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Genetic Diversity and Conservation of Teak

E. P. Indira
Forest Genetics & Biotechnology
K.M.Bhat
Wood Science & Technology
P.K.Thulasidas
Wood Science & Technology

Kerala Forest Research Institute
An Institution of Kerala State Council for Science, Technology and Environment
Peechi – 680 653, Thrissur, Kerala, India

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ABSTRACT OF THE PROJECT PROPOSAL

a. Project number : **KFRI 472/2005**

b. Title : **Genetic diversity and conservation of teak**

c. Funding agency : **KFRI Plan Fund**

d. Principal Investigator : **E.P. Indira**

e. Co-investigators : **K.M.Bhat**
P.K.Thulasidas

f. Duration : **April 2005-March 2010**

g. Objectives:

i) to identify population/ individual variations

ii) to study the genetic diversity with respect to morphological and wood characteristics

iii) to establish a germplasm bank

iv) to compare different ecotypes under uniform condition

h. Expected output:

Information on variations with regard to morphological and wood characteristics in different ecotypes of teak in India will be generated.

A germplasm bank will be established which will serve as a field laboratory to observe and compare different ecotypes under uniform conditions.

The information and gene pools will be of immense value in future breeding programmes.

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ABSTRACT

The present project evaluated the genetic diversity in twenty three natural teak (*Tectona grandis* L.f.) populations in ten states in India (Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Chattisgarh and Orissa) with respect to growth, tree form, leaf and seed characters. Wood properties were also analyzed.

Regarding the tree form characters, straightness, persistence of axis, branch size, branching mode, clear bole ratio and also bole defects like knots, twist, fluting etc were examined. Observations showed that Hudsa (Teli variety) from Dandeli, Karnataka, is the provenance with best tree form having first place for many of the tree form traits. There are other provenances which are best performers in one or two traits. Branching mode without double limbs had highly significant positive correlation with persistence of axis, straightness and less twisting. Hence, branching mode (which can be assessed at an early age) can be an indicator for axis persistence and straightness of a tree.

The results showed that at higher altitudes, trees had a tendency to grow double limbed, and twisted with less axis persistence. Rainfall had highly significant positive correlation with small branch size with horizontal branching pattern. Rainfall also had strong negative correlation with leaf pubescence and a negative correlation with seed filling percentage.

On evaluation of the physical properties of the wood samples, significant variations were noted between provenances. Tree diameter at breast height (DBH) showed a positive correlation with age and heartwood percentage. Higher growth rate with mean ring width of above 4.7 mm and greater heartwood content (>90%) were noted in trees grown in southern states like Kerala, Tamil Nadu and Karnataka. Hudsa (Teli variety) from Dandeli (Karnataka) attained highest heartwood percentage (93%) in age class II (25-34 years) and III (35 to 44 years) in spite of small log size. On a whole, Nilambur provenance also showed high heartwood proportion along with wider growth rings

indicating high growth rate. Teak from drier areas produced 10-15 percent less heartwood than teak from high rainfall areas with narrow growth rings as evident from this study.

Ring width differed significantly between the provenances and it varied within the age classes with maximum values recorded from Nilambur provenance (7.6 mm) followed by other provenances from Kerala and then Tamil Nadu (Ashambu), Karnataka, Maharashtra and Gujarat. The densest wood (692 kg/m3) was recorded from age class III in Banaswara provenance (Rajastan). Lightest wood (473 kg/m3) was obtained from age class I in Khariar provenance (Orissa) which was due to the faster growth rate at early years with a wide early wood band, large vessel diameter/ percentage, low fibre percentage and thin-walled fibres. The longest fibres (1.4 mm) were obtained from Konni.

Teak wood collected from drier localities of central parts of India were darker in colour than South Indian provenances. The Basthar provenance (Chattisgarh) possessed high amount of extractive content (12.3%, which is almost par with that reported from Nilambur provenance) and more attractive colour. Lignin content was found high in Burgi provenance (36.9%) from Madhya Pradesh.

Ex situ conservation of germplasm was established at Nilambur with 25 provenances. Konni, Arienkavu (Kerala) and Mandagadde (Karnataka) were found to be the best performers for early growth. There was high genetic coefficient of variation and moderate heritability for growth, which will help in exploiting the genetic gain through the selection of better provenances.

The study revealed that the South Indian teak provenances showed superior tree form, wood quality as well as growth characteristics suitable for future genetic conservation programmes. Development of hybrids between best performers for growth and excellent provenances for better tree form and other characters like extractive contents (an indicator for durability) would help the improvement of planting stock.

1. INTRODUCTION

Teak (*Tectona grandis* L.f.), belonging to family Verbenaceae, is one of the most important tropical hardwood species in the international market of high-quality timber extracted from both natural forests and plantations. Its timber qualities include attractiveness in colour and grain, durability, lightness with strength, ease of seasoning without splitting and cracking, ease of working and carving, resistance to termites, fungi, and weathering, etc. Teak forests occur naturally in India, Myanmar, Thailand and Laos and cover an area of about 23 million ha and constitutes about 75% of the world's high quality tropical hardwood plantations (FAO, 2001). In India, teak is distributed naturally in the peninsular region below 24° latitude over a wide range of climatic and geographic conditions. The total area of natural teak bearing forests is around 8.9 million ha (Tewari, 1992). The important teak forests are found in the States of Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka, Kerala, Gujarat, Orissa, Rajasthan and Manipur. Teak has developed into different ecotypes during the process of evolution since it occurs in different climatic and edaphic zones found over the entire range (Kedharnath and Matthews, 1962). The variations are seen in vigour, branching habit, straightness, size and colour of leaves, resistance to insect attack, strength, wood colour, grain pattern, fibre length and other characters. These variations may be morphological, physiological or genetical. Basic step in tree improvement programme is the identification and exploitation of the existing genetic variations. 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).

Based on the wood characters teak has been classified into many groups such as lime teak which has light coloured stem with lime concretion in its wood, oily teak which has hard, heavy and shiny wood, wrinkled teak which has its wood with wrinkled fibres and striped teak which has its wood with dark brown stripes. Teak from South India is more straight grained and stronger where as teak from North India though not strong has a very pleasant figure with dark and light coloured streaks (Muniswami, 1977). Teak occurring in rain shadow regions of Western Ghats like Shencottah and Singhampatti are slow grown, short boled, heavier and stronger with their wood close grained and twisted fibre, used for special purposes like axle of bullock carts, plough, beams and rafters (Krishnan Nair, 1997). Even within a small state like Karnataka, Kadambi (1972) has reported different ecotypes like Kakankote teak (Short, branchy with branches arching upwards), Shimoga teak (tall, well formed bole, few branches & rounded crown), Teli variety (oily teak) etc. These ecotypes are to be protected from dilution or loss. The natural teak forests found mixed with other species in various states are exploited extensively and replaced by plantations by which gene pools are eroded (Muniswami, 1977).

Teak is known to display wide variations in the wood characteristics among different growing conditions and regions in India (Bhat and Indira, 1998). 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). The Malabar teak (Nilambur, Kerala) from the Western Ghat region (with high rainfall- 2000-3000 mm) of India, generally displaying good growth and attains large dimensions with desired colour (golden yellowish brown colour) has a wide reputation in the world trade for ship and boat building. On the other hand, the central Indian teak from the drier region which tend to resist forest fire develop twisted/wavy grain, is reputed for better stem form, deeper colour, yield heavier, stronger and close grained timber with beautiful figure is preferred for furniture and decorative needs. From a preliminary study, it was found that percentage of logs with flutes and knots was greater in generally quicker growing location (Nilambur) than in slow growing area (Konni) (Balasundaran and Gnanaharan, 1997).

Hence, steps are to be taken at least to protect these gene pools which are of immense value in future breeding programmes. The establishment of a teak germplasm is of vital necessity to broaden the genetic base as well to conduct in depth studies on the genetic diversity in teak. The germplasm bank will serve as a field laboratory to observe and compare different ecotypes under uniform conditions.

Though these ecotypes of teak were reported from India, systematic analysis on the phenotypic and genetic variations in morphological and wood characters was not yet done. The data of such studies along with a germplasm will be of immense value in future breeding and other related work.

Hence, the project was taken up

i) to identify population/ individual variations,

ii) to study the genetic diversity with respect to morphological and wood characteristics,

iii) to establish a germplasm bank and

iv) to compare different ecotypes under uniform conditions

2. VARIATIONS IN TREE FORM, LEAF, DRUPE AND GROWTH CHARACTERISTICS AND GERMPLASM CONSERVATION

2.1 MATERIALS AND METHODS

Surveys were conducted in natural teak growing areas and few plantations in all teak growing states in India except Manipur. Twenty five populations from ten states, namely Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Chhattisgarh, Madhya Pradesh, Rajasthan, Gujarat and Orissa were selected for the present study (Table 1, Fig.1). Populations were selected and the geographic position of each locality like Latitude, longitude and altitude were noted using a GPS. Data on rain fall was also collected from other sources.

In order to identify the population/individual variations, morphological variations were critically observed and classified. Detailed observations on tree growth and tree form including branching pattern in general were taken in 40 standing mature trees per population. Seeds and leaf samples were collected from these 25 populations and variations in leaf characters and seed characters were noted.

An ideal teak tree is considered to be healthy, vigorous and straight having cylindrical and clean bole, a stem with persistence of axis and a light spreading branching with branch angles around 90^0. The deviations from the ideal situations are evaluated.

Tree growth like height and girth at breast height were measured. Qualitative characters such as tree form (like persistence of axis, straightness) and branching pattern (like branch size, branching mode etc.) are evaluated using the scoring system adopted for International provenance trial (Keiding *et al.*, 1986).

I. Characters of trees observed at the site of seed origin

A. Growth characters

The characters measured were tree height, girth at breast height and crown height. From this the proportion of clear bole height (crown height /tree height ratio) could be calculated which also influence the tree form. The girth - height relation also can be studied from the above measurements. Ten trees from each of the four randomly selected plots within each population (40 trees for each provenance) were used for taking measurements as well as for other observations with regard to tree growth, leaf and tree form characters.

B. Tree form

With respect to quality of the trees, tree form is important where a long, straight and defect free clear bole is desirable. If one can predict the bole character at a younger age, it will be very useful for marker assisted selection. Moreover, if characters are correlated, a tree breeder can select and improve the characters in a desired direction easily. Hence, the following characters were considered for assessing the tree form.

1. ***Branching mode***

Score 1- Double limbs,
Score 2- Pronounced scatter branching,
Score 3- Light forking,
Score 4- Light scatter branching,
Score 5- Regular spreading branches

2. *Branching type*

Score 1- Horizontal
Score 2 - Upward

3. *Branch thickness/size*:

Here 5 classes were identified as follows.

Score 1- Heavy branches of more than half the size of the main stem,
Score 2-Trees with heavy branches of half the size of the main stem,
Score 3-Trees with medium branches with one fourth to half the size,
Score 4- Light branched with one fourth size of the main stem,
Score 5- Light branched trees with very light branches with less than one-fourth size of the main stem

(Scores 4 and 5: ***Light branched trees***)

The number of trees with light branches scoring values 4 or 5 were pooled together to estimate the proportion of light branched trees.

4. *Persistence of axis*

Persistence of unbroken axis is an important characteristic related to commercial value of the bole. The total height of the tree was divided into eight equal parts and numbered from the basal part to the top. The scoring is as given below.

Score 1- Tree is multiple stemmed at the ground level,

Score 2- When the main stem branched out in the lowest quarter,
Score 3- Main stem branched out in lower second quarter,
Score 4- Main stem branched out in lower third quarter,
Score 5- Main stem branched out in lower fourth quarter,
Score 6,7,8 - Main stem forked in the fifth, sixth or seventh quarter
Score 9 - Complete persistence of axis
} ***Trees with good axis persistence***

The trees with scores 4 to 6 were considered to have good axis persistence.

5. *Straightness*

Five classes were given for scoring straightness.

Score 1- Trees with crooked and more than three serious bends,
Score 2- Trees crooked and with 1 to 2 serious bends,
Score 3-Trees slightly crooked with many bends,
Score 4 - Trees slightly crooked and few bends,
Score 5 - Straight trees
} ***Straight trees***

The number of trees from each plot qualifying for score 4 and 5 were pooled to find out the proportion of straight trees.

6. *Position of lowest branch*

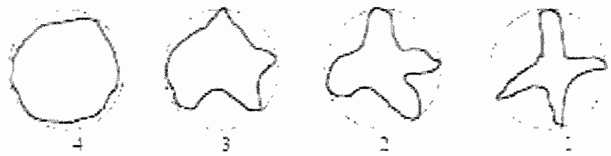
The total height of the tree was divided into eight equal parts and numbered from the basal part to the top as explained earlier. Position of lowest branch is the height at which lowest branch occur.

7. ***Tree height –crown height ratio***

As the trees are in the natural forest, the age of the trees is not known and so the measurement of clear bole height may not be useful. Hence, the proportion of clear bole height (tree height /crown height) has been taken so as to give the clear bole ratio.

8. ***Fluting class***

As shown in the picture below fluting class has been identified



Score 1- Very heavy fluting
Score 2- Heavy fluting
Score 3 – Moderate fluting
Score 4 – Free from fluting

9. ***Twisting***

Score 1 - Very heavy twisting
Score 2 - Heavy twisting
Score 3 - Moderate twisting
Score 4 - Light twisting
Score 5 - No twisting

10. ***Knots***

In the tree a knot is either the base of a side branch or a dormant bud.. It is a particular type of imperfection in a piece of wood; it will affect the technical properties of the wood, usually for the worse, but may be exploited for artistic effect. Knots materially affect cracking (known in the US as checking, and the UK as shakes) and warping, ease in working, and cleavability of timber. They are defects which weaken timber and lower its value for structural purposes where strength is an important consideration. In some decorative applications, wood with knots may be desirable to add visual interest.

Score 1- 75 % stem have knots
Score 2 -50% stem have knots
Score 3 -25% stem have knots
Score 4 - Free from knots

11. ***Epicormics***

Epicormic branches are formed as a response to injury or environmental stress or to sudden change in conditions, such as increased light after heavy thinning.. Epicormic branches are new branches that replace injured, pruned or declining branches.

Commonly, epicormic branches form on the stems and branches of topped trees. Epicormics are normally considered to be undesirable from an economic point of view. It may, however, be of adaptive value. Formation of epicormics is a natural reaction to defoliation, which is very frequent in teak plantations.

All the values including score values measured or estimated for tree form characters have been arranged in such a way that a high value would correspond to a positive characteristic. Percentage of light branching trees, straight trees and trees with good axis persistence were also worked out as shown above. Hence, including this there are altogether fourteen variables.

C. Leaf characters

Variations were reported in leaf characters particularly leaf shape, texture etc., hence the following characters were observed in forty trees from each provenance. This observation was taken so as to identifify possible markers if any, so as to distinguish each provenance form others.

1.Leaf type (Petiolate & sessile)
2.Leaf texture (Rough & smooth)
3.Leaf shape (Elliptical, obovate & ovate)
4.Leaf pubescence (Pubescent, less pubescent, glabrous)

D. Fruit and seed characters

A number of studies have been conducted in teak drupes and seeds, but even now the exact reason for low percentage of germination is not fully understood. From each locality, seeds were collected from 10 randomly selected trees and the seeds were bulked. From each lot of bulked seeds, three replications with twenty seeds each were taken and the following observations were taken.

1. Physical characters

Physical characters like drupe weight (100 drupes), seed weight (twenty five seeds), fruit diameter (length wise), fruit diameter (breadth wise), fruit length- breadth ratio, shell weight, shell diameter (length wise), shell diameter (breadth wise), shell length-breadth ratio, mesocarp weight and mesocarp thickness were measured so as to find out the relation between these characters with seed filling, viability and germination.

Mesocarp values were deduced from the difference between the drupe and shell measurements. For 25 seed weight, drupes were broken and undamaged seeds were collected. Twenty five seeds with three replications were weighed using highly precise electronic balance. 100 drupe weight was taken using seed lots containing hundred seeds with three replications.

2. Characters related to fruit filling and viability

Fruit filling percentage, seed viability, maximum possible germination (MPG) and germination percentage were also studied which all affect fruit viability. Though each drupe contains four locules, only less than four seeds are seen generally. Hence, to find out the filling percentage, drupes were broken and number of seeds was counted. For seed viability test, twenty seeds with three replications were soaked in 1% solution of 2,3,5 triphenyl tetrazolium chloride for 4 hours in the dark. Completely stained seeds were counted as viable and expressed in percentage. The drupes having at least one locule filled with visually healthy seeds are considered as germinable and the percentage of these drupes was given as maximum possible germination (MPG) percentage.

For germination test, three replications of hundred seeds were taken and the seeds were given four cycles of alternate soaking (one day) and drying (one day). They were sown in trays filled with sand. Multiple seedlings from a fruit were counted as one as per International Seed Testing Association (ISTA) (1993) standard. Germination was expressed in percentage after one year long observation.

3.Biochemical aspects

Biochemical aspects like Mesocarp ash, Mesocarp lignin, Endocarp ash and Endocarp lignin were determined following the methods shown below so as to find out the relation between these characters with germination.

Ash Content

Ash content of the corky mesocarp and stony endocarp are gravimetrically estimated. One gram of finely powdered mesocarp and endocarp were treated at 600 C° in a muffle furnace for four hours. The remaining ash was weighed and expressed as percentage of ash content.

Lignin

The lignin content of wood and pulp is generally determined as Klason lignin in accordance with the standard method of Technical Association of the Pulp and Paper Industry 'TAPPI test method T222 om-88' ((TAPPI Test Methods, 2002) and the same method is used here for mesocarp and endocarp lignin estimation.

Germplasm establishment and genetic evaluation

A germplasm bank will serve as a field laboratory to observe and compare different ecotypes under uniform conditions. For establishing the same, seeds were collected from all the 25 selected provenances. These seeds were put in the nursery beds and observations on germination were taken. When the seedlings were 3 months old, they were transferred to polythene bags and at the age of one year, they were transplanted to the field at Nilambur following randomized Block design. Twelve seedlings of each of the 25 provenances were field planted in each of the three blocks at a spacing of 2 x 2 metre. As enough seedlings were not available, Hudsa from Dandeli could be planted only in the first block. Growth measurements like height, collar diameter and internode length were taken at every three months interval.

Statistical analysis

Statistical analysis was done 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. σ^2_{Prov} is the variance component for provenance. Phenotypic and Genotypic coefficient of variation (Pcv and Gcv respectively) and heritability were computed following Singh & Chaudhary

(1985). Correlation coefficients between different parameters were estimated after Goulden (1952). In order to find out homogenous groups for each trait, Dunkan's Multiple Range Test (DMRT) was done though SPSS.

The values of genetic parameters were classified as given below.

Genetic parameter	Low	Moderate	High
Gcv and Pcv	0 - 10 %	10 - 20 %	More than 20%
Genetic gain	,, ,,	,, ,,	,, ,,
Heritability	0 - 30 %	30 - 60 %	More than 60 %

Clustering

Clustering was carried out to understand the over all similarity between the provenances and was done using average linkage between groups algorithm. This corresponds to the "Group average method" reported by Everitt (1974).

Principal Component analysis

The factor analysis was carried out using SPSS software package. The analysis was done on the correlation matrix. Principal component analysis was used as the method of factor extraction (Harman, 1976) and all factors with eigen values >1.00 were considered. These factors were then subjected to orthogonal rotation such as varimax rotation with Kaiser Normalisation (Kaiser, 1958).

