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WOOD AND BARK PROPERTIES OF BRANCHES OF SELECTED TREE SPECIES GROWING IN KERALA

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ABSTRACT

In the present system of logging and timber utilisation, branches remain as the major unutilised reserves of the industry. With a view to evaluating raw material quality, this project aims at the investigation of some important technical properties of branches in relation to those of stem of eleven selected timber species The properties examined are density of wood and bark, percentage of bark and heartwood, proportion of wood components viz. fibres, vessels, rays and parenchyma and fibre length The timbers studied are benteak, cashew, coraltree, dhaman, dillenia. gurjan, irul, kindal, padri, rubberwood and teak.

No statistically significant difference is found between branches and stem either in wood and bark density or in percentage of fibres, vcssels, rays; and parenchyma of majority of the species. The average percentage of bark is siginificantly greater in branches than in stem. It ranges from 10.3 (in benteak) to 28.9 is cashew) in branches as against 4.8 to 16.2 in stem. Heartwood percentage is considerably lower in the branches. On an average, branch fibre length is 12 percent lower than stem fibre length. Mostly, wood density and bark percentage are higher at the top, while the heartwood percentage and fibre length are greater at the bottam of branches and stem. The coefficients of variation and analysis of variance reveal that with a few exceptions, the variability of these properties among branches and stem is not large. Branch diameter is an important quality parameter as it is correlated with bark and heartwood percentage, fibre length and wood and bark density of certain species. The results of this study suggest that branches can be an additional sourse of raw material for pulp, paper and board industries.

The among-species comparison, based on statistical tests, shows that: (1) Coraltree is a low-density (<400 kg/m^3) timber; cashew comes under moderately low-density (400-550 kg/m^3) hardwood and rest of the species are medium density (550-—750 kg/m3) hardwoods, irul being the heaviest timber, (2) With average fibre length below 1 mm, cashew is a short-fibred hardwood; dillenia, with average fibre length of 2.7 mm can be included under long-fihred species and rest of the species come under the hardwoods of medium-sized fibres (average fibre length of 1.0.5 mm). Dillenia is, therefore, of particular interest to the paper industry in meeting the long-fibre needs.

Key words: Tropical hardwoods, branch raw material, bark properties wood density, fibre length, long-fibred

1. INTRODUCTION

'Timber plays a significant role in the economy of Kerala. The development of wood-based industries is, therefore, of great importance to the state. But with the current rate of dwindling timber resources, not only the expansion but even the existence of many of the industries is in jeopardy. This critical situation of the industries calls for drastic changes in the pattern of raw material supply without further delay. One approach to increase the resources is maximisation of timber yield per unit land area by intensive forestry. Since such a plan has to depend upon major limiting factors like land availability, species establishment and rotation cycle, one of the immediate alternatives appears to be the total utilisation of available recources, i.e., complete utilisation of fibre content of nonmerchantable tree parts viz. branches, bark, foliage and roots. As long as the supply of stem logs was sufficient, there was no real need to utilise these residues and the general notion wac that they are inferior to stem wood in technical properties and their logging cost would he prohibitive. But the utilisation of logging residues has now turned out to be a viable alternative in many industrialised countries.

In India. it is estimated that almost 50 percent of tree volume harvested is left in the forest as logging residues. According to Pre-investment Survey (UNDP/FAO 1970), the branches alone account for 25—45 percent of the tree volume of our timbers. Apparently, branches constitute the major unutilised timber reserves of the industry. It is the purpose of this project to estimate some important branch properties in order to assess the raw material quality.

2. BACKGROUND

It is only 20 years ago that the concept of total tree utilisation came into practice in North America and Europe (Young 1964, Hakkila 1971). It has offered considerable scope for the efficient utilisation of branches especially in the manufacture of reconstituted wood products like pulp, paper, particleboard and fibreboard.

2.1 Branches as raw material for pulp and paper industry

Important investigations on the yeild and quality of branch pulp in relation to stem lead to the following conclusions.

- Branch pulp from conifers is either inferior (Young and Chase 1965, Keays and Halton 1971, Fellagi et al 1974, Law and Lapointe 1983) or comparable to the stem pulp (Law and Koran 1982).

- Pulp made from the branches of hardwoods is either inferior as observed in ***Eucalyptus deglupta, Fagus sylvatica*** and ***Populus tremuloides*** (Hunt and Keays 1973, Fellagi et al. 1974, Muliah 1979) or comparable to bole pulp as reported in ***Fagus sylvatica*** (Sacchsee 1973).

