Vazhani**	**Thamara vellachal**	**Asamb u**	**Adilabad**	**Bhadra chalam**	**Allapalli**	**Pench**	**Rajpipla**
Early wood (EW)%	64.7^{ab} (8.5)	67.4^{bc} (6.1)	71.5^{cde} (7.7)	75.1^{efg} (4.2)	75.2^{efg} (2.9)	69.6^{cd} (5.0)	63.6^{a} (7.2)	74.4^{ef} (3.7)	73.5^{def} (5.8)	77.0^{fg} (6.1)	78.8^{g} (3.5)	73.4^{def} (5.6)
Late wood (LW)%	35.3^{fg} (8.5)	32.6^{ef} (6.1)	28.5^{cde} (7.7)	24.9^{abc} (4.2)	24.8^{abc} (2.9)	30.4d^{e} (5.0)	36.4^{g} (7.2)	25.6^{bc} (3.7)	26.5^{bcd} (5.8)	23.0^{ab} (6.1)	21.2^{a} (3.5)	26.6^{bcd} (5.6)
Vessel diameter, µm	179.8^{d} (21.6)	163.0^{bc} (17.8)	169.2^{c} (33.2)	150.9^{a} (17.1)	154.9^{ab} (10.1)	213.1^{e} (17.8)	187.1^{d} (31.7)	220.9^{e} (16.3)	216.4^{e} (21.4)	210.8^{e} (24.5)	216.6^{e} (22.2)	206.0^{e} (9.2)
Vessel frequency /mm^{2}	6.4^{b} (0.9)	6.9^{c} (0.9)	5.0^{a} (0.5)	7.7^{d} (1.3)	6.3^{b} (0..6)	8.6^{e} (0.9)	7.7^{d} (1.2)	8.5^{e} (2.0)	9.2^{f} (0.9)	6.8^{bc} (1.1)	7.3^{cd} (1.1)	7.2^{cd} (1.2)
Vessel %	19.5^{ef} (1.9)	23.8^{g} (7.3)	18.1^{de} (5.1)	13.2^{a} (0.8)	13.9^{ab} (0.8)	17.0^{cd} (2.6)	14.7^{ab} (4.2)	18.2^{de} (2.4)	20.7^{f} (4.7)	15.3^{bc} (2.6)	17.6^{de} (2.3)	14.6^{ab} (2.0)
Fibre %	64.4^{bc} (2.6)	61.6^{b} (8.4)	64.0^{bc} (8.4)	66.1^{c} (2.2)	65.1^{c} (1.8)	63.4^{bc} (3.1)	62.0^{b} (6.7)	63.8^{bc} (2.6)	58.9^{a} (6.3)	66.0^{c} (3.8)	68.7^{d} (3.1)	64.4^{bc} (3.0)
Parenchyma %	16.2^{b} (2.1)	14.6^{a} (2.5)	18.0^{c} (3.5)	20.7^{e} (2.6)	21.0^{e} (2.1)	19.6^{de} (1.3)	23.3^{f} (3.1)	18.0^{c} (2.4)	20.3^{e} (2.9)	18.6^{cd} (2.4)	13.7^{a} (1.1)	21.0^{e} (2.2)
Fibre length, mm	1.0^{a} (0.1)	1.3^{c} (0.1)	1.1^{b} (0.1)									
Fibre diameter, µm	26.8^{c} (2.7)	25.4^{b} (1.4)	24.0^{a} (1.1)									
Lumen width, µm	18.4^{b} (3.5)	15.4^{a} (0.6)	15.3^{a} (0.6)	Fibre dimensions were not measured due to small core samples								
Double wall thickness, µm	8.4^{a} (0.8)	10.0^{b} (1.5)	8.8^{a} (0.5)									