Fig.1 Populations used for Germplasm collection and genetic studies

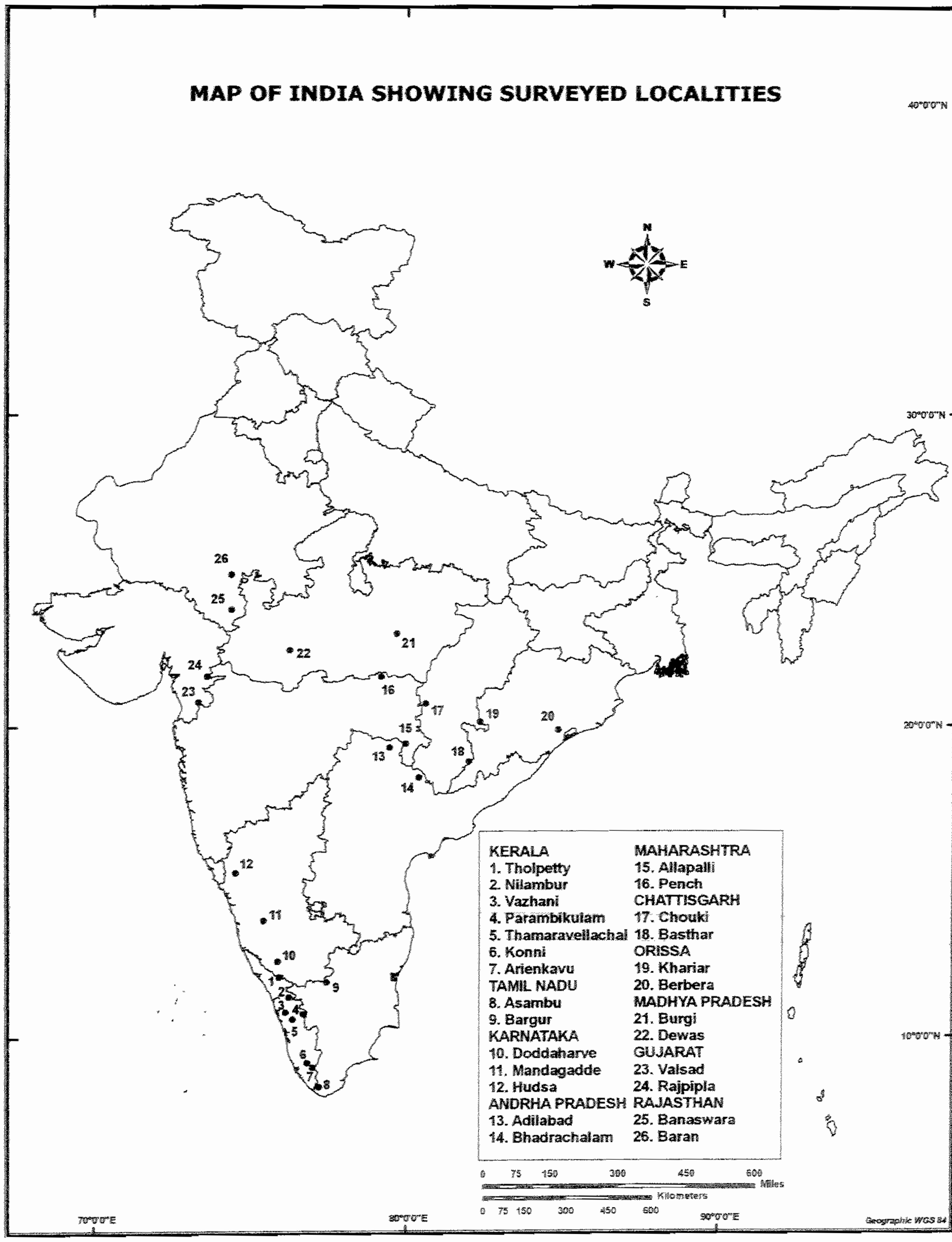


Table 1. Teak populations selected from different states

State	Forest Division & Location		Geo position		Elevation (m.a.s.l)	Rain fall
			Latitude (N)	Longitude (E)		
Kerala	1. Wynad	Tholpetty	11^{0} 54’	76^{0} 05’	752	2137
	2. Nilambur	Karulai	11^{0}20'	75^{0}21'	68	2353
	3. Peechi-Vazhani W.L.S., Thrissur	Vazhani (Machad Range)	10^{0}46’	76^{0}13’	58	2730
	4. Parambikulam	Parambikulam	10^{0} 21'	76^{0} 48'	560	1890
	5. Peechi-Vazhani W.L.S., Thrissur	Thamaravellachal (Peechi)	10° 35’	76° 25’	80	2730
	6. Konni	Konni	9^{0} 10'	76^{0} 57'	220	2229
	7. Thenmala	Arienkavu	8^{0} 59'	77^{0} 07'	381	1694
	9. Chinnar	Chinnar	10^{0} 32’	77^{0} 19’	968	1431
Tamil Nadu	8. Kanyakumari	Ashambu	8^{0} 22’	77^{0} 18’	200	1226
Karnataka	10. Hunsur	Doddaharve (Periyapatna)	12^{0} 24’	75^{0} 57’	877	1258
	11.Shimoga (Thirthahalli subdiv)	Mandagadde	13^{0} 46’	75^{0} 29’	592	1536
	12. Haliyal (Dandeli)	Hudsa (Virnoli) (Teli variety)	15^{0} 15’	74^{0} 37’	531	1860
Andhra Pradesh	13.Adilabad	Adilabad (Echoda)	19^{0} 18'	78^{0} 34'	356	1061
	14.Bhadrachalam N.	Bhadrachalam (Dhummagudam)	18^{0} 31'	80^{0} 57'	181	1453
Maharashtra	15. Allappalli	Allapalli	19^{0} 25'	80^{0} 05'	157	1451
	16. Nagpur	Pench Tiger reserve (Pipariya)	21^{0} 34'	79^{0} 17'	425	1060
Chhattisgarh	17. Rajnandagaon	Chouki	20^{0} 41'	80^{0} 43'	382	1449
	18. Basthar	Basthar (Machkot)	18^{0} 51'	82^{0} 08'	489	1493
Orissa	19. Khariar	Khariar (Sinnapally)	20^{0} 06'	82^{0} 24'	300	1333
	20. Khurda	Berbera (Balugaon)	19^{0} 52'	85^{0} 02'	213	1287
Madhya Pradesh	21. Jabalpur	Burgi	22^{0} 57'	79^{0} 47'	376	1195
	22. Dewas	Dewas (Punjapura)	22^{0} 25'	76^{0} 21'	227	928
Gujarat	23.Valsad North	Valsad (Vasda)	20^{0} 45'	73^{0} 28'	164	2100
	24. Rajpipla East	Rajpipla (Sagbara)	21^{0} 36'	73^{0} 44'	403	1213
Rajasthan	25. Banaswara	Banaswara (Ghatol)	23^{0} 44'	74^{0} 30'	225	853
	26. Baran	Baran (Nahargarh)	24^{0} 51'	76^{0} 46'	308	869

2.2. RESULTS AND DISCUSSION

I. Characters of trees at the site of seed origin

A. Growth characters

As the trees are growing in natural forests, the growth as such can not be compared. However, the proportion of clear bole (tree height/ crown height ratio) could be calculated which was used for analyzing the tree form characters.

B. Tree form characters

With regard to tree form characters, provenances are highly significantly different (0.01 level) for all the characters under study. The mean values/scores for each character is given in Table 2. Few of the tree form variations are given in Plates 1 and 2.

The results show that provenance Hudsa (Teli variety) from Dandeli Division of Karnataka is the best performer for many of the tree form characters such as branching mode without double limbs, good axis persistence, highest position for lower branches & higher tree ht/crown height ratio, straightness as well as percentage of straight trees and also for percentage of trees with good axis persistence (Table 2). But it has more knots. Nilambur is the knot free provenance and it is having the second highest percentage of trees with good axis persistence. Tholpetty has the highest percentage of light branched trees with very small branch size. It has a trend for horizontal branching also (Figs 2 and 3). Valsad from Gujarat is the best provenance for less twisting bole.

With regard to bad performers, Chinnar has the tendency for more double limbs and crooked bole. Baran is the seed source branching at a lowest height and also for more crooked trees. Adilabad has more knots where as Mandagadde has more fluting and it has no straight boled trees. Ashambu, Doddaharve and Madagadde are having larger branch size. Doddaharve also has the lowest percentage of light branched trees.

Experiments elsewhere have shown that stem straightness, clear bole and persistence of stem axis are strongly inherited (i.e. heritability $h^2 = 0.70$) at provenance level in teak (Harahap and Soerinegara, 1977; Keiding *et al.*, 1986; Kaosa-ard, 1993). Based on this information, it is clearly indicated that these characters can be largely improved through provenance selection. Hence, provenances like Hudsa could be exploited for developing trees with faster growth and tree form through hybridization.

A tree with drooping branches

A tree with upward branching

Tree with twisted bole

Plate.1 Different tree forms

Plate 2a. Tree with good axis persistence

Plate 2b. Tree with knots

Table 2. Mean performance for each character in different provenances

Prov	Branch Mode	Persistence of axis	Lowest branch	Straightness	Free from twist	Free from Knots	Free from Flute	Small branch size	Free from epicormics	Branch -Type	% of light branch trees	% of trees with axis persistece	% of straight trees	Tree ht crown ht ratio
Arienkavu	2.22 bcdef	5.45 def	2.05 def	1.43 fghij	4.36 ef	3.38 abc	2.73 def	3.08 def	3.38 abcde	1.30 gh	12.50 efgh	57.50 def	15.00 cdefgh	1.95 def
Chinnar	**1.88** i	5.20 f	2.25 de	**1.00** ij	3.67 gh	3.38 abc	2.75 def	3.13 cdef	**3.88** a	1.55 bcde	15.00 cdefgh	60.00 cdef	2.50 gh	1.93 ef
Konni	2.75 ab	6.38 abc	1.70 efgh	1.28 ghij	3.87 fg	3.13 bcde	2.85 cdef	3.40 b	3.03 efgh	1.33 fgh	37.50 ab	80.00 abcd	**0.00** h	**2.21** bcde
Nilambur	2.55 abcd	6.68 ab	1.08 ijkl	1.90 defgh	3.98 def	**3.68** a	2.68 def	3.38 bc	3.28 cdefg	1.63 abcd	27.50 abcdef	**92.50** a	22.50 bcdef	2.53 b
Parambikulm	2.04 def	**5.13** f	0.93 jkl	1.73 defghij	3.38 h	3.20 bcde	3.30 abc	3.35 bcd	2.83 fghi	1.40 efgh	37.50 abc	**47.50** f	22.50 bcdef	2.02 def
Vazhani	2.13 cdef	6.20 bcde	1.13 hijkl	1.90 defgh	3.59 fg	2.38 g	2.48 ef	3.33 bcde	2.40 ij	1.30 gh	35.00 abcd	80.00 abcd	27.50 bcd	2.44 bc
Tholpetty	2.35 abcdef	5.83 bcdef	1.65 fghi	1.65 efghij	3.60 fg	3.50 ab	3.13 bcd	**3.68** a	3.50 abcd	**1.25** h	**45.00** a	70.00 bcdef	12.50 cdefgh	1.95 def
Ashambu	2.15 cdef	5.35 ef	1.70 efgh	1.18 hij	4.08 bcdef	2.93 def	2.93 cde	3.03 f	3.70 ab	1.70 abcd	5.00 gh	67.50 bcdef	5.00 fgh	2.16 cde
Hudsa (Teli)	**2.88** a	**7.18** a	**4.58** a	**3.88** a	4.58 abc	**1.73** h	3.40 ab	3.13 cdef	3.10 defgh	1.60 abcde	12.50 efgh	**92.50** a	**67.50** a	**3.55** a
Doddaharve	2.45 abcde	6.43 ab	2.50 cd	1.40 ghij	4.00 cdef	2.85 ef	2.85 cdef	3.03 f	**3.88** a	1.78 ab	**2.50** h	77.50 abcd	2.50 gh	1.96 def
Mandagadde	2.00 ef	5.23 f	1.85 efg	1.03 ij	3.85 fgh	2.90 ef	2.43 f	3.03 f	3.28 bcdef	**1.80** a	5.00 gh	65.00 bcdef	**0.00** h	**2.16** cde
Adilabad	2.45 abcde	6.13 bcde	0.93 jkl	1.73 defghij	4.70 a	2.65 fg	2.68 def	3.10 def	2.20 j	1.53 cdef	10.00 efgh	72.50 abcde	10.00 defgh	1.90 ef
Bhadrachalam	2.58 abcd	6.40 ab	2.83 bc	1.78 defghi	4.38 abcde	3.10 bcde	2.73 def	3.08 def	2.78 ghi	1.78 ab	7.50 fgh	85.00 ab	7.50 efgh	2.39 bc
Allappally	2.58 abcd	6.63 ab	1.48 fghij	2.76 bc	4.60 abc	3.03 cdef	2.53 ef	3.30 bcdef	2.20 j	1.55 bcde	30.00 ahcde	85.00 ab	32.50 bc	2.44 bc
Pench	2.28 bcdef	6.30 abcd	1.13 hijkl	2.23 bcdef	4.75 a	3.50 ab	3.08 bcd	3.08 def	2.88 fghi	1.70 abcd	7.50 fgh	82.50 abc	25.00 bcde	2.01 def
Rajpippla	2.15 cdef	5.50 cdef	1.18 hijkl	1.43 fghij	4.80 a	3.03 cdef	2.68 def	3.05 ef	3.58 abcd	1.72 abcd	5.00 gh	57.50 def	7.50 efgh	2.13 cde
Valsad	2.73 ab	6.70 ab	1.25 ghijk	2.23 bcdef	**4.88** a	2.80 ef	3.10 bcd	3.28 bcdef	3.53 abcd	1.68 abcd	25.00 abcdef	87.50 ab	22.50 bcdef	2.04 def

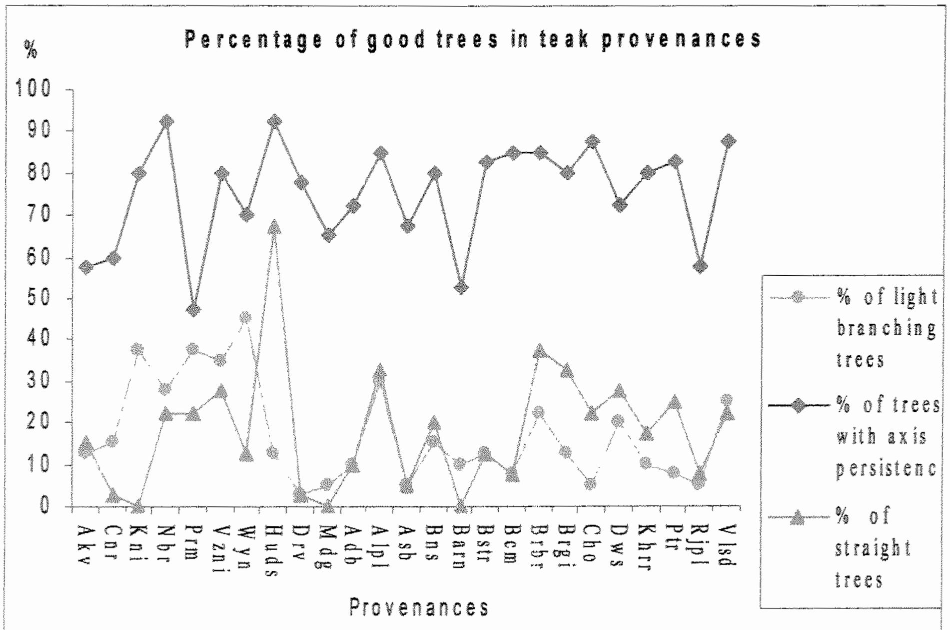
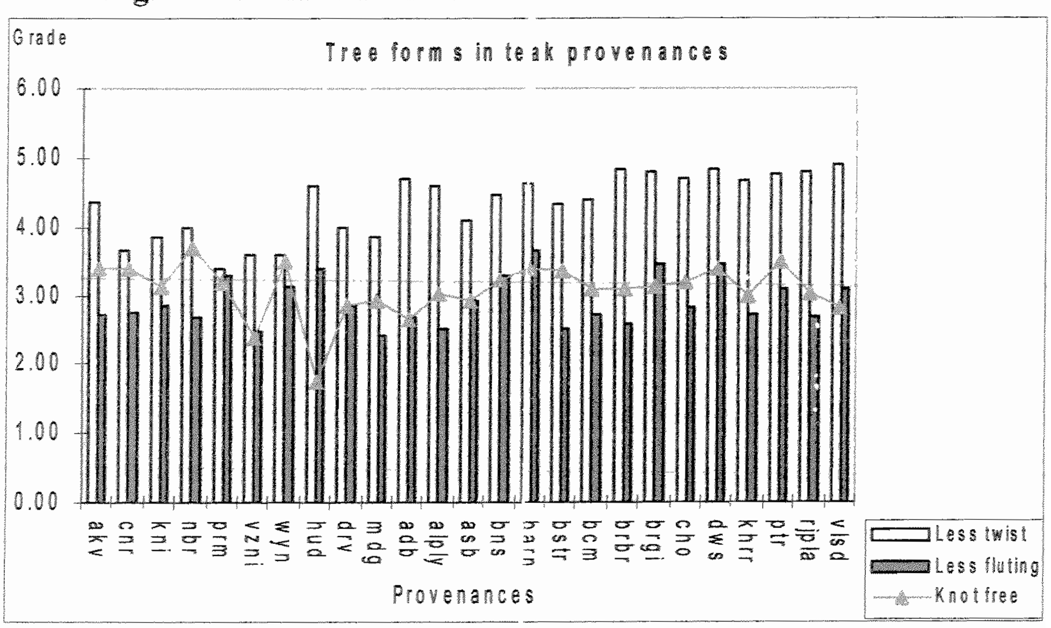


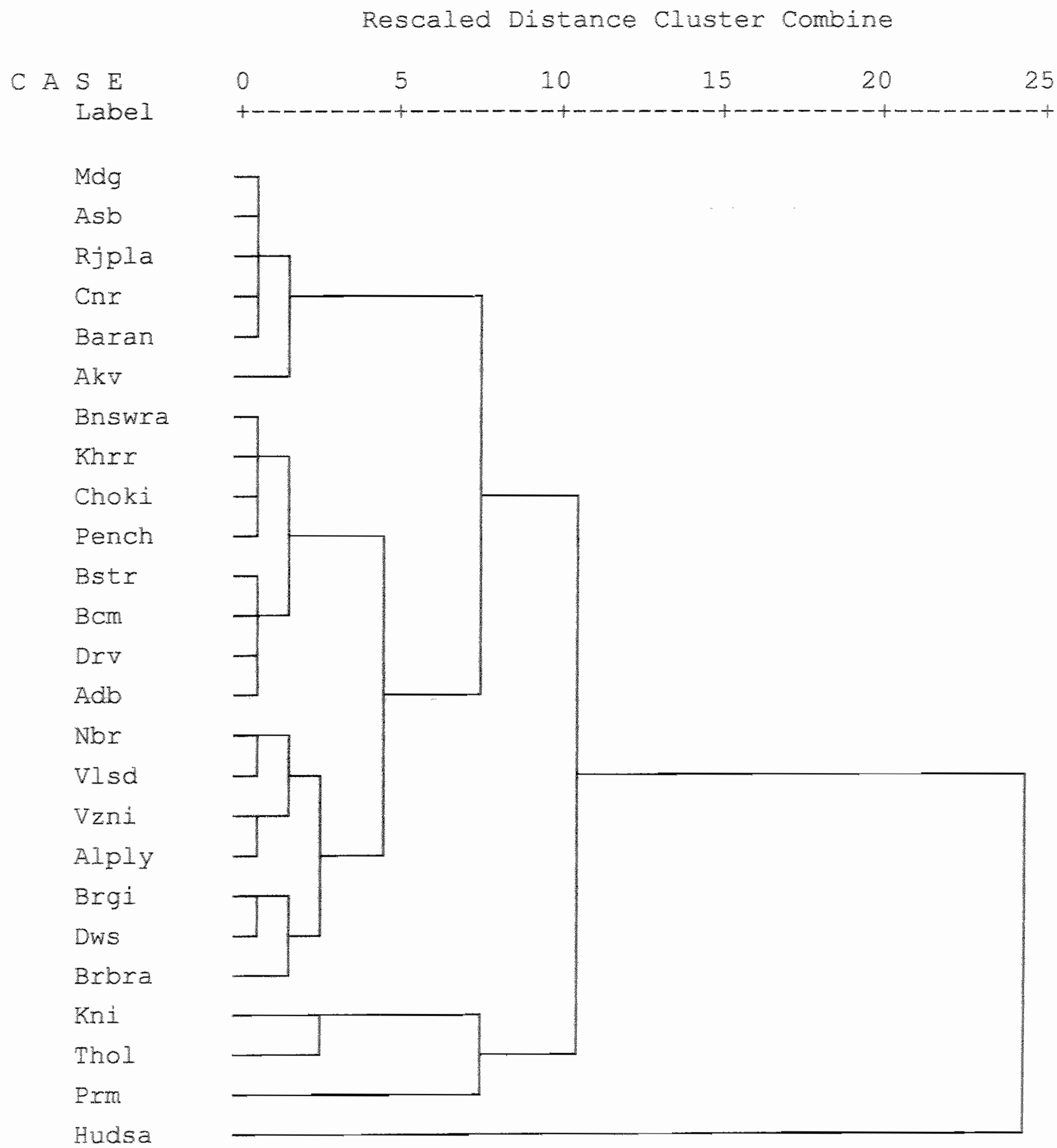
Fig. 2. Provenances for different tree forms

Fig. 3. Provenances for defect free boles



Through hierarchical clustering, twenty five seed origins can be classified into 5 groups, if allowing 25 percent variability within a group (Fig.4). There is no formation of clusters in relation to geographical proximity. Hudsa stands separately and so is the case with Parambikulam also. Konni and Tholpetty are in third cluster. Mandagadde, Ashambu, Rajpipla, Chinnar, Baran and Arienkavu form the fourth group. Other 15 provenances are grouped in to the fifth cluster.

Fig. 4. Dendrogram showing similarity beteen provenances based on tree form



Correlation between tree forms and geo-climatic factors

The correlation between all the traits for tree form is given in Table 3. The relation between these traits with those of geo-climatic factors is also given. There is a highly significant negative correlation between light branches and upward branching. Hence, if branch size is more, there is tendency for upward branching rather than horizontal branching. Horizontal branching with very light branches is preferred for better tree form.

Branching mode without double limbs has highly significant positive correlation with persistence of axis, straightness and less twisting. This shows that from the branching mode, which can be assessed at an early age, we can infer the tendency for axis persistence and straightness of a tree with out waiting till maturity.

Altitude has negative correlation with branching mode (without double limbs), less twisting and percentage of trees with good axis persistence which proves that at higher altitudes, trees tend to be more double limbed, twisted and with less axis persistence. Rain fall has highly significant positive correlation with small branch size and also with percentage of light branched trees. Rain fall has significant negative correlation with less twisting and also with branching type (upward branches). This result shows that at higher rain fall areas, trees tend to have horizontal branching but will be more twisted. It is generally known that under very moist conditions, the tree is large and fluted (Kaosa-ard, 1998), but the present study could not find any significant correlation between rain fall and fluting though there is a negative correlation.

Principal components for the traits under tree form

Branching mode, persistence of axis, height at the lowest branch occur, straightness, less twisting, knot free, less fluting, low branch size, less epicormic branches, branching type (horizontal or upward), tree-crown ratio, percentage of light branching trees, percentage of trees with axis persistence and percentage of straight trees were the variables included for the analysis.

The extraction value of the communalities of all the variables is sufficiently high. Least variance is explained in the case of freedom from knots, which is also greater than 74 percent. Hence, all the variables were included in the analysis.