- Branch pulp has many superior qualities like higher stretch, tensile and burst strengths (Hakkila 1971).

  These contradictory findings could convincingly be explained if attention is given to the technical properties of branches used in pulp and paper-making.

- It is generally agreed thiit the lower pulp yield from branches is due to higher bark content of branch chips (Hakkila 1971, Phillips et al. 1976). Branches with bark give pulp with considerably lower strength values (Hunt and Keays 1973). When the debarked branches are pulped, the yield and strength are comparable to those of stem pulp (Law and Koran 1982). With the increasing proportion of bark in wood chips, the consumption of chemicals in cooking increases and sheet cleanliness decreases (Hartler et al. 1977).

- It is well documented that basic wood density is the most important single factor that determines the pulp yield per unit volume of wood (Panshin and de Zeeuw 1980). Various studies show that branch wood density is greater than stem wood density in hardwoods like ash, birch, beech, black alder, oak and poplar (Fegel 1941, Sacchsee 1973, Markonic 1974, Fellagi et a/. 1974, Taylor 1977, Vurdu and Bensend 1979, Core and Moschler 1980). On the other hand, no significant difference is reported between branch and stem wood density of hickory and black gum (Taylor 1977). As compared to the stem, higher and lower branch wood densities are also reported in conifers (Watanabe et al. 1962, Rozens 1972 and Phillips et al 1976).

- Pulp yield is also known to depend on tha amount of fibre available in a given wood volume. Recently, the pulp yield differences are attributed to the variations in the relative proportion of different wood tissues viz. fibres, vessels, rays and parenchyma (Law and Lapointe 1982). Branches of black alder are reported to have greater fibre percentage than stem (Vurdu and Bensend I980), while no significant difference is found in birch (Bhat and Karkkainen 1981a).

- Another property, which has been a subject of intensive research, that influences pulp and paper quality is fibre length. Several authors attribute the lower tear strength of the paper made from branches to shorter fibres (Hakkila 1971). In both hardwoods and conifers branch fibres are consistently shorter than stem fibres (Manwiller 1974, Taylor 1977, Bhat and Karkkainen 1981b).

2.2 Branches as raw material for particleboard and fibreboard industry

Industrial utilisation of branches is perhaps easier to implement in board manufacture where the raw material quality specifications and processing problems are few. For example, considerable amount of bark is permitted in the board raw material especially when the separation of bark from branch chips is difficult. Sacchsee (1973) finds no marked difference in the strength of particleboards made from branch and stem of beech wood. Fibreboards made from branches are reported to

3. OBJECTIVES

It is obvious from the foregoing account that most of the published work pertaining to branch properties is confined to temperate tree species and no adequate data are available for Indian timbers. This project envisages investigation of the important branch properties of eleven tree species to determine the raw material quality of the products viz. pulp, paper, particleboard and fibreboard.

The main 'objective is to quantify some important physical and antomical properties of branches and compare them with those of stein. The properties studied are wood and bark density, proportion of bark and heartwood, percentage of wood elements (fibres, vessels rays and parenchyma) and fibre length. Attention is also given, wherever possible to compare the species in order to assess the property differences among the species.

4. MATERIALS AND METHODS

Considering the tiinbers of current industrial importance in Kerala, eleven species were selected for this study. Five mature trees, with no visible defects, were .chosen from the felling sites for each species. The tree characteristics by species and sampling location are presented in Table 1.

From each tree, three sound branches representing small, medium and large .diameter were chosen for estimating branch properties. Thus 15 branches were available for each species. The mean branch diameter with range for eaeh species is given in Table 1.

About 6 cm thick transverse discs were removed from the stump level (30 cm above ground), and 50 percent and 75 percent of tree heights for estimating stem properties at the bottom, middle and top (crown) portions. Similarly, three disc samples were cut from the branches, representing the positions at the base (10 cm above the branch insertion to the stem), 50 percent and 75 percent of branch lengths (Fig. I). Each disc was transversely divided into two halves. One half was used for the estimation of percentage of bark and heartwood (wherever distinct). Bark percentage was calculated from the following formula:

$$\text{Bark percentage} = \frac{\text{Weight of o. d. bark}}{\text{Weight of o. d. bark} + \text{Weight of o. d. wood}} \times 100$$