Properties	Age Class V											
	Mean											
	Basthar	Burgi	Nilambur	Vazhani	Parambi kulam	Thamara vellachal	Asambu	Dodda harve	Adilabad	Bhadra chalam	Allapilli	Pench
Early wood (EW) %	69.8^{c} (6.5)	59.6^{a} (9.5)	75.0^{d} (5.2)	75.3^{d} (7.7)	66.4^{b} (4.6)	70.5^{c} (6.7)	62.4^{a} (8.1)	77.8^{de} (5.2)	70.9^{c} (5.4)	74.9^{d} (4.1)	75.8^{de} (5.3)	78.6^{e} (4.9)
Late wood (LW)%	30.2^{c} (6.5)	40.4^{e} (9.5)	25.0^{b} (5.2)	24.7^{b} (7.7)	33.6^{d} (4.6)	29.5^{c} (6.7)	37.6^{e} (8.1)	22.2^{ab} (5.2)	29.1^{c} (5.4)	25.1^{b} (4.1)	24.2^{ab} (5.3)	21.4^{a} (4.9)
Vessel diameter, µm	169.0^{bc} (33.7)	173.4^{c} (29.5)	171.8^{c} (14.9)	150.6^{a} (11.7)	156.9^{ab} (10.9)	216.0^{e} (13.8)	191.9^{d} (36.4)	217.8^{e} (18.5)	209.1^{e} (21.9)	208.6^{e} (20.5)	213.3^{e} (24.9)	216.9^{e} (17.1)
Vessel frequency /mm^2	6.9^{cd} (0.7)	6.1^{ab} (1.2)	7.1^{d} (1.1)	7.2^{d} (1.0)	5.8^{a} (1.0)	8.3^{e} (1.6)	6.6^{bc} (1.4)	7.8^{e} (1.0)	8.2^{e} (1.4)	8.4^{e} (0.9)	8.0^{e} (1.5)	7.7^{e} (0.8)
Vessel %	20.3^{fg} (5.7)	20.5^{g} (4.9)	14.0^{ab} (2.5)	13.0^{a} (1.1)	14.8^{bc} (2.4)	17.9^{de} (2.9)	16.6^{cd} (5.0)	15.5^{bc} (2.5)	17.6^{de} (3.7)	17.32^{de} (2.3)	15.7^{c} (2.9)	18.4^{ef} (2.0)
Fibre %	59.0^{a} (5.8)	58.6^{a} (6.6)	66.9^{ef} (4.6)	67.1^{ef} (2.0)	64.2^{cd} (3.4)	63.2^{bcd} (4.2)	61.7^{b} (6.2)	67.8^{g} (4.1)	62.2^{bc} (6.0)	65.0^{de} (3.6)	65.2^{de} (3.8)	63.4^{bcd} (3.0)
Parenchyma %	20.7^{fg} (2.3)	20.9^{fg} (2.0)	19.1^{cde} (3.1)	19.9^{def} (1.7)	21.1^{fg} (2.3)	18.9^{bcd} (2.6)	21.7^{g} (2.5)	16.7^{a} (2.5)	20.2^{ef} (3.2)	17.8^{ab} (3.0)	19.2^{cde} (1.4)	18.2^{bc} (1.7)
Fibre length, mm	1.0^{a} (0.2)	1.1^{b} (0.1)	Fibre dimensions were not measured due to small core samples									
Fibre diameter, µm	22.9^{a} (1.8)	23.6^{b} (3.2)										
Lumen width, µm	13.1^{a} (0.7)	14.0^{b} (2.5)										
Double wall thickness, µm	9.8^{b} (1.1)	9.5^{a} (0.7)										

APPENDIX - 11

Correlation coefficients (Pearson 2-tailed) for interrelationships of selected wood anatomical properties like early wood (EW), late wood (LW), vessel diameter, vessel frequency, vessel, fibre and parenchyma percentage

Age Classes	Characteristic properties	Characteristic properties						
		1 EW%	2 LW%	3 Ves. dia	4 Ves. freq	5 Ves.%	6 Fib.%	7 Par.%
I	1.EW %	1	-1.000**	.629**	-.342**	.130	-.106	.025
	2. LW %		1	-.629**	.342**	-.130	.106	-.025
	3. Vessel diameter			1	-.527**	-.048	-.057	.113
	4. Vessel frequency				1	.225	-.135	-.020
	5.Vessel %					1	-.617**	-.066
	6. Fibre %						1	-.745**
	7.Parenchyma %							1
II	1. EW %	1	-1.000**	.133	-.053	.228**	-.083	-.111
	2. LW %		1	-.133	.053	-.228**	.083	.111
	3. Vessel diameter			1	.375**	.512**	-.659**	.512**
	4. Vessel frequency				1	.127	-.169*	.136
	5.Vessel %					1	-.794**	.206*
	6. Fibre %						1	-.758**
	7.Parenchyma %							1
III	1. EW %	1	-1.000**	.238**	.094	.273**	-.196**	-.012
	2. LW %		1	-.238**	-.094	-.273**	.196**	.012
	3. Vessel diameter			1	.200**	.391**	-.377**	.154**
	4. Vessel frequency				1	.405**	-.453**	.279**
	5.Vessel %					1	-.836**	.166**
	6. Fibre %						1	-.673**
	7.Parenchyma %							1
IV	1.EW %	1	-1.000**	.263**	.006	.213**	-.179**	-.004
	2. LW %		1	-.263**	-.006	-.213**	.179**	.004
	3. Vessel diameter			1	.186**	.266**	-.259**	.047
	4. Vessel frequency				1	.138**	-.249**	.195**
	5.Vessel %					1	-.748**	-.160**
	6. Fibre %						1	-.536**
	7.Parenchyma %							1
V	1. EW %	1	-.999**	.284**	.359**	.051	.063	-.190**
	2. LW %		1	-.283**	-.358**	-.051	-.062	.188**
	3. Vessel diameter			1	.290**	.406**	-.205**	-.192**
	4. Vessel frequency				1	.115*	.038	-.234**
	5.Vessel %					1	-.862**	.218**
	6. Fibre %						1	-.675**
	7.Parenchyma %							1

*** Correlation is significant at $P \leq 0.01$ level (2-tailed); * significant at $P \leq 0.05$*