Table. 3. Correlation between tree form characters and geo-climatic factors

Traits & geo-climatic factors	Branching Mode	Persis of Axis	Pos.of low Branch	Straightness	Twist	Knots	Fluting	Branch size	Epicormics	Branch type	% light branching trees	% trees with good axis persis	% of straight trees	Tree-Crown ratio
Branch Mode	1	.875**	.353	.614**	.575**	-.229	.099	.112	-.071	.156	.076	.747**	.442*	-.373
Persis of Axis		1	.349	.757**	.553**	-.320	-.055	.111	-.186	.151	.070	.933**	.608**	-.456*
Pos.of lowest branch			1	.331	-.060	-.445*	-.230	-.148	.279	.166	-.175	.331	.314	-.637**
Straightness				1	.533**	-.436*	.205	.115	-.297	.027	.115	.655**	.954**	-.443*
Less twist					1	-.114	.215	-.334	-.058	.473*	-.412*	.451*	.365	.106
Less knots						1	.046	.178	.255	-.045	.113	-.262	-.464*	.436*
Less fluting							1	.060	.036	-.063	.045	-.177	.249	.322
Branch size								1	-.171	-.664**	.947**	.095	.156	-.109
Epicormics									1	.299	-.312	-.167	-.285	.210
Branch type										1	-.721**	.195	-.099	-.060
% light branching tree											1	.033	.184	-.175
% trees with good axis persis												1	.515**	-.503*
% of straight trees													1	-.455*
Tree-Crown-Ratio														1
Latitude	.370	.318	-.249	.362	**.840****	.082	.331	-.314	-.102	**.473***	-.350	.214	.209	.310
Longitud	.280	.284	.198	.230	.255	.213	-.329	-.081	.053	.145	-.122	.289	.106	.070
Altitude	**-.421***	-.386	.276	-.293	**-.436***	.079	.060	-.082	**.449***	-.020	-.169	**-.397***	-.258	.186
Rain Fall	.026	.154	.132	.034	**-.524****	-.209	-.290	**.665****	-.103	**-.556****	**.680****	.219	.153	-.380

**, * significant at 1% and at 5% respectively

Table 4. Variation in the tree form characters under five factors

Variable	Factor				
	1	2	3	4	5
Branching Mode	**0.801**			0.369	
Persistence of axis	**0.908**			0.322	
Height at lowest branch	**0.509**		**-0.673**		0.375
Straightness	**0.906**				
Twist	0.453	**-0.547**	**0.583**		
Knot	**-0. 546**		0.423	**0.506**	
Flute			**0.595**	-0.418	**0.571**
Branch size		**0.908**			
Epicormics		-0 .417		0.417	**0.690**
Branching type		**-0 .844**			
Tree-crown ratio	**0.734**		-0.499		
Percentage of light branching trees		**0.959**			
Percentage of trees with good axis persistence	**0.834**			0.395	
Percentage of straight trees	**0.818**			-0.349	

Variation below 30% not given in the Table

According to Kaiser's criterion, the number of factors to be extracted equals the number of eigen values higher than one. Hence, five factors have been identified, which altogether accounted for 87 percent of the total variation in tree form characters. A total of 36.03 percent of the total variance is explained by the first factor, 57.84 percent of their variance is explained by first & second factors, 70.18 percent of the total variance of all variables is explained by three factors, four factors explain 79.59 percent of the total variance and five factors explain 87.25 percent of the total variance.

Looking at the data presented in the Rotated Component Matrix, it can be observed that seven variables are best correlated to the first factor. The first factor, named as 'Tree bole characters', includes straightness (90.6%), persistence of axis (90.8%), branching mode (80.1%), tree- crown ratio (73.4%) and the height at lowest branch occur (50.9%), free from knots (-54.6%) and also with percentage of trees with axis persistence (83.4%) and percentage of straight trees (81.8%) (Table 4). Second factor is given the name 'Branching factor', is a combination of percentage of trees with light branches (95.9%), small branch size (90.8%) and horizontal branching type (84.4%) and twisting (-54.7%).

Third factor is an assemblage of the height at lowest branch occur (-67.3%), less fluting (59.5%) and less twisting (58.3%). Fourth factor is correlated with fewer knots (50.6%) and fifth factor with fewer epicormic branches (69%) and less fluting (57.1%).

Leaf characters

Provenances are highly significantly different (0.01 level) for each leaf character under observation. The percentage of trees with petiolate and sessile leaves, rough and smooth textured leaves, different shapes of leaves and leaf pubescence are given in Table 5. The Dunkan's Multiple Range Test (DMRT) shows the homogenous groups for each character (Table 5).

The data show that in Kerala provenances, Nilambur stands separately having 87.5% of the trees with sessile leaves. Like wise in Berbera (Orissa), all the trees are with sessile leaves. Regarding leaf shape, only Parambikulam is having most of its leaves as obovate. All other provenances have most of their leaves to be elliptical. Ovate leaves are seen only in Chinnar, Arienkavu, Konni, Vazhani, and Kharriar (Table 5). Leaves of all the provenances except those from Kerala as well as Doddaharve (Karnataka) and Ashambu (Tamil Nadu) are pubescent.

On hierarchical clustering five clusters were formed on allowing 25 % variability with in provenances, first one is Nilambur and second one is Ashambu (Fig.6). Third cluster consists of Arienkavu, Chinnar, Konni, Vazhani, Tholpetty, Doddaharve and Parambikulam. Basthar, Bhadrachalm and Berbera formed another cluster. The fifth cluster comprised of provenances from North and Central India along with Mandagadde and Hudsa from Karnataka. On allowing 40% variability within provenances, all the provenances from Kerala are in one cluster.

Correlation between leaf characters and geo-climatic factors

Correlation between leaf characters like shape, texture, pubescent was worked out with geo-climatic factors like latitude, longitude, altitude and rainfall. Table 6 shows that rainfall has highly significant negative correlation with rough leaves and pubescent leaves. Trees in high rainfall areas have smooth leaves with scanty pubescence. The observation that a species produced more pubescent leaves under arid than under humid

Table 5. Percentage of trees with different leaf type, texture, shape and pubescence

Prov	Petiolate	Sessile	Rough	Smooth	Elliptical	Obovate	Ovate	Pubescent	Scanty Pubes
Arienkavu	95 abc	5	12.5 cde	87.5	85 cd	12.5 bcde	2.5 cd	2.5 d	97.5
Konni	95 abc	5	10 de	90	72.5 ef	22.5 b	5 bc	5 cd	95
Chinnar	100 a	0	7.5 de	92.5	80 de	10 cdef	10 a	0 d	100
Parambikulam	95 abc	5	22.5 cd	77.5	**40 f**	**60 a**	0 d	17.5 bc	82.5
Nilambur	**12.5 g**	**87.5**	25 c	75	97.5 ab	2.5 ef	0 d	20 b	80
Vazhani	92.5 abcd	7.5	25 c	75	77.5 de	15 bcd	7.5 ab	17.5 bc	82.5
Tholpetty	95 abc	5	20 cde	80	80 de	20 bc	0 d	15 bcd	85
Doddaharve	90 abcd	10	22.5 cd	77.5	95 abc	5 def	0 d	17.5 bc	82.5
Mandagadde	42.5 f	57.5	95.8 a	4.2	100 a	0 f	0 d	95.8 a	4.2
Hudsa	82.5 abcde	17.5	49.5 b	50.5	87.5 bcd	12.5 bcde	0 d	100 a	0
Ashambu	77.5 cde	22.5	10.9 cde	89.1	100 a	0 f	0 d	10.9 bcd	89.1
Adilabad	100 a	0	100 a	0	100 a	0 f	0 d	100 a	0
Bhadrachalam	95 abc	5	91.7 a	8.3	100 a	0 f	0 d	91.7 a	8.3
Allapally	75 de	25	100 a	0	100 a	0 f	0 d	100 a	0
Pench	85 abcde	15	100 a	0	100 a	0 f	0 d	100 a	0
Banswara	67.5 e	32.5	100 a	0	100 a	0 f	0 d	100 a	0
Baran	100 a	0	100 a	0	100 a	0 f	0 d	100 a	0
Valsad	77.5 cde	22.5	100 a	0	100 a	0 f	0 d	100 a	0
Rajpippla	77.5 cde	22.5	100 a	0	100 a	0 f	0 d	100 a	0
Dewas	80 bcde	20	100 a	0	100 a	0 f	0 d	100 a	0
Burgi	97.5 ab	2.5	100 a	0	100 a	0 f	0 d	100 a	0
Basthar	92.5 abcd	7.5	100 a	0	100 a	0 f	0 d	100 a	0
Choki	90 abcd	10	100 a	0	100 a	0 f	0 d	100 a	0
Berbera	**0** h	**100**	100 a	0	77.5 de	22.5 b	0 d	100 a	0
Kharriar	92.5 abcd	7.5	100 a	0	95 abc	0 f	5 bc	100 a	0

Mean values appended with same letters are homogenous conditions has been noted by many workers and has been inferred to be an adaptation to the arid conditions. Leaf pubescence may be of adaptive benefit to leaves by reflecting light in high light environments, although this is not always the case. Leaf pubescence may possibly increase the thickness of the leaf boundary layer, thus reducing the rate of water loss in water limited habitats (Wooley, 1964). The various types of leaves in different provenances may help in marker assisted selection in future.

Fig. 6. Dendrogram for similarity between provenances based on leaf characters

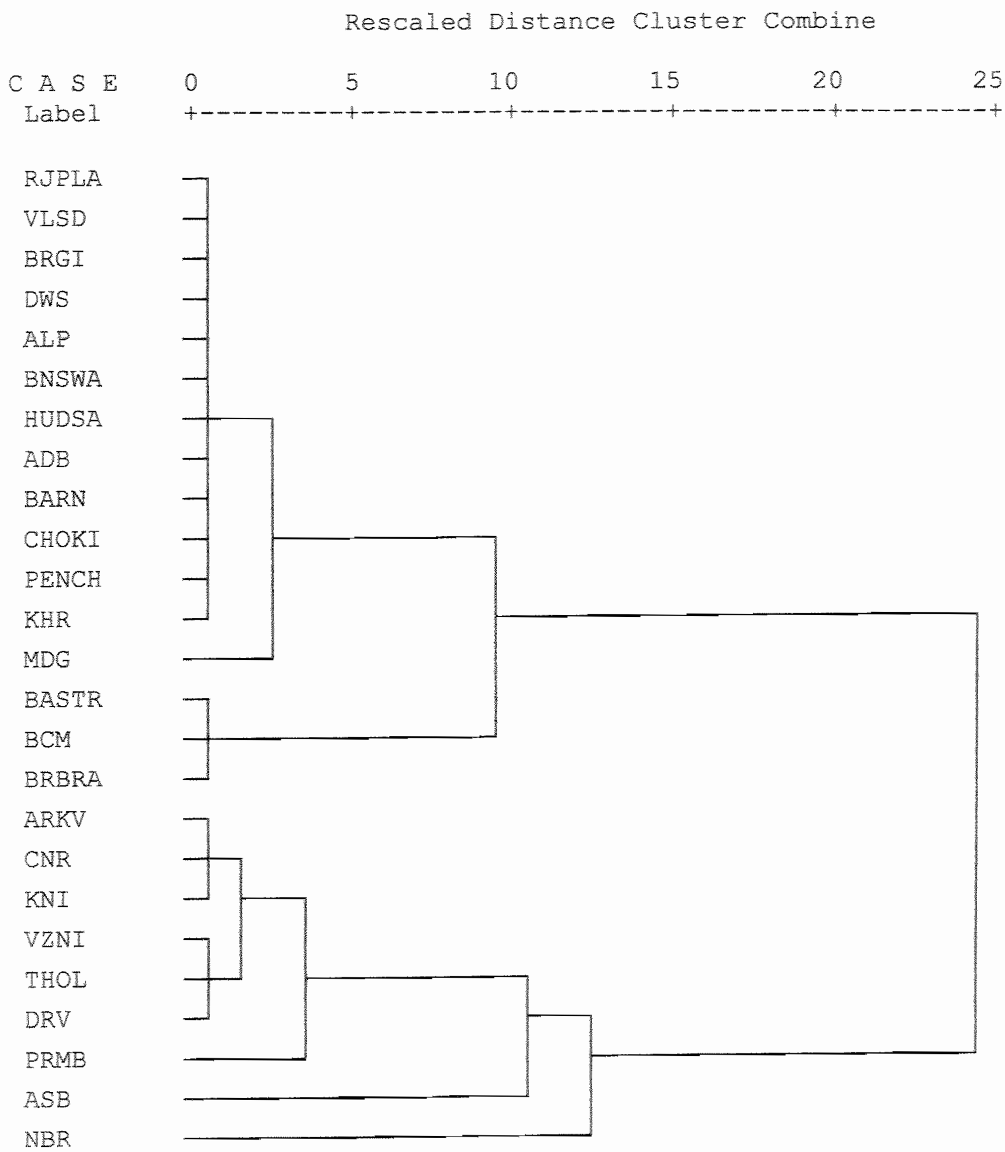


Table 6. Correlation between leaf characters and geo-climatic factors

Characters	Latitude	Longitude	Altitude(m)	Rainfall
Percentage of petiolate leaves	-0.012	-0.133	0.312	-0.081
Percentage of rough leaves	0.928**	0.324	-0.293	-0.575**
percentage of pubescent leaves	0.928**	0.324	-0.287	-0.577**

Seeds

Regarding seed characters, provenances are significantly different for all the observations except shell diameter (Length /Breadth) (Table 7). Even colour, shape and size were quite different between provenances (Plate 3). The Dunkan Multiple Range Test (DMRT) showed the grouping of provenances for each character (Table 8).

Present study shows that teak drupes from Doddaharve are heaviest, followed by Parambikulam. We also observed that the Khariar seeds were the lightest drupes. Sivakumar *et al*. (2002) also reported Khariar as the lightest drupe bearing provenance. Mesocarp thickness and weight are highest in Paramabikulam and Doddaharve. The shell weight is also highest in Doddaharve and Parambikulam and lowest in Kharriar. Seed weight is also highest in parambikulam. Adilabad and Doddaharve have shown the maximum seed filling percentage where as Vazhani has the low value. Vazhani is an area where low pollinator activity was reported though it is an undisturbed natural forest (Indira, 2010). Though Berbera had maximum seed viability, dewas had highest germination percentage. Hudsa had low percentage of seed filling, seed viability and germination.

Germination does not show any significant correlation with any of drupe traits studied, though previous workers had found that mesocarp weight has profound negative effect on germination (Sivakumar *et al*. 2002). In the present study neither the thickness nor the weight of mesocarp affected the germination.

Table 7 ANOVA for seed characters

Variable	Mean	SD
25 seed wt	0.42**	0.07
Drupe diameter(L)	1.13**	0.13
Drupe diameter(B)	1.25**	0.13
Drupe diameter(L/B)	0.90**	0.04
Shell diameter (L)	0.85**	0.10
Shell diameter(B)	0.93**	0.07
Shell diameter(L/B)	0.99ns	0.33
Drupe weight	0.48**	0.12
Shell weight	0.33**	0.08
Mesocarp wt	0.16**	0.05
Mesocarp thickness	0.15*	0.03
Filling percentage	16.38**	7.31
MPG	49.13**	17.00
Seed viability	30.20**	15.07
Germination	14.14**	6.26
Mesocarp lignin	38.86**	4.35
Mesocarp ash	4.60**	1.73
Endocarp lignin	35.03**	1.53
Endocarp ash	2.03**	0.18

Hierarchical clustering shows that 25 provenances can be classified into seven homogeneous groups, on allowing 25 percent variability within a group (Fig.8). Provenances from Kerala form one cluster, if 40 percent variability is allowed. Doddaharve from Karnataka stands separately since the fruits are largest in size, heavier with maximum thickening of mesocarp and maximum drupe filling percent. Seeds are also heavier in this provenance.

Plate 3a. Colour and shape variations in fruits without calyx cover

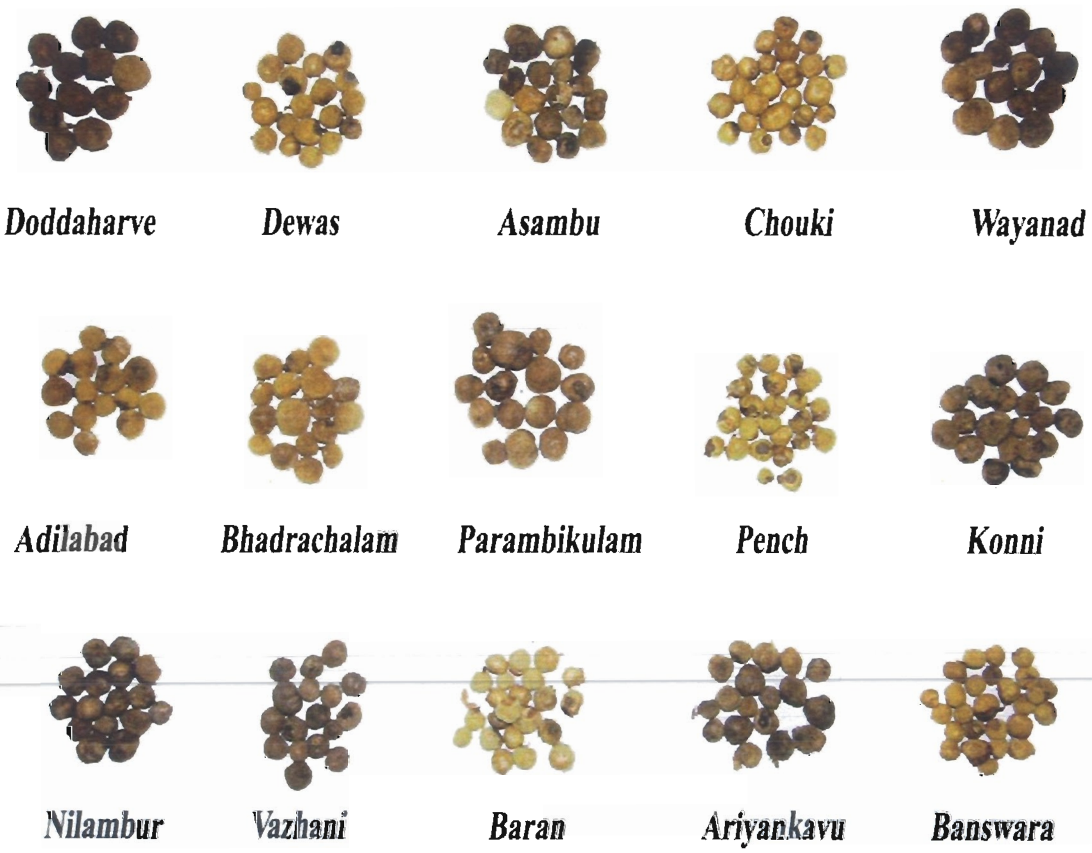


Plate 3b. Colour and shape variations in fruits with calyx

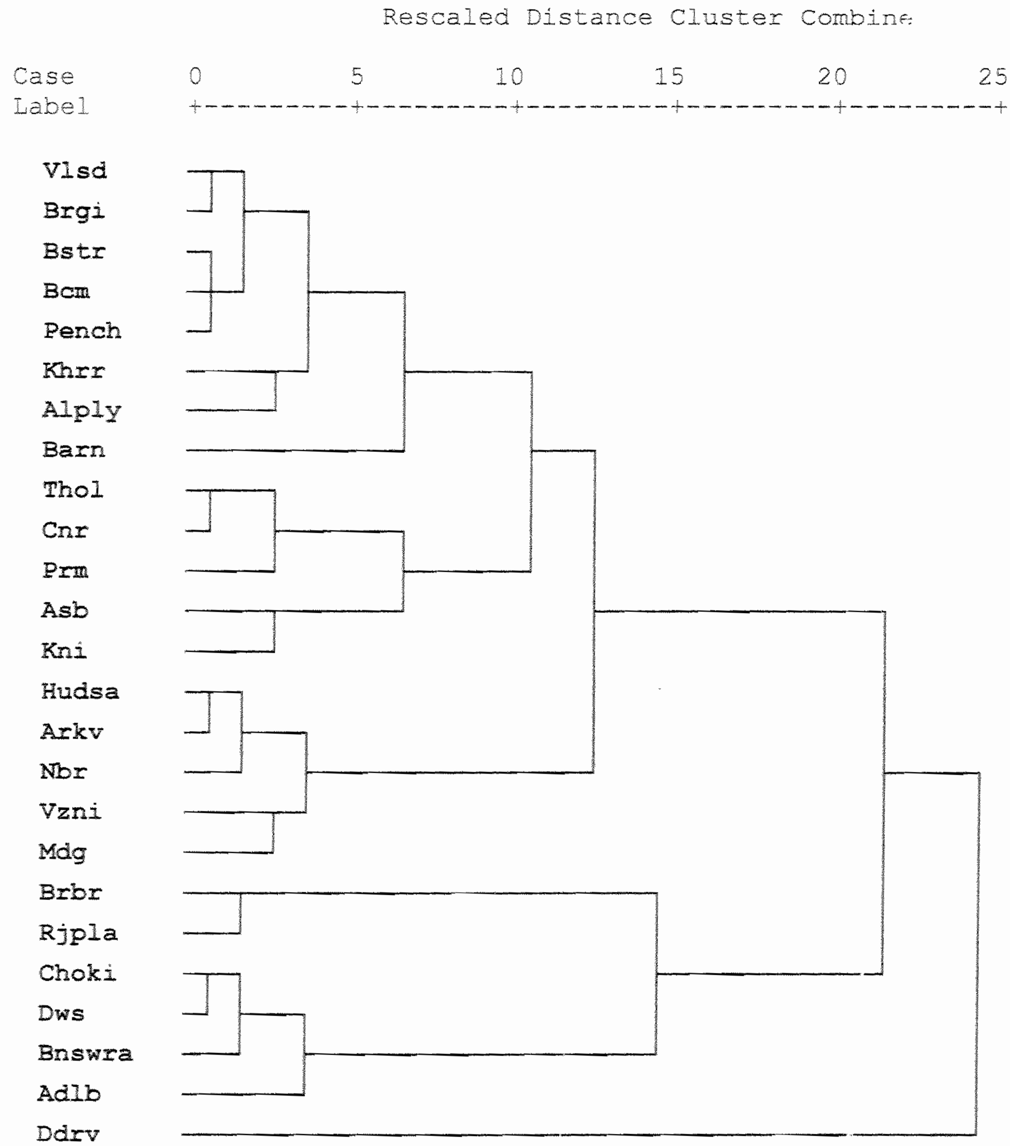
Table 8. Mean performance for each character in different provenances