Table 1. Sample tree characteristics by species and location of sampling

Trade Name (species name in parentheses)	Location with forest type	Tree height, m mean	(range)	Stem diameter (base), cm mean	(range)	Branch diameter (base), cm mean	(range)
Benteak (*Lagerstroemia microcarpa* Wight)	Kannoth, Chimmini (Moist deciduous)	22.7	(16.0-35.0)	36.4	(25.3-52.5)	7.7	(2.4-15.9)
Cashew (*Anacardium occidentale* Linn.)	Nilambur (Mixed stand)	10.0	(8.0–13.0)	32.3	(21.0-4.5)	6.7	(2.0–10.5)
Coraltree (*Erythrina stricta* Roxb.)	Chimmini, Vazhachal (Moist deciduous)	13.0	(11.O-18.0)	24.5	(11.0-57.7)	5.1	(2.5--10.4)
Dhaman (*Grewia latifolia* Vahl.)	Kannoth (Semi-evergreen)	17:3	(16.0- 18.0)	28.5	(14.3—39.4)	5.9	(4.1—9.1)
Dillenia (*Dillenia pentagyna* Roxb.)	Kannoth, Chimmini (Moist deciduous)	15.8	(12.0–18.0)	32.6	(29.0–36.0)	8.8	(4.5-17.0)
Gurjan (*Dipterocarpus indicus* Bedd.)	Chimmini (Evergreen)	27.5	(26.0–29.0)	41.6	(35.3-48.0)	11.2	(4.9—21.4)
Irul [*Xylia xylocarpa* (Roxb.) Taub.]	Chimmini (Semi-evergeen)	20.7	(19.7-22.0)	29.2	(24.0—33.8)	7.6	(4.5-13.2)
Kindal (*Terminalia paniculata* Roth)	Mundakadavu (Moist deciduous)	26.5	(25.0—28.0)	39.7	(34.5-45.0)	7.I	(5.8—10.7)
Padri [*Stereospermum chelonoides* Auct. non (Linn.f.) DC)	Kannoth (Moist deciduous)	15.7	(l0.0-l9.0)	26.2	(19.6—34.3)	5.8	(3.3—11.9)
Rubberwood *Hevea brasiliensis* (HBK) Muell. Arg)	Pullangode (Rubber Estate)	19.3	(17.0-23.3)	37.1	(33.0-44.5)	5.5	(3.3—9.3)
Teak (*Tectonagrandis* Linn.f.)	Karulai (1929-plantation)	20.7	(17.0—28.3)	34.9	(21.1—47.5)	7.7	(2.4-16.3)

The average bark percentage of individual stem or branch was calculated by giving weightage to the volume of discs they represented in stem/branch.

To estimate the heartwood percentage, the heartwood area and disc area were calculated by measuriug four radii at right angles to one another and four measurements were averaged for each disc. Weightage was also given to the volume, to estimate stern and branch heartwood percentage.