Prov	Fruit wt	25 seed wt	Mesocarp thicknes	Mesocarp wt	Shell wt	% fruit filling	MPG (germination)	Seed viablity	Germination %	Mesocarp ash	Mesocarp lignin	Endocarp ash	Endocarp lignin
Arienkavu	0.442 cdef	0.445 efg	0.166 abcd	0.131 fgh	0.311 efgh	17.59 ij	30 ef	24.04 ij	18.11 fgh	2.51 jk	42.35 b	2.04 bcd	34.88 efgh
Chinnar	**0.636 b**	0.474 d	0.159 abcde	0.223 b	0.414 bc	23.4 efgh	55 bcd	32.01 efghij	**9.36 j**	6.39 b	39.42 d	2.03 bcd	34.26 gh
Konni	0.525 c	0.484 cd	0.165 abcd	0.161 def	0.364 cdef	17.87 hij	36.67 def	38.04 cdef	27.91 ab	3.5 gh	42.46 b	1.52 e	**35.69 cdef**
Nilambur	0.533 c	0.421 ghi	0.15 abcde	0.135 fgh	0.399 bcd	**17.56 ij**	30 ef	29.68 fghij	18.25 fgh	4.67 ef	40.8 c	**2.22 ab**	36.67 bc
Parmbikulam	0.706 b	**0.533 a**	0.217 a	0.296 a	0.41 bc	21.98 fghi	45 cde	23.74 ij	26.45 abc	5.55 cd	45.3 a	**1.59 e**	33.04 ij
Vazhani	0.420 def	0.401 jk	0.155 abcde	0.129 fgh	0.291 fghi	12.73 j	20 f	36.13 defgh	25.58 bcd	4.58 ef	45.88 a	2.09 abc	34.63 fgh
Tholpetty	0.642 b	0.441 efg	0.172 abcd	0.221 b	0.421 bc	25.89 cdefg	58.33 bc	**28.54 fghij**	21.96 def	**4.6 ef**	**43.11 b**	2.02 bcd	34.61 fgh
Ashambu	0.664 b	0.448 ef	0.156 abcde	0.205 bc	0.459 b	21.66 fghi	43.33 cde	39.21 cdef	21.96 def	4.75 e	39.71 cd	1.97 cd	32.11 j
Hudsa	**0.537 c**	**0.358 mn**	**0.169 abcd**	**0.15 def**	0.386 bcde	14.35 j	23.33 f	23.16 ij	6.93 j	5.64 c	43.05 b	**2.08 abc**	**34.3 gh**
Doddaharve	0.795 a	0.501 bc	0.213 ab	0.262 a	0.533 a	32.9 a	70 ab	28.66 fghij	**17.39 ghi**	5.47 cd	**40.3 cd**	1.95 cd	32.47 j
Mandagadde	0.388 efg	0.482 cd	0.14 bcde	0.152 def	0.236 hij	13.37 j	18.33 f	26.45 ghij	14.95 hi	**3.24 hi**	37.58 e	2.21 ab	**37.02 ab**
Adilabad	0.500 cd	0.338 no	0.147 abcde	0.169 cde	0.331 defg	33.09 a	81.67 a	47.87 abc	22.72 cde	6.76 b	36.27 fg	2.09 abc	35.07 efgh
Bhadrcnlam	0.422 def	0.408 ij	0.144 abcde	0.146 def	0.276 ghij	23.35 efghi	45 cde	28.66 fghij	15.32 hi	4.96 de	36.47 efg	2.29 a	37.87 a
Allapally	0.341 fg	0.323 o	0.144 abcde	0.123 fgh	0.218 ij	24.67 defg	56.67 bcd	34.23 defghi	14.18 i	6.54 b	39.01 d	1.94 cd	36.37 bcd
Pench	0.396 efg	0.230 p	0.122 cde	0.067 i	0.329 defg	21.72 fghi	45 cde	29.52 fghij	25.82 abcd	4.34 ef	40.93 c	2.12 abc	34.3 gh
Rajpla	0.444 cde	0.373 lm	0.09 e	0.141 efgh	0.303 efgh	21.68 fghi	45 cde	50.95 ab	24.09 bcde	6.25 b	31.43 i	2.16 abc	35.84 bcdef

Valsad	0.414 def	0.509 b	0.088 e	0.097 hi	**0.317 efgh**	22.4 fghi	48.33 cde	22.59 j	26.29 abc	4.02 fg	34.25 h	1.95 cd	32.67 j
Baran	0.383 efg	0.477 d	0.145 abcde	0.131 fgh	0.252 ghij	28.29 abcde	**70 ab**	21.9 j	22.83 cde	1.87 l	31.65 i	2.02 bcd	**38.08 a**
Banswara	0.377 efg	0.448 ef	0.121 de	0.117 gh	0.259 ghij	32.14 ab	70 ab	41.12 bcde	27.23 ab	9.45 a	46.49 a	2.11 abc	34.77 efgh
Dewas	0.417 def	0.354 mn	**0.141 bcde**	0.118 gh	0.298 fghi	30.52 abc	70 ab	37.09 defg	29.78 a	3.08 hijk	34.48 h	2.17 abc	36.01 bcde
Burgi	0.402 defg	0.427 fgh	0.132 cde	0.143 efgh	0.259 ghij	25.75 cdefg	50 bcde	24.04 ij	25.83 abcd	2.42 kl	33.39 h	1.82 d	35.21 defg
Bastar	0.438 cdef	0.381 kl	0.136 cde	0.143 efgh	0.295 fghi	20.3 ghi	43.33 cde	25.19 hij	**20.55 efg**	2.74 ijk	33.64 h	2.08 abc	33.9 hi
Choki	0.453 cde	0.354 n	0.166 abcd	0.16 def	0.293 fghi	29.66 abcd	70 ab	43.07 bcd	26.08 abc	5.53 cd	37.32 ef	2.1 abc	35.1 efgh
Berbra	0.499 cd	0.461 de	0.196 abc	0.183 bcd	0.316 efgh	21.13 ghi	48.33 cde	55.85 a	24.56 bcd	3.03 hijk	40.27 cd	2.15 abc	35.4 defg
Kharir	0.314 g	0.324 o	0.146 abcde	0.116 gh	0.199 j	27.1 bcdef	55 bcd	24.04 ij	20.55 efg	3.16 hij	35.85 g	2.15 abc	35.43 defg
Mean	**0.484**	**0.416**	**0.151**	**0.157**	**0.327**	**23.24**	**49.13**	**32.63**	**21.39**	**4.6**	**38.86**	**2.01**	**35.03**

Mean values appended with same letters are homogenous

Fig. 8 Clusters showing similarity between provenances based on seed characters



Correlation between fruit characters & geo-climatic factors

Fruit, shell and mesocarp weight are found to have significant positive correlations with altitude. Correlation studies show that rainfall has significant negative correlation with fruit filling percentage and maximum possible germination. Mohanadas *et al.* (2002) have reported that during rainy days, activities of pollinators are reduced. Rainfall has significant positive correlation with mesocarp lignin (Table 9). Lignin, being a hydrophobic substance generally protects the seeds from the deteorating effects of continuous moisture and subsequent drupe infestation by pathogens.

Table 9. Correlation with climatic and edaphic factors

Variable	Latitude	Longitude	Altitude	Rain fall
25 seeds weight (g)	-0.421*	-0.338 ns	0.213 ns	0.262
Endocarp ash (%)	0.337ns	0.138 ns	-0.127 ns	-0.251
Endocarp lignin (%)	0.353 ns	0.182 ns	-0.325 ns	-0.137
Mesocarp lignin (%)	-0.587**	-0.185 ns	0.053 ns	0.459*
Mesocarp ash (%)	-0.001 ns	-0.313 ns	0.108 ns	-0.096
Maximum possible germination (%)	0.516**	0.153 ns	0.157 ns	-0.638**
Shell diam length wise	-0.731**	-0.189 ns	0.530**	0.401*
Shell diam breadth wise	-0.690**	-0.201 ns	0.318 ns	0.317
Shell diameter(length / breadth)	0.099 ns	0.037 ns	0.187 ns	0.318
Drupe diameter (length)	-0.713**	-0.037 ns	0.540**	0.342
Drupe diameter (Breadth)	-0.701**	0.015 ns	0.371 ns	0.292
Drupe diameter (length / breadth)	-0.164 ns	-0.089 ns	0.468*	0.145
Fruit weightt	-0.654**	-0.227 ns	0.565**	0.202
Shell weight	-0.636**	-0.316 ns	0.479*	0.234
Mesocarp weight	-0.557**	-0.045 ns	0.591**	0.114
Mesocarp thickness	-0.542**	0.247 ns	0.361 ns	0.184
Fruit filling %	0.494*	0.092 ns	0.157 ns	-0.640**
100 drupe weight	-0.659**	-0.272 ns	0.524**	0.177
Seed viability	0.165 ns	0.178 ns	-0.241 ns	-0.238
Germination	0.330 ns	-0.036 ns	-0.382 ns	-0.078

**, * significant at 1% and at 5% level respectively; ns- non-significant

Principal Component Analysis for seeds

Factor analysis for seed characters identified six factors (Table 10), which together accounted for 81 per cent of the total variation in the fruit characters. It is seen that communalities of all variables is sufficiently high, except in the case of germination.

The first factor, named as 'fruit dimension factor' accounted for 35.52 per cent of the total variation in the fruits and had a high positive loadings on drupe diameter (length wise) (97%), drupe diameter (breadth wise) (94%), shell diameter (91%), mesocarp weight (86%), 100 drupe weight (83%), shell weight (81%) and mesocarp thickness (77%). The second factor, 'fruit filling factor', accounted for 12.8 per cent of the total variation in the seed characters and had a high positive loadings on maximum possible germination or percentage of fruits with at least one seed (93%) and filling percentage (91%).

The third factor, 'shell diameter factor', accounted for 11.1 per cent of the total variation in the seed characters and had a high positive loadings on shell diameter (lngth/breadth) (80.6%) and high loadings on shell diameter (breadth wise) (-76.8%). The fourth factor, 'drupe diameter factor', accounted for 7.99 per cent of the total variation in the seed characters and had positive loadings on drupe diameter (length/breadth) (82.2%). The fifth factor accounted for 7.24 per cent of the total variation in the seed characters and had positive loadings on mesocarp ash (89.4%) and mesocarp lignin (68.3%). This factor measures the chemicals in mesocarp.

The sixth factor accounted for 6.03 per cent of the total variation in the seed characters and had positive loadings on endocarp ash (77.8%) and endocarp lignin (70.4%) This factor measures the chemicals in endocarp.

Germination had a non significant positive correlation with fruit filling factor. It had a negative correlation with endocarp ash and lignin though not significant which support the observation of Dharmalingam (1995) that the reason for low germination includes the germination inhibitors in the mesocarp (physiological block), thick and hard endocarp (physical barrier).

Table 10. Variation in the fruit characters grouped under six factors

Variable	Factor					
	1	2	3	4	5	6
Drupe diam.(L)	0.971					
Drupe diam.(B)	0.940					
Shell diam. (L)	0.913					
Mesocarp wt	0.856					-.303
100 drupe wt	0.832		-0.305		.351	-.358
Shell wt	0.810				.359	-.390
Meso thickness	0.774		0.431	-.301		
Maximum possible germination(MPG)		0.931				
Filling %		0.909				
Shell diam.(L/B)	0.378		0.806			
Shell diam.(b)	0.546		-0.768			
Drupe diam.(L/B)				0.822		
Germination		0.393		-0.456		-0.369
Seed viability		0.384	-0.318	-0.432	0.394	0.359
Mesocarp ash		0.306			0.894	
Mesocarp lignin	0.388	-0.349			0.683	
Endocarp ash						0.778
Endocarp lignin	-0.307				-0.412	0.704

Germplasm establishment and genetic evaluation

Growth characteristics

The seedlings in the nursery as well as in the field were healthy (Plate 4). The provenances were evaluated only for growth as other characters are not expressed fully in the two year old seedlings. Highly significant differences between provenances were noted with respect to the growth characters at all ages from 3 months to 2 years (at an interval of 3 months). Mean growth performance of different provenances is given in Table 11 and 12.

Mandagadde from Karnataka was found to be the best performer during early growth upto 1.5 years. But later, at the age of two years, Konni and Arienkavu (after the second rainy season) excelled over Mandagadde (Table 12 & Fig. 9). Rajpipla from Gujarat and Burgi from Madhya Pradesh are the poor performers. The trend in early growth performance may change in later years since provenances need an adptability and stabilization in the new environment and soil conditions.

Table 11. Mean growth in different provenances at different age

Provenance	Height in Cm						Collar diam in cm					
	Months						Months					
	3	6	9	12	15	18	3	6	9	12	15	18
Arienkv	31.01	35.77	49.15	65.81	77.06	**90.73**	0.79	0.94	1.34	1.69	1.93	2.01
Chinnr	20.76	23.23	26.81	32.15	34.37	46.06	0.57	0.65	0.88	1.01	1.1	1.20
Konni	29.86	32.13	48.85	63.60	71.61	77.37	0.83	1.01	1.45	1.84	2.08	**2.10**
Nlambr	25.81	30.00	38.18	49.05	62.42	74.33	0.66	0.81	1.08	1.33	1.58	1.61
Parmbi klm	33.45	39.01	50.57	61.92	66.53	75.25	0.85	0.99	1.23	1.49	1.58	1.63
Vazhni	29.89	33.06	42.69	52.25	58.29	66.01	0.79	0.93	1.32	1.55	1.73	1.81
Tholpty	28.59	36.42	56.39	73.93	**79.01**	90.80	0.75	0.89	1.22	1.53	1.64	1.78
Ashab	23.12	26.62	37.95	52.18	59.76	68.57	0.59	0.7	1.12	1.39	1.54	1.60
Hudsa*	27.92	32.90	42.58	59.66	65.89	91.50	0.71	0.84	1.28	1.65	1.9	1.92
Dodhrv	22.00	30.69	45.48	57.77	65.55	81.66	0.62	0.81	1.16	1.43	1.59	1.69
Manda gadde	28.35	37.88	**59.46**	**79.36**	**89.77**	**101.78**	0.92	**1.17**	**1.6**	1.95	2.15	**2.24**
Adilabd	18.24	25.16	43.78	59.12	62.74	67.33	0.81	1.0	1.42	1.72	1.8	1.82
Bhadra chalam	13.68	16.38	24.09	31.17	35.79	38.41	0.55	0.61	0.84	1.02	1.14	1.16
Allapilly	15.77	19.19	31.71	42.05	46.23	53.19	0.67	0.75	1.05	1.28	1.38	1.44
Pench	12.88	18.82	32.01	44.91	51.06	57.21	0.56	0.7	1.12	1.35	1.46	1.50
Rjpipla	13.13	16.38	23.18	26.69	32.09	36.74	0.56	0.63	0.85	0.96	1.12	1.15
Valsad	14.55	20.27	31.17	40.55	43.45	48.70	0.74	0.86	1.18	1.43	1.51	1.58
Baran	11.74	17.65	30.16	37.82	39.30	42.93	0.65	0.77	1.04	1.23	1.26	1.31
Bnswar	11.15	14.18	22.62	29.41	30.79	34.87	0.52	0.6	0.86	1.02	1.07	1.10
Dewas	9.84	14.20	21.29	26.47	31.94	39.77	0.56	0.64	0.86	1.03	1.2	1.24
Burgi	12.61	17.85	25.13	31.15	33.18	35.71	0.59	0.67	0.9	1.12	1.2	1.22
Bastar	16.86	22.34	42.16	55.54	59.00	62.58	0.75	0.85	0.28	1.51	1.59	1.60
Choki	14.28	16.41	23.60	31.37	33.89	37.50	0.57	0.64	0.91	1.14	1.19	1.22
Berbra	28.38	33.12	52.86	73.88	77.29	85.77	1.01	1.26	1.71	2.11	2.27	**2.32**
Khriar	13.10	15.78	26.04	32.05	35.84	42.70	0.67	0.74	1.03	1.22	1.33	1.36

* *only one replication in Hudsa*

Table 12. Mean growth in provenances at two years

Provenance	Height (in cm)	Collar diameter	Provenance	Height (in cm)	Collar diameter
Arienkavu	**155.92**	**2.78**	Allapally	88.05	1.95
Chinnar	69.78	2.03	Pench	84.01	1.83
Konni	**172.78**	**3.49**	Rajpipla	**47.22**	**1.45**
Nilambur	112.9	2.38	Valsad	67.06	2.01
Parambikulam	110.5	2.06	Baran	61.49	1.74
Vazhani	99.41	2.19	Banswara	58.72	1.66
Tholpetty	114.82	2.15	Dewas	54.02	1.49
Ashambu	99.27	2.35	Burgi	**52.53**	**1.41**
Hudsa*	135.48	2.79	Basthar	98.00	2.18
Doddaharve	102.12	1.97	Choki	58.24	1.47
Mandagadde	144.05	2.92	Berbera	131.68	2.42
Adilabad	106.39	2.48	Kharriar	61.16	1.57
Bhadrachalam	65.29	1.51			

* *Only one replication is available in Hudsa*

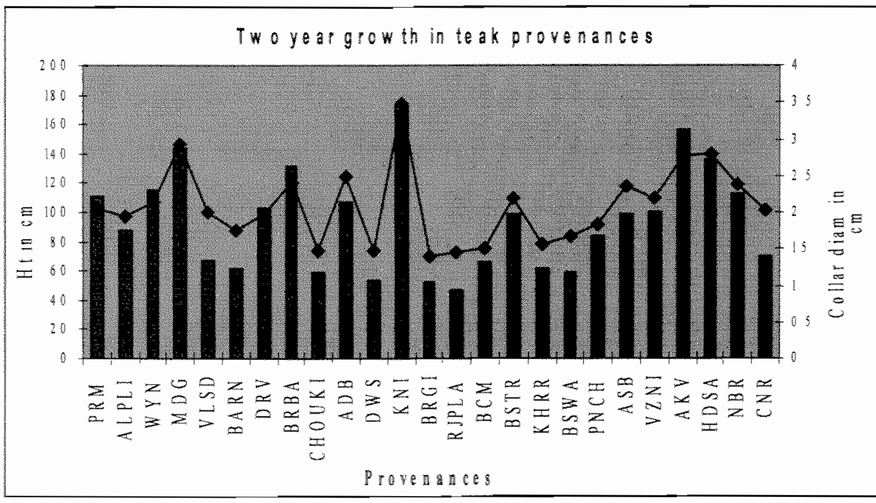


Fig. 9. Growth performance in different provenances

Hierarchical clustering has shown three clusters at the age of 1.5 years on allowing 20% variability within a group. All the provenances from South India except Chinnar and Bhadrachalam were in the first cluster, in which Berbera from Orissa and Basthar from Chattisgarh were also included though they were from North East part (Fig.10) of India.

Provenances, Allappali and Pench Tiger reserve from Maharashtra formed another cluster. Other provenances from Central and North India were in the third cluster. After another rainy season, at the age of two years, clustering again showed three groups on allowing 20% variability within groups (Fig. 11). The first one comprised of Konni, Arienkavu (Kerala), Berbera (Orissa) and Mandagadde (Karnataka). Another cluster comprised of all other provenances from South India and also Allappali and Pench Tiger reserve from Maharashtra as well as Basthar from Chattisgarh. All other provenances from North and Central India and also Chinnar (Kerala) and Bhadrachalam (from Andhra Pradesh) from South formed the third cluster.

Correlations between height and collar diameter and with geo-climatic factors

When correlations were taken in to consideration, it is seen that rainfall has a significant positive correlation and latitude has a significant negative correlation with both height and collar diameter at 1.5 years and 2 years (Table 13). No linear regression was seen between Latitude, Longitude, Altitude and Rainfall with height and collar diameter. When growth vs period was analysed up to 1.5 years, there is very high value for regression which is above 0.9. The growth trend also shows this fact (Fig.12).

Plate 4a. Different provenances in the nursery

Plate 4 b. Provenances in the field

Fig.10 Clusters showing similarity between provenances based on 1.5 year growth

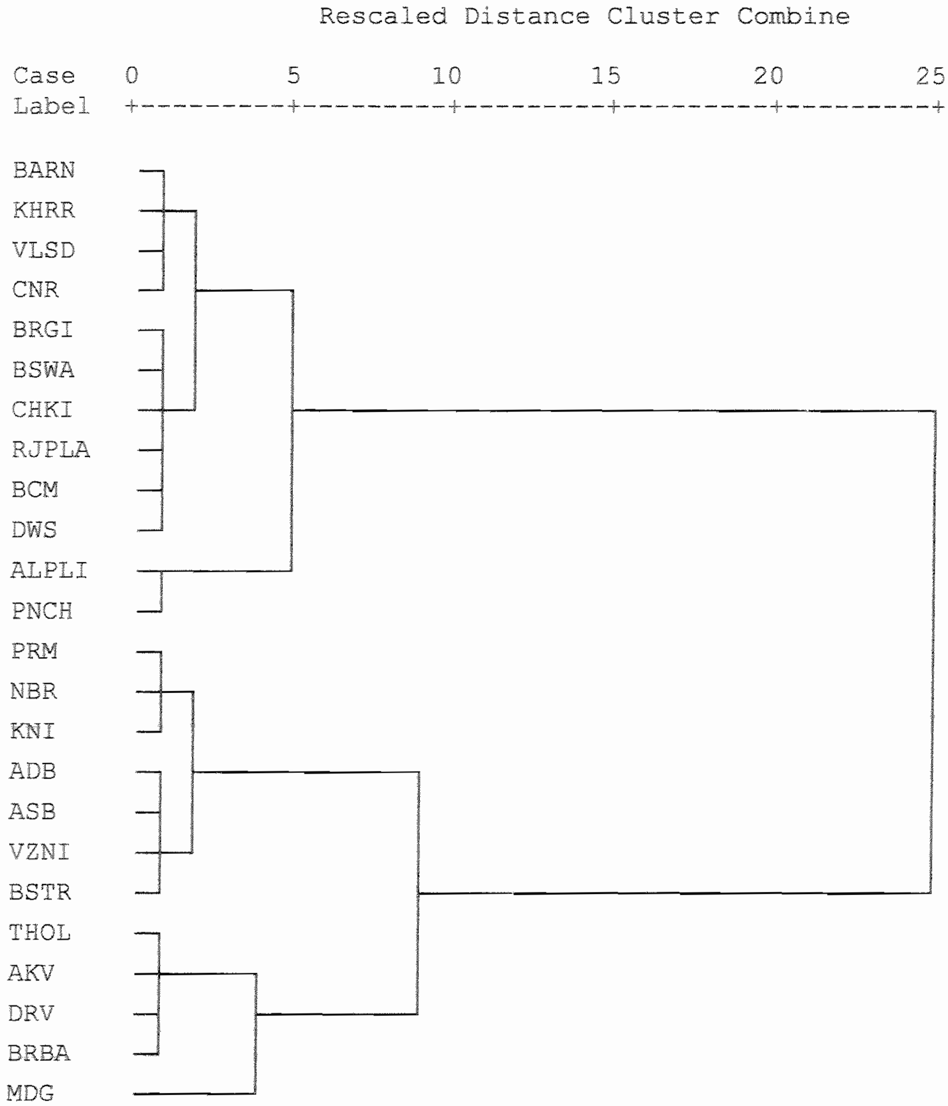


Fig. 11 Clusters showing similarity between provenances based on two year growth

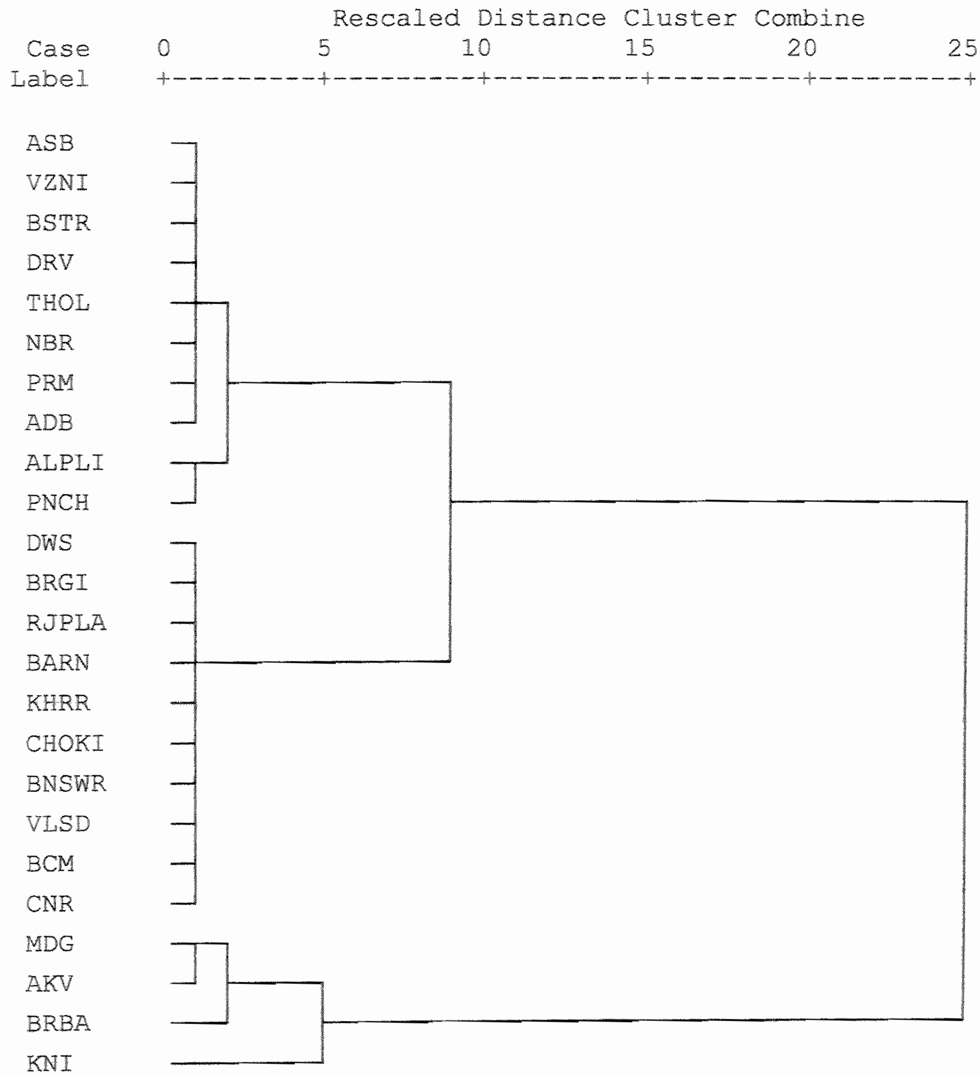


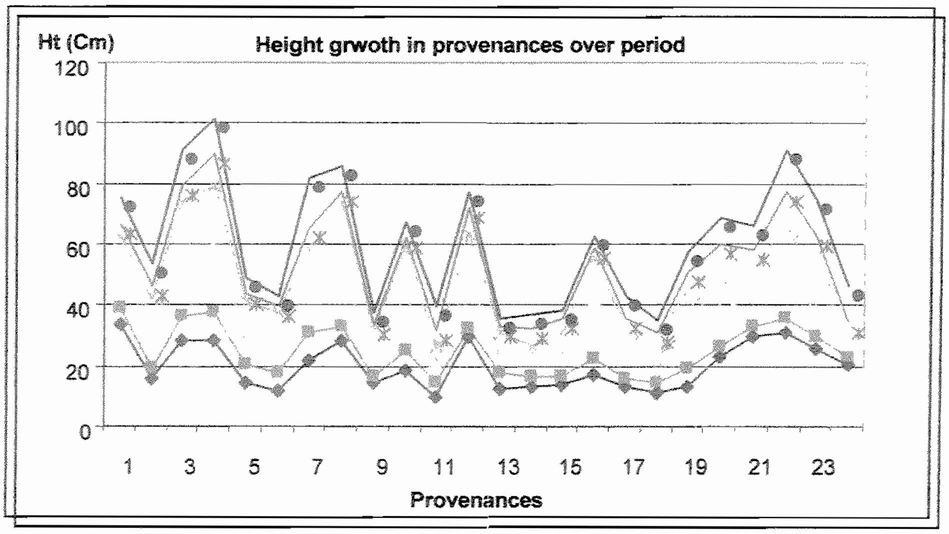
Table 13. Correlations with geo-climatic factors

a	Height at 18 months	Collar diameter at 18 months	Latitude	Longitude	Altitude	Rainfall
Height at 18 months	1	.908**	-.691**	-0.052	0.248	0.435*
Collar diameter 18 months	0.908**	1	-.518**	0.097	0.009	0.423*

b	Height at two years	Collar diameter at two years	Latitude	Longitude	Altitude	Rainfall
Height at two years	1	.946**	-.687**	-.038	.089	.492*
Collar diameter at two years	.946	1	-.654**	-.156	.037	.484*

**, * significant at the 0.01 and 0.05 level respectively

Fig. 12 Growth trend in provenances over period



Genetic parameters

The genetic parameters estimated show that Phenotypic coefficient of variation (PCV) and Genotypic coefficient of variation (GCV) are high for both height as well as collar diameter where as heritability is moderate (Table 14). If provenances are selected at 5% selection intensity, high genetic gain is possible for growth.

Table 14. Genetic parameters for growth (as %)

Variable	PCV	GCV	Heritability	Genetic gain
Two year Height	44.64	33.72	57.02	48.1
Two year Collar diameter	30.65	21.9	51.09	66.3

3. VARIATIONS IN WOOD PROPERTIES

3.1. MATERIALS AND METHODS

As explained earlier, one of the objectives of the present study is to assess the wood property variations in Indian teak provenances with reference to growth rate, heartwood proportion, wood colour, density, extractive content, lignin and anatomical variations and to utilise the provenance variation for future tree improvement programmes.

Sampling locations

As illustrated earlier, sample survey was conducted in the moist and dry deciduous forests of ten Indian States (Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Gujarat, Orissa, Chattisgarh and Rajasthan) where teak is growing naturally. Study materials for wood property originated from 82 trees of various ages, sampled from natural teak bearing forests of 23 localities in India (Fig.13). Data pertaining to sampling localities, its geographic coordinates and mean annual rainfall are shown in Table 1.

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 (4 mm) were withdrawn from the outermost growth increment to the inner core near pith at breast height (BH) using increment borer. To prevent moisture loss, all the samples were wrapped in polythene bags and taken to the laboratory for various physico-chemical and anatomical studies.

Wood physical properties

Since all the wood samples collected belong to the natural populations, age determination was carried out in the laboratory after counting the annual rings. The samples were grouped into five age classes (I–V) for studying various wood properties as shown below. For a given age class, each provenance represents three trees, sometimes the same provenance may occur more than 2 times in different age classes.

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

To estimate heartwood percentage of disc samples, the heartwood area and disc area were calculated by measuring four radii at right angles to one another and the four measurements were averaged for each disc. The same wood discs were used for measuring basic density, colour, extractive content and lignin analysis. The basic density of wood was determined on oven-dry (OD) weight to green volume basis. The green volume was measured by water displacement method.

For increment core samples, core length (cm) from outer sapwood to pith was measured and used as the stem radius inside bark (*R*). After smoothening with a fine sand paper, the number of growth rings from outer sapwood to pith (*NR*) was counted under a stereomicroscope to determine age of trees. False ring if occurred was eliminated in the precise determination of age. The sapwood–heartwood boundary was sharply defined by heartwood colour. Heartwood width (*HW*) was measured. Other variables related to heartwood and radial growth was calculated from the measured variables: sapwood width ($SW = R - HW$), heartwood percentage ($HW\% = (HW^2/R^2) \times 100$), and average ring width or radial growth rate ($GR = R/NR$).

Wood colour

Wood colour variation was studied using the Munsell notation (1976) for colour determination, the visual matching method. The 5 cm cross-sectional discs and the increment core samples were smoothened by a fine sand paper and were subjected to colour analysis. Accurate comparison was obtained by holding the wood sample directly behind the apertures separating the closest matching colour chips. The colour was then identified by its hue, value and chroma. The hue value ranged from 9.9R to 1.0Y, from red to yellow. The scale of value ranged from 0 for absolute black to 10 for pure white; indicating lightness/brightness of colour. Chroma was the departure of colour from its neutral colour of the same value. Colours of low chroma were considered weak, while those of high chroma were highly saturated, strong or vivid.

Extractive content and lignin analysis

The same disc samples measured for physical properties were used to determine the total extractive content and lignin analysis. It is well known fact that total extractive content gave indication on the durability of teak wood as it contains toxic polyphenolic compounds which impart resistance to termite and fungal attack. ASTM D 1107-56 (1984) for the determination of ethanol-benzene solubility of wood was followed. Whole heartwood samples from pith to periphery in one radial direction was selected and powdered in a Cyclotech mill. Test specimens consisting of 1g air-dried sieved saw dust (in duplicate) was placed in extraction thimbles in a 6 unit automated Soxtech extraction apparatus (Soxtec 2043; FOSS-Tecator, Sweden) and extracted with 40 ml of ethanol and benzene (1:2 ratio) in the extraction cup (aluminium) with a standardized protocol (30 minutes boiling, 3 hours rinsing and 10 minutes solvent recovery) programmed in the control unit. This automated extraction system have the advantage of minimal use of solvent with reduced extraction time and complete recovery of the solvent and extractives separately. After drying the extractives obtained in the aluminium cup at 105°C for 1 hour, the contents (extractive content) were cooled in a dessicator and weighed to determine the percentage of ethanol-benzene soluble extractive content based on moisture- free sawdust.

The Klason lignin (acid insoluble lignin) and acid soluble lignin were determined following the procedure of TAPPI UM- 250 (TAPPI Useful Methods, 1991) and TAPPI T 222 om-88 (TAPPI Test Methods, 2002).The extracted wood meal was transferred to the same Soxtec apparatus and extracted with 95% v/v ethanol for 4 h and washed with hot distilled water. The extracted sample was transferred to a Büchner funnel; excess solvent was removed by suction and washed with distilled water. After extraction, filtered on a Büchner funnel and washed with 500 ml of boiling distilled water.

Sulphuric acid (72%, 7.5 ml) was added to 0.5 g of extract-free, air-dried sample in a 50 ml beaker according to the improved procedure of Manfred and Barbara (2002) and the mixture was placed in a shaking water bath at 20°C for 2 h. The sample was diluted to a final concentration of 3% H_2SO_4 with hot distilled water and refluxed for 4 h. The flask was kept in an inclined position overnight to allow the finely dispersed lignin to settle. The supernatant was used for the analysis of acid soluble lignin in accordance with TAPPI UM- 250. The sample was vacuum filtered through a glass-filtering crucible with a sintered glass disc of a fine porosity. Acid-soluble lignin content (B) in the filtrate in g/1000 ml was calculated spectrophotometrically by measuring the absorbance at 205 nm. The percentage of acid-soluble lignin content in the sample was determined using the formula:

$$\text{Soluble lignin \%} = \frac{B \times V}{1000 \times W} \times 100$$

where;

B = Lignin content in the filtrate, g/1000 ml

V = Total volume of the filtrate, i.e., 277.5 ml for wood

W = Oven-dry weight of wood specimen, g

Klason lignin (acid insoluble lignin) was determined by weighing the mass of residue after drying at 105°C overnight in a hot-air oven. Klason lignin content was calculated using the formula:

$$\text{Klason lignin \%} = \frac{A}{W} \times 100$$

where;

A = Weight of the lignin, g

W= Oven-dry weight of the sample, g

The Klason lignin and acid soluble lignin values were combined to obtain the total lignin content.

Anatomy and microscopy

Anatomical investigations were completed for the 57 disc samples belonging to 9 provenances. Cross sections of 15-20 μm thickness were taken from the wood samples collected, using a sliding microtome. Anatomical properties were studied at every 5th growth ring interval starting from near the pith to outer sapwood periphery to cover the entire radial variation. Standard microtechnique procedure was followed to prepare the sections for microscopic observation. Anatomical properties, studied within a growth ring, were early- and latewood percentage, 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 length, fibre diameter, lumen width and double wall thickness were measured after maceration of tissues in glacial acetic acid and hydrogen peroxide in equal proportion. To study the radial variation of fibre dimensions, 50 largest unbroken cells from the macerated tissues were measured representing inner, middle and outer periphery irrespective of growth rings. Image analysis system with the help of *Leica QWin software* has been employed for precise quantification of wood anatomical features under the microscope.

Statistical analysis

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

3.2. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) revealed that there was significant difference between provenances with respect to diameter of trees at breast height (dbh), heartwood percentage, ring width and basic density for all the age classes taken separately and together (Table 15).

Table 15. ANOVA for physical properties in different age classes

Age Classes	Source of variation	d.f.	DBH		Heartwood %		Ring width		Basic density	
			MSS	F-value	MSS	F-value	MSS	F-value	MSS	F-value
I	Provenance	4	0.219	31.24**	216.37	23.94**	0.302	95.15**	16059.5	8.45*
	Error	10	0.007		9.04		0.003		1900.13	
II	Provenance	7	0.216	23.7**	134.2	17.59**	0.301	19.60**	5931.40	20.88**
	Error	16	0.009		7.63		0.015		284.0	
III	Provenance	12	0.266	24.15**	168.03	25.63**	0.260	18.67**	6481.80	5.76*
	Error	26	0.011		6.56		0.014		1125.68	
IV	Provenance	11	0.364	29.11**	130.56	52.30**	0.517	56.66**	2833.10	2.50*
	Error	24	0.012		2.50		0.009		1135.02	
V	Provenance	11	0.240	37.69**	73.05	26.80**	0.237	25.11**	2080.74	3.37*
	Error	24	0.006		2.73		0.009		618.03	
Pooled over all age classes	Provenance	22	0.874	34.91**	400.92	30.86**	0.506	10.38**	5523.60	2.29*
	Error	127	0.025		12.991		0.049		2413.51	

*** Significant at P≤0.01, * Significant at P≤0.05*

Tree size (DBH)

The dbh of all the trees showed a positively linear trend with age (Fig. 13) and heartwood percentage (Fig.15). Mean dbh of trees of age up to 24 yrs from Baran (Rajasthan) was lowest among the entire provenances studied (14.5 cm) with reduced

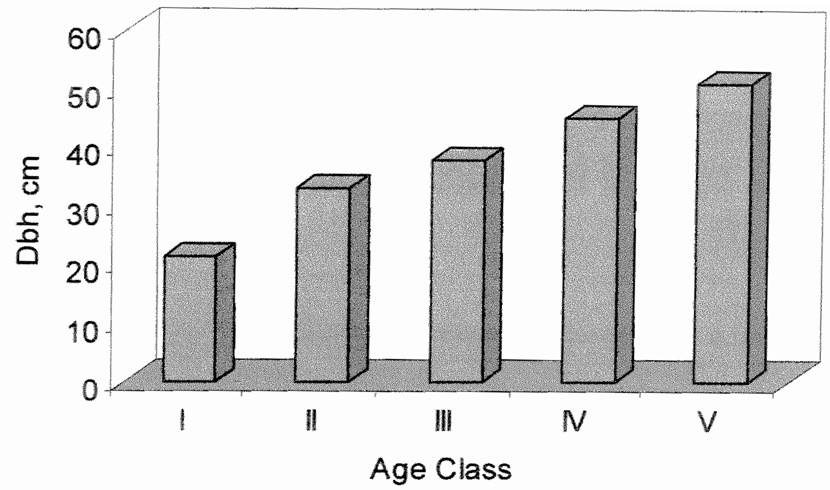


Fig. 13. Mean DBH of 23 teak provenances in different age classes

ring width and low percentage of heartwood (Figs. 14a & c). However, the results show variation in dbh of teak samples within the same age class collected from different ecological zones and it indicates that location has an important role in determining the wood quality. Teak attains maximum diameter in the states of Kerala, Tamilnadu, Karnataka, Maharashtra and Gujarat (Figs. 14c, d & e). Nilambur provenance was superior with dbh of 72.5 cm in age class V (>55 yrs) and it has shown increased dbh among other age classes as well (Figs. 14c, d & e). This was followed by Thamaravellachal, Vazhani, Parambikulam and Arienkavu provenances in Kerala, Ashambu (Tamilnadu), Allappilli (Maharashtra), Rajpipla (Gujarat) and Doddaharve (Karnataka). The Gujarat provenances of teak, Valsad and Rajpipla were able to produce log diameter (43.8 cm) similar to Site quality I of All India Yield Table (FRI, 1970) at the age of around 35 years with wider rings (Figs. 14b & 15b).

The natural teak provenances examined from Kerala at the rotation age (age class V- >55 yrs) produced logs of larger dimensions with maximum heartwood percentage (Fig.14d) followed by Doddaharve (Karnataka). In Nilambur, teak grows naturally in well-drained alluvial soils with high rainfall, ideal for attaining maximum dimensions and heartwood percentage. On comparing 35 year old home-garden teak with the same age of teak

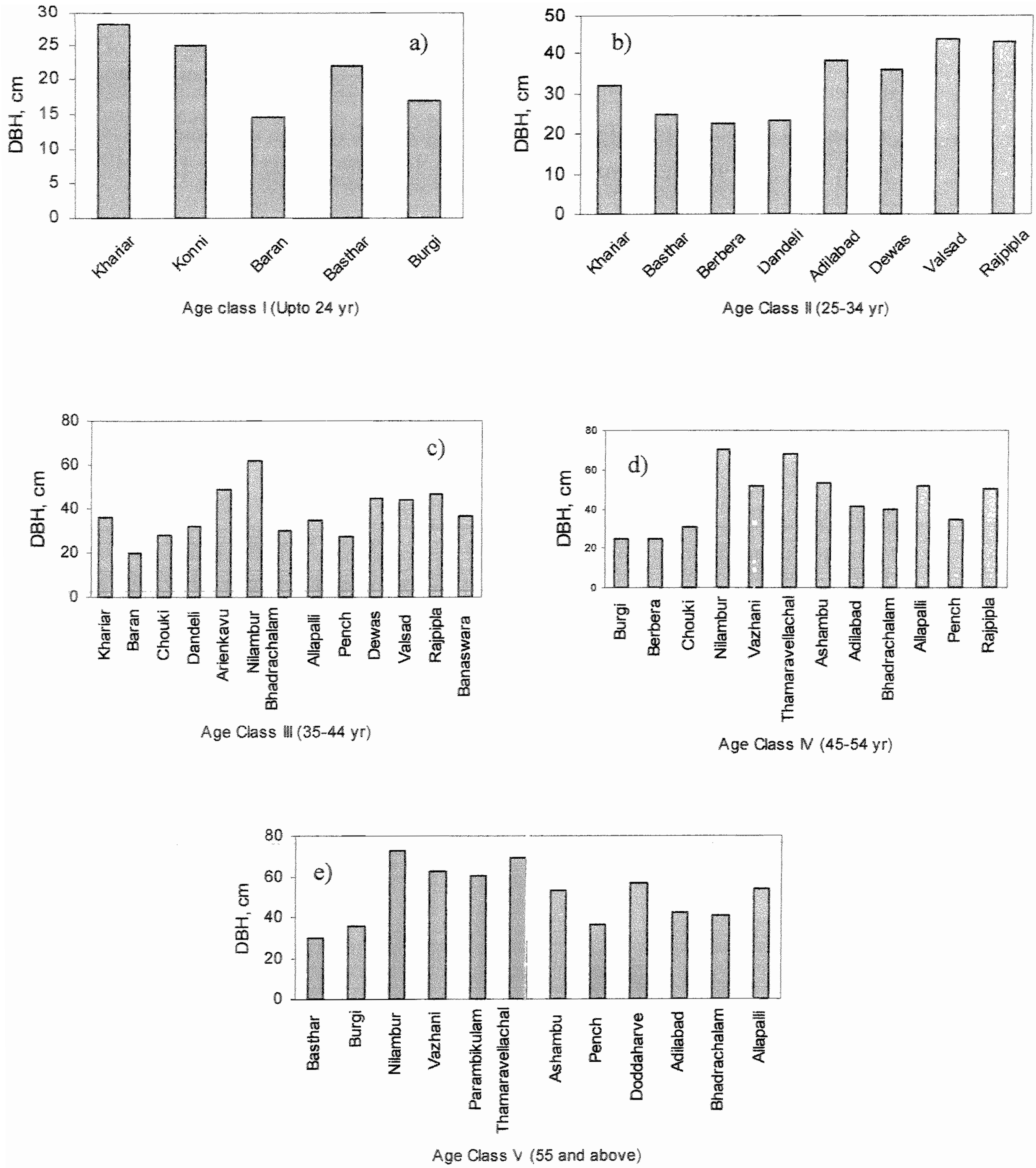


Figure 14 a-e. Variations in DBH of trees between provenances with age

Plantation at Nilambur, Thulasidas and Bhat (2009) could find that in both the populations, heartwood was around 73 percent, though the average log dbh of home garden teak was higher (39.6cm) than that of Nilambur plantation (31 cm). In age class III, the natural Nilambur provenance teak attained double the size of plantation teak (dbh 62.1 cm) with over 90% heartwood as reported in the present study (Figs. 14c & 16c).