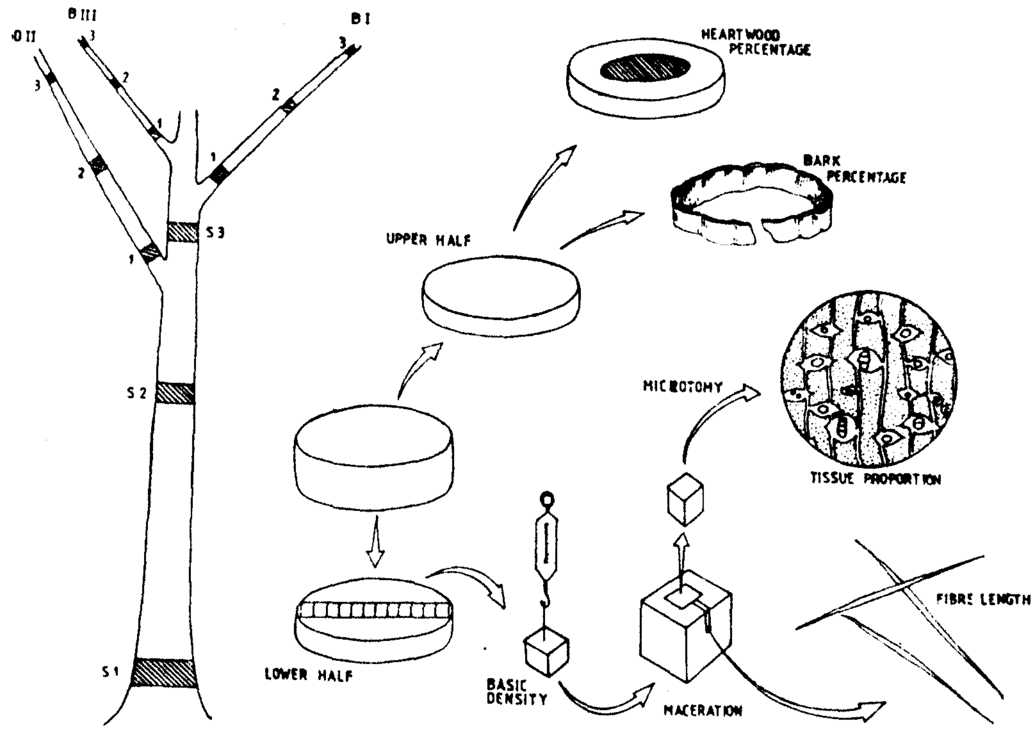


Fig. 1. **Diagrammatic representation of sampling pattern.**

The other half (see Fig. **1)** was used for the determiantion of basic density and anatomical properties. A diametrical segment was cut and 3x 3x 3 cm blocks were prepared from the pith outwards on both radii. The distance from the pith to the outer margin of each block was noted. Two bark samples from opposite radii were available for the estimation of bark density of the discs. The density of wood and bark was measured on oven dry (o. d.) weight to green volume basis. The green volume was measured/by water displacement method, using top pan balance. Entire discs were used for the measurement of green volume and o. d. weight wherever branch discs were less than 6 cm in diameter. Disc basic density was computed as weighted average value of blocks in relation to the volume of wood they represented in the discs.

$$\text{Average disc density} = \frac{v1d1+v2d2+ \ldots\ldots\ldots +vn\ dn}{v1+Iv2+ \ldots\ldots\ldots +vn}$$

where $v_1, v_2 \ldots v_n$, and $d_1\ d_2 \ldots d_n$ were volume and basic densities of the blocks (wood or bark) respectively. Similarly, the average density for stem/branch was calculated by giving weightage to the disc densities in relation to the volume they represented in the stem/branch.

After measuring the density, 15-30pm thick transverse sections were cut on a sliding microtome from three blocks of one radius. They were selected in such a way that the blocks represented the portion near the pith, near the bark and intermediate distance between pith and bark. The standard microtechnique procedure was followed to prepare the sections for observation under microscope. Measurement of cellular proportion was made according to a point count technique. using eye piece graticule (Curtis 1960). The eye piece graticule has 25 points asymmetrically arranged within a circular field. The proportion of points lying over the image of each type of tissue (fibres, vessels, rays and parenchyma) is statistically proportional to the area occupied by that tissue. Two positions of eye piece per field were taken into consideration in order to increase accuracy (Quirk 1975). On an average, 150 point counts were made from each of the 36 samples per species. To avoid the radial and tangential gradients of the wood elements, eye piece fields were passed across the sample in the pattern described in an earlier study (Bhat and Karkkainen 1981a).

For fibre length measurement, about 2 mmthick (radially) segments were removed from each block of one radius (pith outwards). Fibres were macerated by Franklin's method (1946). Separated fibres were thoroughly mixed and length measurements of 50 unbroken fibres were made from each sample slide on a projection microscope. The number of fibres required per sample slide was determined by Stein's procedure (1945). The total number of fibres measured in the present study is 32,400.

In order to obtain an estimate of the average fibre length of each disc, the sample fibre length values were weighted by the formula.

$$\text{Average fibre length} = \frac{r_1 f_1 + r_2 f_2 + \ldots + r_n f_n}{r_1 + r_2 + \ldots + r_n}$$

where $r_1 \ldots r_n$ are radial distancesof the sampling from pith; $f_1 \ldots f_n$ are the mean fibre lengths of the samples. The average values for stem and branches were estimated in the way followed to estimate wood density.