Heartwood percentage

Heartwood proportion is one of the parameters of wood property that directly influences timber price and economic returns from teak plantations. As noted earlier, the results showed that heartwood content differed significantly between the provenances (Table 15 and Fig.15). However, for a given age class, dbh and heartwood percentage varied considerably among the geographic locations implying the role of provenance in determining growth rate and heartwood content (Table 16, Figs. 16a to d). Kjaer *et al.* (1999) investigated the heartwood percent in a 17- yea- old trial, and found a high degree of variation between trees, where heartwood content varied between 30 to 90% for trees of the same size. On anlysis of teak at various ages, Kokutse *et al.* (2004) reported that percentage of Togolese teak heartwood differed significantly in trees depending on the ecological zones.

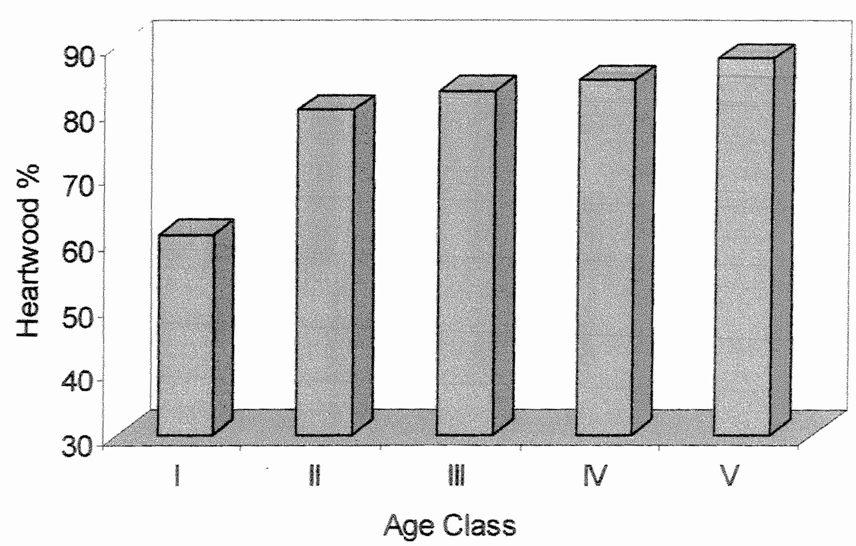


Fig. 15. Mean heartwood percentage of teak provenances with age

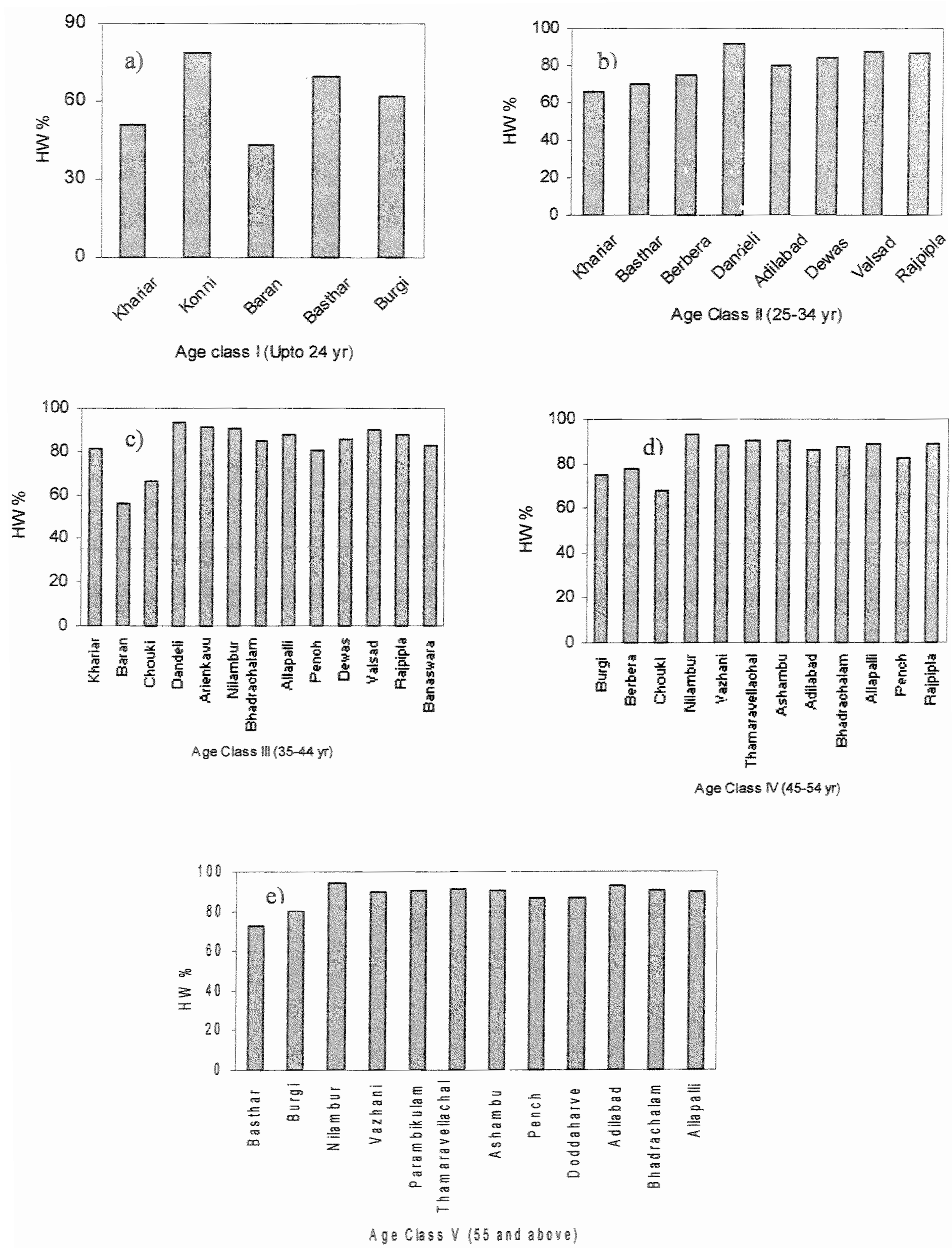


Fig. 16a-e. Variation in heartwood % between provenances with age

The higher growth rate with mean ring width >4.7 and greater heartwood content (>90%) were noted in trees grown in southern states like Kerala, Tamilnadu and Karnataka. The results also showed positive correlation between age and dbh and with age and heartwood content (Table 17; Fig.15). The Nilambur provenance in Kerala shows the maximum dbh with highest amount of heartwood (94.8%) and minimum sapwood at the age above 55 years as observed in this study. The result is in good agreement with the earlier report of Bhat (1998) on the consistent relationship of age on increased heartwood volume in teak of longer rotations. They recorded 87.8% heartwood in 65-year old teak with a narrow sapwood width of 1.4 mm. Several studies reported variations in the percentage of heartwood, colour, durability and mechanical properties depending on ecological conditions (Kokutse *et al.,* 2004; Moya *et al.,* 2003; Bhat *et al.,* 2005). In age class II and III, Dandeli (Teli variety teak) provenance from Karnataka attained the highest heartwood percentage of around 93 among other provenances studied in the age class (Fig.14c) in spite of small log size. Teak from drier areas having small log dimensions had heartwood around 10-15 % less than teak from high rainfall areas up to age class IV and almost similar proportions in age class V with narrow growth rings as evidenced in this study (Figs.16a-e). However, it is to be noted that trees of longer rotations produce logs of large wood volume with more than 90% heartwood.

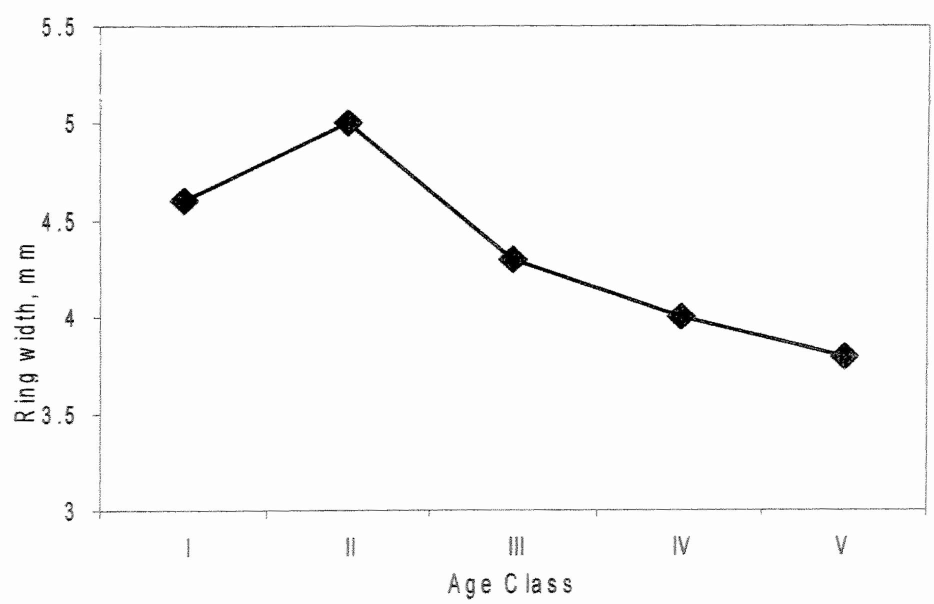


Fig. 17. Mean ring width of 23 teak provenances with age

Ring width

Ring width differed significantly between the 23 provenances and it varied within the age classes (*P≤0.01*) with maximum values recorded from Nilambur provenance (Figs. 15 & 15c). The dbh increased with age and the mean ring width (growth rate) decreased after initial increase up to age class II (Fig.17). In the subsequent age classes, dbh increased with age while ring width decreased showing its consistent relationship with age of the tree rather than the growth rate, in later years. The result is in conformity with the report of Bhat and Priya (2004) that teak from a 21-year-old relatively fast growing location in Nilambur had wider rings with a gradual transition between early- and late wood. For a given age class, Nilambur provenance shows higher dbh with a mean ring width (growth rate) of 7.6 mm followed by other provenances from Kerala, Tamilnadu, Karnataka, Maharashtra and Gujarat (Figs.18a-e).

Table 16. Mean values of selected wood properties in different age classes

Age class	Location		Property			
			Dbh (cm)	Heartwood %	Ring width (mm)	Basic density (Kg/m^3)
	Khariar		28.0^{c}	51.0^{a}	6.4^{d}	473^{a}
	Konni		25.0^{bc}	78.6^{c}	5.0^{c}	584^{bc}
I (up to 24-yr)	Baran		14.5^{a}	43.3^{a}	2.8^{a}	576^{b}
	Basthar		22.0^{b}	69.4^{b}	5.0^{c}	659^{c}
	Burgi		17.0^{a}	62.1^{b}	3.9^{b}	504^{ab}
		Mean	**21.3**	**60.9**	**4.6**	**559**
			(5.6)	(14.1)	(1.3)	(73.0)
	Khariar		32.0^{b}	66.0^{a}	5.0^{b}	529^{a}
	Basthar		25.0^{a}	70.2^{ab}	2.9^{a}	540^{ab}
	Berbera		22.5^{a}	75.1^{bc}	3.6^{a}	667^{e}
	Dandeli		23.5^{a}	91.7^{f}	3.6^{a}	556^{abc}
II (25-34-yr)	Adilabad		38.2^{cd}	79.9^{cd}	5.9^{bc}	583^{cd}
	Dewas		36.2^{bc}	84.3^{de}	5.1^{b}	608^{d}
	Valsad		43.8^{d}	87.4^{ef}	6.6^{c}	564^{bc}
	Rajpipla		43.0^{d}	86.5^{def}	7.0^{c}	556^{abc}
		Mean	**33.0**	**80.1**	**5.0**	**575**
III (35-44-yr)			(8.6)	(9.0)	(1.5)	(44.4)
	Khariar		36.0^{cd}	81.0^{c}	3.6^{bc}	665^{ef}
	Baran		20.0^{a}	56.3^{a}	2.4^{a}	615^{bcde}
	Chouki		28.0^{b}	66.3^{b}	3.5^{bc}	569^{ab}
	Dandeli		32.0^{bcd}	93.8^{g}	3.5^{bc}	664^{ef}

	Arienkavu	49.0^{f}	91.1^{ef}	5.3^{de}	594^{abcd}
	Nilambur	62.1^{g}	90.9^{ef}	7.6^{f}	554^{ab}
	Bhadrachalam	30.3^{bc}	85.0^{de}	3.2^{b}	585^{abc}
	Allapalli	35.0^{cd}	87.9^{de}	3.6^{bc}	538^{a}
	Pench	27.4^{b}	80.9^{c}	3.9^{bc}	608^{bcde}
	Dewas	44.6^{f}	85.7^{cde}	5.2^{de}	636^{cdef}
	Valsad	44.2^{ef}	89.8^{e}	5.1^{de}	650^{def}
	Rajpipla	47.0^{f}	87.5^{de}	5.4^{e}	596^{abcd}
	Banaswara	36.9^{de}	82.4^{cd}	4.2^{cd}	692^{f}
	Mean	**37.9**	**83.0**	**4.3**	**613**
		(11.2)	(10.6)	(1.3)	(46.5)
IV (45-54-yr)	Burgi	25.0^{a}	75.0^{a}	1.7^{a}	552^{a}
	Berbera	25.0^{a}	77.4^{b}	2.5^{b}	583^{ab}
	Chouki	31.0^{b}	67.7^{a}	2.6^{b}	587^{ab}
	Nilambur	70.1^{e}	92.8^{f}	6.6^{f}	592^{bc}
	Vazhani	51.3^{d}	88.1^{de}	4.9^{d}	577^{ab}
	Thamaravellachal	67.9^{e}	89.9^{e}	5.9^{ef}	657^{e}
	Ashambu	53.0^{d}	89.9^{e}	5.0^{de}	626^{cd}
	Adilabad	41.4^{c}	86.1^{d}	3.3^{c}	635^{cd}
	Bhadrachalam	39.3^{c}	87.4^{de}	3.5^{c}	615^{cd}
	Allapalli	51.7^{d}	88.6^{de}	4.8^{d}	626^{cd}
	Pench	34.7^{bc}	82.6^{c}	2.4^{b}	627^{cd}
	Rajpipla	50.3^{d}	89.1^{de}	4.2^{d}	633^{cd}
	Mean	**45.1**	**84.6**	**4.0**	**615**
		(15.0)	(7.5)	(1.5)	(24.9)
V (55 and above)	Basthar	30.0^{a}	72.8^{a}	2.2^{a}	669^{f}
	Burgi	35.6^{b}	80.1^{b}	2.6^{ab}	627^{abcd}
	Nilambur	72.5^{h}	94.8^{g}	4.5^{de}	632^{abcde}
	Vazhani	62.3^{fg}	90.0^{de}	4.6^{de}	614^{ab}
	Parambikulam	60.1^{ef}	90.5^{e}	4.5^{de}	673^{f}
	Thamaravellachal	68.8^{gh}	91.4^{e}	5.3^{e}	638^{abcde}
	Ashambu	53.0^{e}	90.6^{e}	4.0^{d}	660^{cde}
	Pench	36.6^{bc}	87.1^{cd}	2.7^{b}	663^{de}
	Doddaharve	56.6^{ef}	86.7^{c}	4.4^{d}	608^{a}
	Adilabad	42.3^{d}	92.6^{ef}	3.2^{c}	653^{bcde}
	Bhadrachalam	41.0^{cd}	90.8^{e}	3.0^{bc}	618^{abc}
	Allapalli	54.1^{ef}	89.7^{cde}	4.3^{d}	644^{bcde}
	Mean	**51.1**	**88.1**	**3.8**	**635**
		(13.8)	(6.0)	(1.0)	(34.1)

Note: Cell values differing by a letter in the superscript in each column, under each age class corresponding to a property is significantly different at P≤0.05. (SD in parenthesis) (*N=150*)

In age class I, Khariar provenance showed highest growth rate with higher dbh followed by Konni provenance. In the same age class, Konni provenance produced higher proportion of heartwood (78.6%) in the shortest period. Even though dbh and ring width was slightly less than that of Khariar provenance, Konni provenance showed superiority in terms of heartwood proportion. In age class II, Rajpipla and Valsad (Gujarat) exhibited higher dbh and ring width. Burgi provenance (Madhya Pradesh) in age class IV had the lowest dbh (25 cm) and ring width (1.7 mm) among the provenances. Teak being a deciduous species showing distinct growth periodicity in its cambial activity, temperature and precipitation plays an important role in tree growth. The narrow growth rings in teak have been found to match with low rainfall as shown in Table 1. Significant positive response of teak tree- ring chronologies with monsoon and annual rainfall patterns have been reported for the central Indian teak provenances (Somaru *et al.*, 2008) and for the Western Ghats region of India (Priya and Bhat, 1998, 1999; Bhat and Priya, 2004; Deepak *et al.*, 2010).

Basic density

Density of teak showed an increasing trend up to age class II (Fig.19) and more or less constant in subsequent age classes although slightly denser wood is obtained in age class V due to inherent age-related structural changes taking place with increasing cambial age (Zobel and Sprague, 1998). For a given age class, density displayed a fluctuating trend among the provenance. The densest (692 kg/m^3) wood was recorded from Banaswara (Rajastan) and lightest wood (473 kg/m^3) from Khariar (Orissa) (Figs. 20a & c). The density values reported here are similar to the reports of various authors (Bhat *et al.,* 1987; Bhat, 1995; Shukla and Mohan Lal, 1994; Indira and Bhat, 1998; Perez and Kanninen, 2003). Wood density is known to be the best single indictor of wood quality and it is proven to be under strong genetic control (Zobel and Talbert, 1984). But in teak, wood density in clones is strongly controlled by the planting site and not the place of seed origin (Indira and Bhat, 1998). It is correlated with many anatomical, physical and mechanical properties and various end use characteristics.

Wood density did not find any significant relationship between age and growth rate (Table 17) and the result was similar to the report of Sekhar (1972). Also, it did not vary with tree size as reported by Sanwo (1987) on 27-year-old teak plantations from Nigeria and teak from home-garden forestry in India (Bhat *et al.,* 2004). As there was no significant relationship between growth rate and wood density, the result obtained in the present study does not reveal any influence of moisture/rainfall on wood density. Some of the earlier studies showed negative correlation between growth rate and wood density and the general notion among the wood users is that fast grown trees produce only light, weak and spongy wood (Bryce, 1966). In contrast, Bhat *et al.* (1987) indicated 14% higher wood density for fast growing dominant trees than suppressed trees of the same stand. Bhat (1995) compared the wood density of young and mature trees of the same location and stated that only 5% increase in wood density in 50-year old trees as compared to 8-year-old trees.

Due to the dwindling supply of quality teak timber from natural forests, world-wide efforts are now being made to raise fast growing teak plantations of shorter rotations (25-30 years) as against the traditional rotation of 50-70 years to meet the global demand. In the present study of teak from the natural forests in age class I, trees attained the moderate density of 559 kg/m^3 (Fig.19) and thereafter, no significant differences were observed in subsequent age classes even though age related structural changes are anticipated and produce slightly denser wood. Earlier studies based on teak samples obtained from different countries such as Bangaldesh, India and Myanmar indicate that the strongest wood is produced from a modest annual radial growth of 4-5 mm (Limaye, 1942).

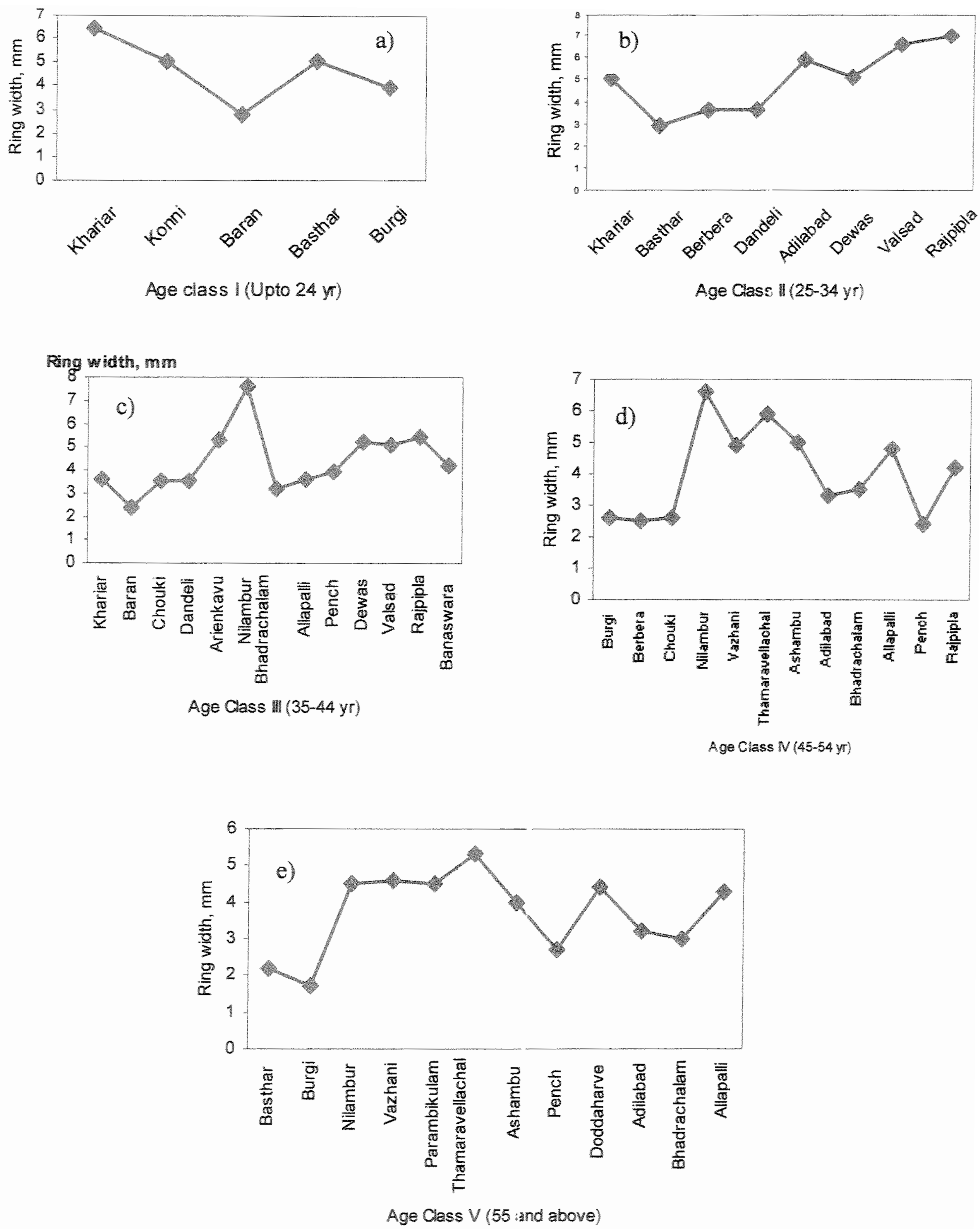


Fig. 18a-e. Variation in mean ring width between provenances with age

Table 17. Correlation between selected wood properties

Age Classes	Characteristic properties	Characteristic properties			
		1 (DBH)	2 (Heartwood %)	3 (Ring width)	4 (Basic density)
I	1. DBH	1.000	0.342^{ns}	0.930**	-0.178
	2. Heartwood %		1.000	0.285^{ns}	0.237^{ns}
	3. Ring width			1.000	-0.181
	4. Basic density				1.000
II	1. DBH	1.000	0.326^{ns}	0.915**	-0.175
	2. Heartwood %		1.000	0.352^{ns}	0.060^{ns}
	3. Ring width			1.000	-0.127
	4. Basic density				1.000
III	1. DBH	1.000	0.596**	0.961**	-0.168
	2. Heartwood %		1.000	0.503**	-0.013
	3. Ring width			1.000	-0.194
	4. Basic density				1.000
IV	1. DBH	1.000	0.774**	0.974**	0.426**
	2. Heartwood %		1.000	0.785**	0.563**
	3. Ring width			1.000	0.376*
	4. Basic density				1.000
V	1. DBH	1.000	0.662**	0.940**	-0.309
	2. Heartwood %		1.000	0.619**	-0.248
	3. Ring width			1.000	-0.218
	4. Basic density				1.000

*** Correlation significant at $P \leq 0.01$ level, * significant at $P \leq 0.05$; ^{ns}- non- significant*

Wood Colour

Wood has different chemical components which vary according to species and therefore each wood exhibits peculiar colour. It is an important factor for end user to consider and the price of wood is often dependent on its colour parameters. Wood colour as determined by Munsell notation, varied among the provenances from yellowish brown to light yellowish brown or dark yellowish brown and occasionally brown to dark brown (Table 18). Teak is a premium hardwood valued for its attractiveness with golden yellowish brown colour. Wood samples collected from drier localities of central parts of India were darker in colour than South Indian provenances (Plate 5) which were dark yellowish brown to dark brown. The Adilabad teak (Andhra Pradesh) is lighter in colour. Heartwood colour is mainly due to the extractives present in wood. Teak wood from Basthar (Chattisgarh) and Burgi (Madhya Pradesh) were dark yellowish brown in colour with the heartwood blending into sapwood (Plate 5) and are well known in Indian market for its colour and texture. In the present study, all the south Indian provenances have varying shades of dark yellowish brown to dark brown colour.

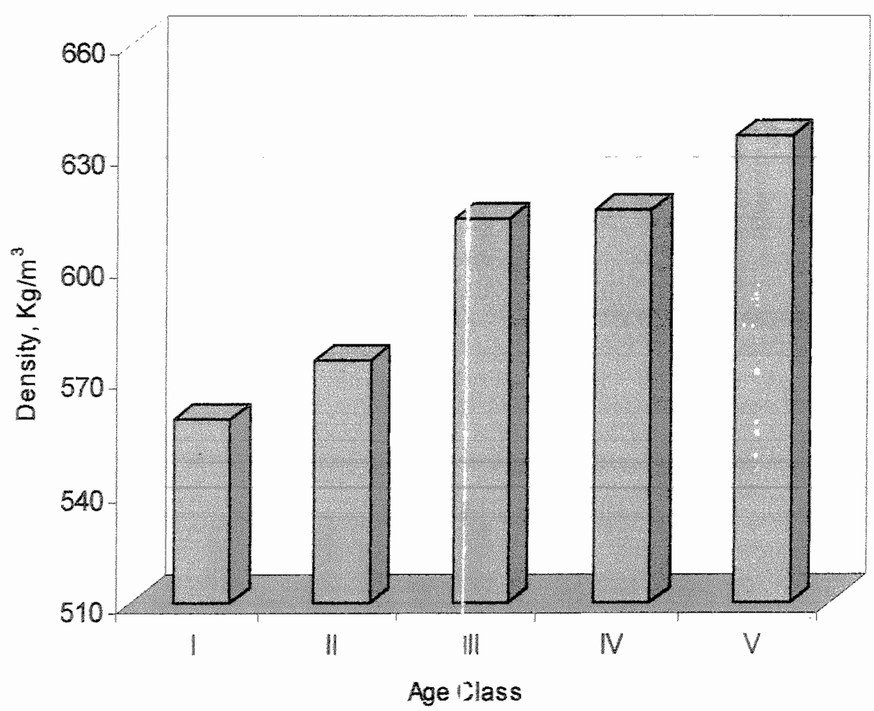


Fig. 19. Mean basic density variation of 23 teak provenances with age

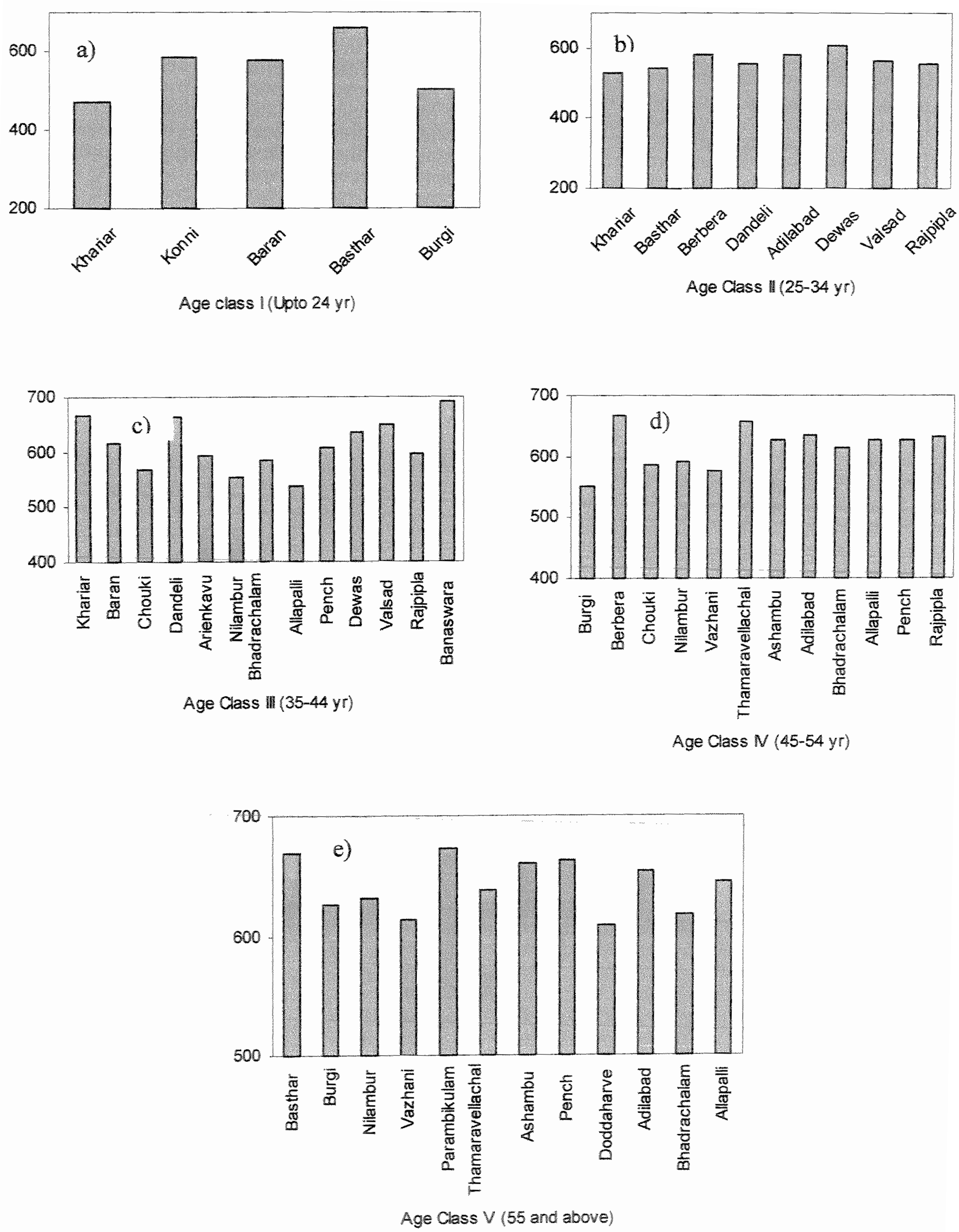


Fig. 20a-e. Mean basic density variation between provenances with age

Table 18. Wood colour variation in different teak provenances

Location	Munsell system			Colour description	
	Hue	Value	Chroma		
Thamaravellachal	10	4	4	4/4 10 YR	Dark yellowish brown
Vazhani	10	5	4	5/4 10 YR	Yellowish brown
Nilmbur	10	4	4	4/4 10 YR	Dark yellowish brown
Parambikulam	10	4	3	4/3 10 YR	Dark brown
Arienkavu	10	5	6	5/6 10 YR	Yellowish brown
Konni	10	5	6	5/6 10 YR	Yellowish brown
Doddaharve	10	5	3	5/3 10 YR	Brown
Dandeli	10	4	4	4/4 10 YR	Dark yellowish brown
Ashambu	10	5	3	5/3 10 YR	Brown
Adilabad	10	6	4	6/4 10 YR	Light yellowish brown
Bhadrachalam	10	5	4	5/4 10 YR	Yellowish brown
Banaswara	10	4	4	4/4 10 YR	Dark yellowish brown
Baran	10	4	4	4/4 10 YR	Dark yellowish brown
Pench	10	4	4	4/4 10 YR	Dark yellowish brown
Allapalli	10	4	4	4/4 10 YR	Dark yellowish brown
Rajpipla	10	4	4	4/4 10 YR	Dark yellowish brown
Valsad	10	4	4	4/4 10 YR	Dark yellowish brown
Dewas	10	4	3	4/3 10 YR	Dark brown
Burgi	10	4	4	4/4 10 YR	Dark yellowish brown
Chouki	10	4	4	4/4 10 YR	Dark yellowish brown
Basthar	10	4	4	4/4 10 YR	Dark yellowish brown
Berbera	10	5	4	5/4 10 YR	Yellowish brown
Khariar	10	4	4	4/4 10 YR	Dark yellowish brown

(N=150)

The Malabar teak (Nilambur) is known world-wide due to its peculiar golden brown colour and natural durability. As the golden brown wood colour is one of the most attractive timber qualities, the variation in teak wood colour and texture with respect to site and different ecological zones has been widely studied (Sandermann and Simatupang, 1966; Kaosa-ard, 1993, Derkyi *et al.,* 2009). Thulasidas and Bhat (2006) studied the colour variability of home-garden teak and compared it with plantation teak from Nilambur. They reported highly saturated colour indices blended in Nilambur teak as studied by the visual matching method, the Munsell system and confirmed by spectrophotometric method. Faster growth and shorter rotation of cultivated teak have been reported to cause wood to be paler in colour (Bryce, 1966; Bhat *et al.,* 2005). On appearance, the Dandeli teak provenance looked paler in colour although it was measured dark yellowish brown by Munsell system (Plate 5, Table 18) probably due to the low extractive content (5.2%) recorded. Kaosa-ard (1993) has reported that there is no or little significant effect of provenance on wood colour and wood density. A study on clonal variation in wood colour and texture in Thailand in a 20-year-old clonal test clearly demonstrated that teak wood colour and texture is strongly controlled by the planting site (Kaosa-ard, 1995).The cause of such variation is still not known but is possibly due to differences in soil chemistry and moisture content in the two planting sites.

Extractives and lignin content

The ANOVA showed significant variation in extractive content among the different age classes except in age class I, where it was found non-significant (Table 19). The results of the mean values of total extractive content and lignin content of the 57 disc samples of nine provenances belonging to different age classes are presented in Table 20a. The extractive content varies from 5.2- 12.3% and the lignin content 21-36.9% between the provenances. The total extractives and lignin content increase with age and offer more durability and strength to the timber. The quantity of total extractive content as indicator of relative natural durability of teak has been established by several workers (Simatupang *et al.,* 1996; Yamamoto *et al.,* 1998). In teak wood, the total extractive content is around 10% and tectoquinone was responsible for termite resistance and naphthoquinone for fungal decay. On a study on 35-year-old home garden teak from Kerala, Bhat *et al.* (2005) reported that teak wood from high rainfall area are paler in colour due to low amount of extractives (10%) and are susceptible to brown-rot fungi and the drier area teak are more durable with comparatively higher extractive content (15.98%) with dark yellowish brown colour. Further, Thulasidas and Bhat (2007) studied the factors responsible for this variability in home garden teak. They found positive correlation with the individual extractive compounds rather than total extractive content responsible for decay resistance of teak timber. The Basthar provenance possesses high amount of extractive content (12.3%) and has more attractive colour. In an earlier study, 12 percent extractive content was observed in Nilambur teak by Bhat *et al.* (2005). But Dandeli teak (Karnataka) appeared paler in colour probably due to low amount of extractives (5.2%) (Plate 5).

Table 19. ANOVA on extractives and lignin content

Age Classes	Source of variation	d.f	Extractive content %		Total lignin %	
			MSS	F-value	MSS	F-value
I	Provenance	4	4.83	2.22 ^{ns}	7.73	9.84*
	Error	10	2.16		0.786	
II	Provenance	1	20.07	295.92**	9.92	109.3**
	Error	4	0.068		0.091	
III	Provenance	6	8.802	14.19**	2.05	2.55*
	Error	14	0.620		0.804	
IV	Provenance	2	12.06	27.97**	2.30	7.60*
	Error	6	0.431		0.303	
V	Provenance	1	11.21	141.59**	7.18	365.8**
	Error	4	0.079		0.020	

*** Significant at P≤0.01; * Significant at P≤0.05*

The lignin content reported in this study was standard for mature tropical hardwoods and was indicative of its relative mechanical properties. However, no definite relationship could be established between extractives and lignin; both are independent with regard to its properties. Lignin content was found high in Burgi provenance from Madhya Pradesh (36.9%) (Table 20). The elastic behaviour of timbers (stiffness) for solid end-use characteristics is being influenced by the variability in lignin content. Since only nine out of 23 provenances were analysed for extractive content and lignin; more in depth qualitative assessment between all the provenances is required for its direct influence on wood properties which was not attempted in the present study due to non-availability of adequate powder samples.

Anatomical properties

Anatomical observations, might offer some explanations for the differences observed in the physical behaviour of wood. The ANOVA and the mean values of anatomical properties of 9 provenances studied are presented in Tables 21, 22 and 23. The results of ANOVA showed that the provenances belonging to age class I, III and V differed significantly with regard to early- and latewood percentage. However, it shows non- significant variation in age class II and IV ($P=0.01$). In Table 21, the ANOVA indicates significant difference between provenances under age class I, II and III with regard to parameters, viz., vessel diameter/ frequency, vessel%, fibre% and parenchyma%. No significant difference between provenances in age class V was observed for the above anatomical properties; whereas in age class IV significant difference was observed for vessel frequency, vessel% and parenchyma% except for vessel diameter and fibre percentage.

The lighter wood of Khariar provenance (Orissa) recorded in age class I (Fig.20a) 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 23, Plate 6). However, the fibre length showed maturity (1.2 mm) in age 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 accompanied by reduced vessel diameter/

percentage, lignified fibre walls with high proportion of fibres and low percentage of parenchyma (Figs.20b & c).

Table 20. Mean values of total extractive content and lignin

Age class	Provenance		Property	
			Total extractive content (%)	**Total lignin (%)**
I	Khariar		8.14^{a}	30.18^{a}
	Konni		10.02^{ab}	36.55^{b}
	Baran		8.45^{ab}	30.14^{a}
	Basthar		11.19^{b}	31.45^{a}
	Burgi		8.67^{ab}	32.2^{a}
		Mean	**9.29** (1.3)	**32.10** (2.6)
II	Khariar		8.42^{a}	21.01^{a}
	Dandeli		5.22^{b}	26.94^{b}
		Mean	**6.82** (2.3)	**23.98** (4.2)
III	Khariar		9.49^{b}	33.23^{ab}
	Baran		11.20^{c}	32.28^{ab}
	Basthar		10.35^{a}	32.75^{ab}
	Berbera		10.35^{a}	32.75^{a}
	Chouki		10.63^{b}	32.60^{b}
	Dandeli		10.44^{b}	32.70^{ab}
	Arienkavu		10.47^{b}	32.68^{b}
		Mean	**10.42** (0.5)	**32.71** (0.3)
IV	Burgi		9.35^{a}	33.23^{b}
	Berbera		7.59^{b}	31.37^{a}
	Chouki		11.68^{c}	34.18^{b}
		Mean	**9.54** (2.0)	**32.93** (1.4)
V	Basthar		12.39^{a}	33.30^{a}
	Burgi		10.02^{b}	36.94^{b}
		Mean	**11.21** (1.7)	**35.12** (2.6)

Note: Cell values differing by a letter in the superscript in each column, under each age class are significantly different at P≤0.05 SD in parenthesis (N=57)

Plate 5a. Teak wood discs displaying colour variation between different provenances.

Note the deep dark yellowish brown teak from Baran (Rajastan) (top left); the paler coloured wood from Dandeli (Karnataka) (bottom)

Contd..

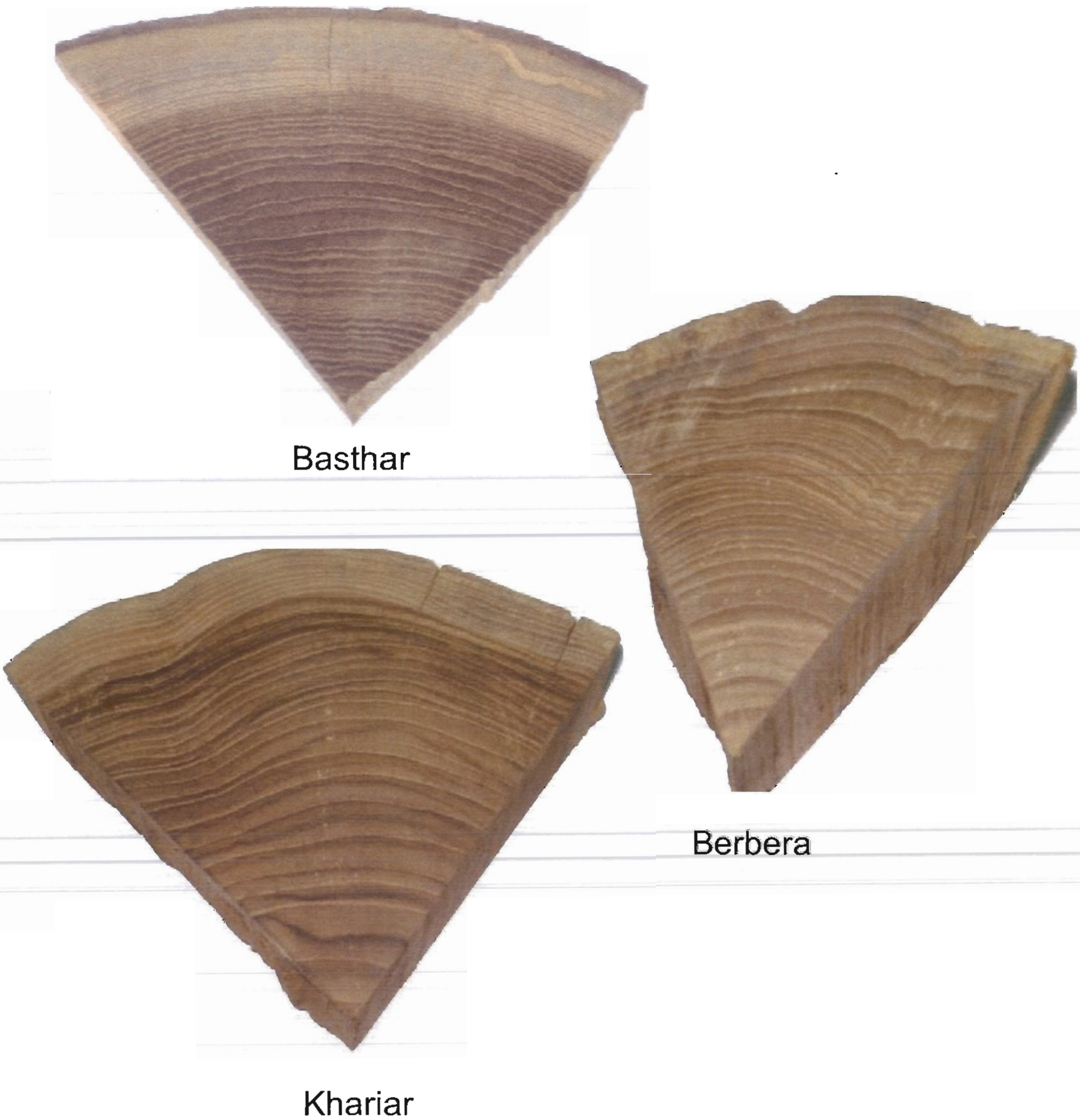
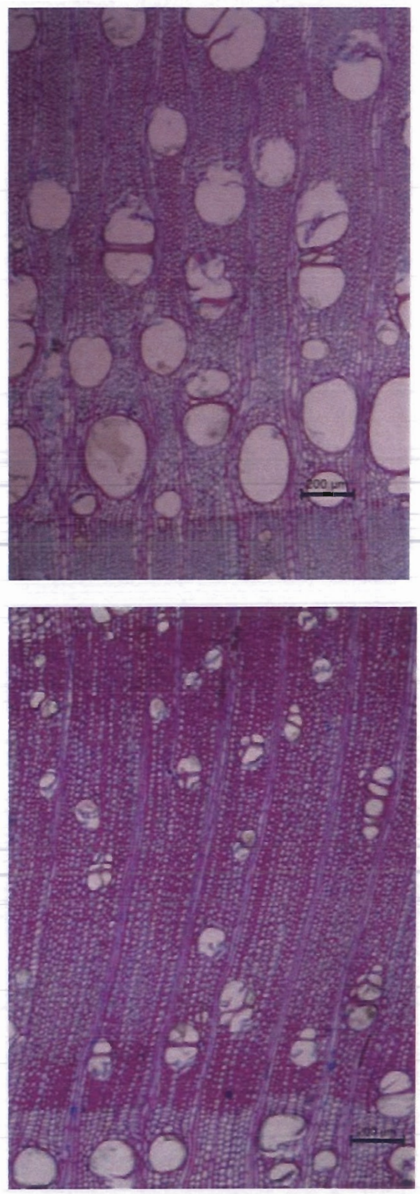


Plate 5b. Teak wood from central India displaying more or less uniform colour



Age class I

Age class III

Plate 6. T.S. of teak wood from Khariar provenance belonging to Age class I (top) and Age class III (bottom) showing anatomical variation of the provenance with age.

Note the high percentage of large diameter vessels and thin walled schlerenchyma tissue in Age class I (top). *Narrow growth ring with small diameter vessels and highly lignified schlerenchyma tissue in Age class III (bottom).*

Table 21. ANOVA for anatomical properties

Age Class	Source of variation	d.f	F values						
			Early wood	Late wood	Vessel diameter	Vessel frequency	Vessel	Fibre	Paren chyma
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	3	1.25 ns	1.25 ns	50.61**	2.74*	44.83**	56.98**	26.12**
	Error	68	23.95	23.95	0.009	0.024	5.97	5.22	3.98
III	Provenance	4	2.4*	2.4*	26.46**	7.14**	28.87**	32.95**	38.62**
	Error	115	33.3	33.3	0.014	0.041	6.07	5.74	3.42
IV	Provenance	2	2.59 ns	2.59 ns	2.88 ns	43.8**	3.56**	1.25 ns	10.24**
	Error	87	51.16	51.16	0.027	0.019	14.90	18.26	4.91
V	Provenance	1	29.05**	29.05**	0.44 ns	15.2**	0.06 ns	0.05 ns	0.77 ns
	Error	70	23.71	23.71	0.043	0.023	15.86	13.42	2.38

*** significant at P≤0.0,; * significant at P≤0.05, ns- non significant*

Dandeli teak (Teli variety) provenance from Western Ghats region of Karnataka (age class II & III) had significantly low vessel diameter and percentage and high proportion of fibre tissue (71%) and comparatively low amount of parenchyma (16.8%) in the narrow rings, while the early-and late wood percentage showed non-significant variation (Table 21). The result is contradictory to the findings of Bhat and Indira (2005) that the slow growing North Kanara provenance (21-year-old teak) 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 provenance adaptation with the higher amount of storage parenchyma possibly being related to soil rich conditions. In the present study also, the Konni provenance in age class I showed a similar trend (Table 23). The Basthar and Burgi provenance in age class V displays non-significant variations both in terms of anatomical properties and density (*P=0.01*). Irrespective of the age classes, all the central provenance teak showed significant variation in tissue percentages while the vessel diameter varies up to age class III and thereafter it is non-significant (Table 19).

Table 22. ANOVA for fibre properties between provenance and radial positions

Age Classes	Source of variation	d.f	F values			
			Fibre length	Fibre diameter	Lumen width	Double wall thickness
I	Provenance	4	50.34**	204.76**	57.88**	16.82**
	Position within tree	6	23.44**	22.42**	6.97**	3.95*
II	Provenance	3	254.62**	7.65*	5.7*	10.78**
	Position within tree	6	43.15**	33.10**	34.3**	10.78**
III	Provenance	4	79.38**	18.48**	22.80**	47.65**
	Position within tree	6	23.32**	17.06**	5.01*	2.46*
IV	Provenance	2	231.04**	171.37**	395.58**	1473.64**
	Position within tree	6	10.85**	12.01**	5.09*	0.38 ^{ns}
V	Provenance	1	64.47**	184144.9**	396144.1**	29481.8**
	Position within tree	6	21.56**	16.47**	5.49*	0.02 ^{ns}

*** significant at $P \leq 0.01$, * significant at $P \leq 0.05$, ^{ns}- non significant*

With regard to the fibre dimensions, maximum fibre length was obtained in Konni provenance (1.4 mm), whereas, thick walled fibres were observed in the central provenance teak with small fibre lumen. The fibre properties varied significantly between the 9 provenances and along radial positions from pith to periphery irrespective of the age classes (Table 22). The maturity age of fibres in teak was found to be around 20-25 years (Bhat *et al.*, 2001) and the present results are in conformity with their report.

The present study of anatomical properties on 9 provenances is insufficient to draw conclusions on the variability between the provenances and warrants anatomical investigations on the remaining 14 provenances.

Table 23 (a). Mean values for wood anatomical properties in different provenances

Properties	Age Class 1					Age Class II			
	Mean					Mean			
	Khriar	Konni	Baran	Burgi	Bastar	Khriar	Bastar	Berbra	Dandli
Early wood %	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^{a} (7.1)	72.1^{a} (6.2)	73.4^{a} (7.9)	69.2^{a} (9.1)
Late wood %	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^{a} (7.1)	27.9^{a} (6.2)	26.6^{a} (7.9)	30.8^{a} (9.1)
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^{b} (10.8)	194.3^{c} (19.4)	154.2^{b} (11.2)	131.5^{a} (17.7)
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)
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^{b} (3.5)	23.8^{c} (4.1)	18.3^{b} (2.1)	11.7^{a} (3.2)
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^{b} (4.1)	57.0^{a} (5.2)	68.3^{c} (2.8)	71.3^{d} (2.8)
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^{c} (2.4)	19.2^{c} (2.2)	13.5^{a} (2.8)	16.9^{b} (2.6)
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 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)

Note: Cell values differing by a letter in the superscript in each row, under each age class corresponding to each property are significantly different at $P \leq 0.05$ (SD in parenthesis)

Table 23 (b). Mean values for wood anatomical properties in different provenances

Properties	Age Class III					Age Class IV			Age Class V	
	Mean					Mean			Mean	
	Khriar	Baran	Choki	Dandeli	Arienkv	Burgi	Berbera	Choki	Bastar	Burgi
Early wood %	63.4[a] (9.9)	68.9[ab] (9.7)	71.3[b] (5.8)	65.4[a] (6.5)	66.2[ab] (13.2)	64.7[a] (8.5)	67.4[ab] (6.1)	71.5[b] (7.7)	69.8[a] (6.5)	59.6[b] (9.5)
Late wood %	36.6[b] (9.9)	31.5[ab] (9.7)	28.8[a] (5.8)	34.6[b] (6.5)	33.8[ab] (13.2)	35.3[b] (8.5)	32.6[ab] (6.1)	28.5[a] (7.7)	30.2[a] (6.5)	40.4[b] (9.5)
Vessel diameter (µm)	137.8[a] (14.4)	156.6[b] (19.6)	174.3[c] (13.3)	129.8[a] (16.1)	166.8[bc] (23.3)	179.8[b] (21.6)	163.0[a] (17.8)	169.2[ab] (33.2)	169.0[a] (33.7)	173.4[a] (29.5)
Vessel frequency /mm²	6.5[c] (0.9)	6.5[c] (1.7)	5.5[ab] (0.8)	6.0[bc] (1.1)	5.1[a] (1.3)	6.4[b] (0.9)	6.9[c] (0.9)	5.0[a] (0.5)	6.9[a] (0.7)	6.1[b] (1.2)
Vessel %	13.8[a] (2.2)	16.9[b] (3.8)	20.6[c] (3.2)	12.4[a] (3.7)	12.9[a] (2.6)	19.5[a] (1.9)	23.8[b] (7.3)	18.1[a] (5.1)	20.3[a] (5.7)	20.5[a] (4.9)
Fibre %	69.8[d] (3.7)	59.7[a] (4.5)	63.3[b] (3.5)	70.9[d] (3.8)	66.6[c] (4.0)	64.4[a] (2.6)	61.6[a] (8.4)	64.0[a] (8.4)	59.0[a] (5.8)	58.6[a] (6.6)
Parenchyma %	16.3[a] (2.1)	23.4[c] (2.6)	16.1[a] (1.9)	16.8[a] (3.1)	20.6[b] (2.7)	16.2[b] (2.1)	14.6[c] (2.5)	18.0[a] (3.5)	20.7[a] (2.3)	20.9[a] (2.0)
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)	1.0[a] (0.1)	1.3[c] (0.1)	1.1[b] (0.1)	1.0[a] (0.2)	1.1[b] (0.1)
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)	26.8[c] (2.7)	25.4[b] (1.4)	24.0[a] (1.1)	22.9[a] (1.8)	23.6[b] (3.2)
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)	18.4[b] (3.5)	15.4[a] (0.6)	15.3[a] (0.6)	13.1[a] (0.7)	14.0[b] (2.5)
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)	8.4[a] (0.8)	10.0[b] (1.5)	8.8[a] (0.5)	9.8[b] (1.1)	9.5[a] (0.7)

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

4. SUMMARY AND CONCLUSIONS

The present project was undertaken to study the genetic diversity in teak (*Tectona grandis* L.f.) with respect to morphological and wood characteristics, to establish a germplasm bank and to compare different ecotypes under uniform conditions. Populations were selected in the natural teak forests in ten states in India (Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Chattisgarh and Orissa) and observations were taken on morphological variations like growth, tree form and leaf characters. Fruits were also collected from these populations and observations were taken on the seed variability. An *ex situ* germplasm bank was established. Wood samples in the form of disc or core samples were also taken for analyzing the wood properties.

Regarding the tree form characters, straightness, persistence of axis, branch size, branching mode, clear bole ratio and also bole defects like knots, twist, fluting etc were examined. Observations showed that Hudsa (Teli variety) from Dandeli, Karnataka is the provenance with best tree form having first place for many of the tree form traits. There are other provenances which are best performers in one or two traits. Tholpetty had a trend for horizontal branching and also had the highest percentage of light branched trees. Nilambur was knot free provenance and had highest percentage of trees with axis persistence apart from Hudsa. With regard to bad performers, Chinnar had the tendency for more double limbs and crooked bole. Baran was the seed source which branched at a lowest height and with more crooked trees. Ashambu, Doddaharve and Mandagadde had larger branch size. Branching mode without double limbs had highly significant positive correlation with persistence of axis, straightness and less twisting. This shows that from the branching mode, which can be assessed at an early age, we can infer the trend for axis persistence and straightness of a tree without waiting till maturity.

The results showed that at higher altitudes, trees had a tendency to grow double limbed, and twisted with less axis persistence. Rainfall had highly significant positive correlation with small branch size and also with percentage of light branched trees. At higher rain fall areas, trees had horizontal branching with light branches.

Out of the six provenances from Kerala, only Nilambur had predominantly sessile leaves. Likewise, all the trees with sessile leaves were seen in Berbera (Orissa). Leaves of all the provenances except those from Kerala as well as Doddaharve (Karnataka) and Ashambu (Tamil Nadu) were pubescent. Rainfall had strong negative correlation with leaf pubescence. Drupe characters such as size variations, seed filling percentage, seed viability, endocarp and mesocarp lignin content and germination percentage were also investigated. Rainfall had a negative correlation with seed filling percentage.

The present study also evaluated the physical properties of the wood samples collected from the 23 Indian teak provenances. Extractive contents and anatomical properties were analysed in nine provenances. Tree diameter at breast height (DBH) showed a positive correlation with age and heartwood percentage. Teak attained maximum diameter in the states of Kerala, Tamil Nadu, Karnataka, Maharashtra and Gujarat out of the ten states. The Central Indian teak provenances collected from the Madhya Pradesh, Chattisgarh, Orissa, Andhra Pradesh and Central Maharashtra had low log diameter and reduced heartwood proportions compared to the provenances from Western Ghats region.

Higher growth rate with mean ring width of above 4.7 mm and greater heartwood content (>90%) were noted in trees grown in southern states like Kerala, Tamil Nadu and Karnataka. In age class II (25-34 years) and III (35 to 44 years), Hudsa (Teli variety teak) from Dandeli in the Western Ghat region of Karnataka state attained highest heartwood of around 93 percentage in spite of small log size. On a whole Nilambur provenance also showed high heartwood proportion along with wider growth rings.The effects of growth rate on heartwood content seem to be reducing with age as seen in age class III onwards. Teak from drier areas produced 10-15 percent less heartwood than teak from high rainfall areas with narrow growth rings as evident from this study.

Ring width differed significantly between the 23 provenances and it varied within the age classes with maximum values recorded from Nilambur provenance (7.6 mm) followed by other provenances from Kerala, Tamil Nadu (Ashambu), Karnataka, Maharashtra and Gujarat. Mean ring width (growth rate) decreased after initial increase up to age class II. In the subsequent age classes, dbh increased with age while ring width decreased showing its consistent relationship with age of the tree rather than the growth rate in later years. Teak being sensitive to moisture/rainfall, the narrow growth rings obtained in Burgi (Madhya Pradesh), Basthar (Chattisgarh), Baran (Rajasthan) and Berbera (Orissa) provenances has been found to match with low/ moderate rainfall.

Basic density of wood stabilised after attaining maturity in age class I (up to 24 years) and thereafter did not show any significant variation except the age related structural changes. For a given age class, density displayed a fluctuating trend among the provenances. The densest wood (692 kg/m3) was recorded from age class III in Banaswara (Rajastan) and the lightest wood (473 kg/m3) from age class I in Khariar (Orissa).

Wood colour as determined by Munsell notation, varied among the provenances from yellowish brown to light yellowish brown or dark yellowish brown and occasionally brown to dark brown. In the present study, all the South Indian provenances have varying shades of dark yellowish brown to dark brown colour. Teak wood collected from drier localities of central parts of India were darker in colour than South Indian provenances. On appearance, the Hudsa teak from Dandeli looks paler in colour.

Total extractive content and lignin content of the 57 disc samples of nine provenances indicated significant variation between provenances. The extractive content varies from 5.2- 12.3% and the lignin content 21-36.9% between the provenances. The Basthar provenance (Chattisgarh) possessed high amount of extractive content (12.3%) and more attractive colour, whereas, Hudsa teak (Dandeli, Karnataka) appeared paler in colour probably due to low amount of extractives (5.2%) recorded. No definite relationship could be established between extractives and lignin; both are independent with regard to its properties. Lignin content was found high in Burgi provenance (36.9%) from Madhya Pradesh.

The lighter wood of Khariar provenance (Orissa) recorded in age class I (up to 24 years) was due to faster growth rate with a wide early wood band, large vessel diameter / percentage, low fibre percentage and thin-walled fibres. Irrespective of the age classes, all the central provenance teak showed significant variation in tissue percentages while the vessel diameter varies up to age class III (35 to 44 years) and thereafter it was found non-significant. The fibre properties varied significantly between the nine provenances studied and along radial positions from pith to periphery irrespective of the age class. The longest fibres (1.4 mm) were obtained from Konni provenance.

Ex situ conservation of germplasm was established at Nilambur with 25 provenances. Konni, Arienkavu (Kerala) and Mandagadde (Karnataka) were found to be the best performers for early growth. There was high genetic coefficient of variation and moderate heritability for growth, which will help in exploiting the genetic gain through the selection of better provenances.

The study revealed that the South Indian teak provenances showed superior tree form, wood quality as well as growth characteristics suitable for future genetic conservation programmes. Hybridization programmes involving best performer for growth and excellent provenances having best tree form (Hudsa), highest heart wood percentage (Nilambur and Hudsa), highest ring width (Nilambur) and highest extractive content (Basthar) would lead to the production of superior planting stock.

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

1. There are significant variations between provenances for characters controlling the tree form, leaf characters, drupes and growth. Hence, there is immense scope for tree improvement through provenance selection and hybridization.
2. With regard to tree form, Hudsa (Teli variety) from Dandeli, Karnataka is the best performer for most of the characters like straightness, axis persistence, clear bole length etc. For few other characters, provenances like Tholpetty, Nilambur and others are best.

3. Geo-climatic factors such as altitude and rainfall have strong correlation with few of the characters under tree form, which show that these are adaptations which may or may not be genetic.
4. If branches are double limbed there is every chance for the trees to be forked with poor axis persistence. This information will help in early selection of trees with good axis persistence. If branches are of small size, there is a tendency for the trees to have horizontal branching which is preferred for knot free timber.
5. With respect to leaf characters, Nilambur provenance stands separately from other provenances from Kerala. Rough and pubescent leaves are seen in Central and North Indian provenances.
6. Rain fall has significant negative correlation with fruit filling percentage. Seed germination has no significant correlation with any of the other seed factors, though it has nonsignificant positive correlation with fruit filling percentage and negative correlation with endocarp ash and lignin.
7. With regard to growth, Konni, Arienkavu (Kerala) and Mandagadde (Karnataka) have shown highest growth at early age.
8. 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.
9. Better provenances for characters of economic value, like growth and those controlling tree forms, should be utilized for genetic improvement through hybridization or other means.
10. The slow growing dry locality teak from central provenances had small dimensional logs with 10-15% less heartwood than South Indian provenances of Western Ghats region receiving high rainfall.
11. The higher growth rate (wider rings) and logs of large dimensions having high proportion of heartwood (>90%) were noted in trees grown in southern states like Kerala, Tamilnadu and Karnataka followed by Maharashtra, Gujarat and Andhra Pradesh. Nilambur provenance stands unique among all the provenances as it produces the large diameter logs (72.5 cm) with maximum heartwood content (94.8%) at the rotation age above 55 years.

12. Wood density stabilized after attaining maturity in age class I. Thereafter there was no significant variation between provenances in any of the age classes. Density did not vary with tree size or with tree age and is independent of growth rate. The densest wood (692 kg/m^3) was recorded in age class III from Banswara (Rajastan) and lightest wood (473 kg/m^3) in age class I from Khariar provenance (Orissa).
13. The wood colour varied significantly between provenances. Teak wood samples collected from central part of India were darker in colour than south Indian provenances which were dark yellowish brown to dark brown. The pale colour of Dandeli teak was attributed to low extractive content (5.2%).
14. Extractive content and lignin content showed a fluctuating trend between provenances in all the age classes. The Basthar provenance recorded the maximum extractive content (12.4%) which is on par with that reported earlier from Nilambur provenance.The Burgi provenance showed maximum lignin (36.9%) among the nine provenances studied. The study is inconclusive as the remaining 14 provenances are to be analysed for the above properties.
15. Anatomical investigations completed for the nine provenances revealed the reasons for certain differences observed in the physical properties. The lightest wood of Khariar provenance (473 kg/m^3 in age class I) was due to the fast growth rate with a wide early wood band, larger vessels/ percentage, low fibre percentage and thin walled fibres. However, within the same provenance, there was an increase in wood density in subsequent age classes and the wood quality was not affected as evaluated by anatomy. Anatomical investigations on the remaining 14 provenances would give the explanations for the differences between provenances with respect to physical properties.
16. Fibre dimensions did not vary significantly between different age classes and the fibre length was longer in Konni teak. All the central provenances displayed thick walled fibres with small fibre lumen. However, significant variation was observed in radial direction from pith to periphery irrespective of the age classes and provenances studied.

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