5. RESULTS AND DISCUSSION

5.1 Wood density

The weighted average values for branch wood and stem wood density are given in Table 2. For four of the species, branch wood has higher density than stem wood while for the rest, stem wood has greater values. The paired t-test results show that no significant difference exist between branch and stem wood density. The two exceptions, however, are cashew and dillenia, the branch wood being denser in the former and lighter in the latter. Such between-species differences in the relationship

Table **2.** Wood density values (kg/m3) for branches and stem

Trade Name	Branch Average	Branch (Range)	Stem Average	Stem (Range)	Significance of t-value
Benteak	**583.9**	**(371.2-697.0)**	**536.7**	**(371.2-690.5)**	ns
Cashew	**485.3**	**(377.0—577.0)**	**437.2**	**(343.8-526.4)**	**
Coraltree	**276.0**	**(191.4—368.0)**	**232.8**	**(170.0—371.0)**	ns
Dhaman	**573.3**	**(434.1—737.8)**	**627.0**	**(457.1—773.4)**	ns
Dillenia	**588.4**	**(480.4—686.2)**	**610.0**	**(488.6—647.6)**	**
Gurjan	**604.7**	**(531.9—726.5)**	**588.9**	**(505.0-701.6)**	ns
Irul	**684.0**	**(584.5-821.6)**	**740.8**	**(515.9—895.4)**	ns
Kindal	**584.0**	**(500.5—624.6)**	**608.5**	**(486.0—678.7)**	ns
Padri	**627.0**	**(464.2-785.7)**	**638.7**	**(508.6—778.0)**	ns
Rubberwood	**494.1**	**(385.0-555.8)**	**543.7**	**(434.6—625.9)**	ns
Teak	**587.0**	**(409.2—794.6)**	**612.2**	**(400.1-792.1)**	ns

** Significant at **1** percent level

ns Not significant

of branch wood density to stem wood density are found in American hardwoods (Taylor **1977,** Manwiller **1979).** The different patterns of radial (pith-to-bark) variation among species also reveal these differences. Except in benteak, dillenia and padri, the radial variation in density can be defined by second degree parabolic curves. The quadratic regression equations are presented in Table **3.** The relatively low R^2 values show that the amount of radial variation is quite small in these hardwood species. Although, the rate of change is small, wood density shows curvilinear increase from the pith to the bark in the stem of most of the species (Table **3** and Fig. **2).** In contrast, for cashew the curve declines from the pith to the bark showing greater density in the juvenile wood (Table **3** and Fig. **2).** As the branch wood is presumed to be physiologically similar to juvenile wood, higher branch wood density noted in cashew is thus justified. Further, different patterns of radial variation are noticed at different height levels of the same tree and often at the same height level of different trees in some species.

Table 3. Significant regression models for radial patterns of variation in wood density (kg/m3) and fibre length (mm) of stem; where distance from pith (mm) independent variable (x)

Timber		Equation	R^2(%)	sy.x
Benteak	Fibre length	= 0.68720+0.00563x0.00001x2	57.4	0.160
Cashew	Density	= 462.373- 0.543x+0.001 x2)	8.2	37.2
	Fibre length	= 0.5614+0.0031x 0.00001x2	40.5	0.054
Coraltree	Density	= 206.722+ 0.886x-0.001x2	46.0	41.9
	Fibre length	= 1.4201+0.00220x - 0.000003x2	32.2	0.166
Dhaman	Density	= 552.149+ 2.204x 0.008x2	14.9	81.1
	Fibre length	= 0.99407+0.01075x 0.00005x2	19.9	0.257
Dillenia	Fibre length	= 2.33310+0.00803x0.00002x2	50.1	0.197
Gurjan	Density	= 598.421+0.103 x-0.001x2	13.0	50.2
	Fibre length	= 1.3180+0.00418x - 0.00001x2	21.4	0.132
Irul	Density	= 618.684+2.165x-0.011x2	6.8	82.7
	Fiber length	= 1.0165+0.00422-0.00001x2	58.1	0.059
Kindal	Density	= 539.601+1.296x-0.004x2	17.9	49.9
	Fiber length	= 1.2865+0.00343x-0.00001x2	16.0	0.120
Padri	Fibre length	= 0.84524+0.003388x-0.000008x2	61.1	0.078
Rubberwood	Density	= 500.493+ 1.292x- 0.006x2	16.0	37.9
	Fibre length	= 0.9834+0.0042-0.00001x2	34.0	0.070
Teak	Density	= 614.458-0.317x+0.002x2	6.3	74.2
	Fibre length	= 0.7190+0.00948x-0.00003x2	57.1	0.135

The patterns of average density variation along the axis, in three positions of both branches and stem are illustrated in Fig. 3. Two distinct patterns are:

- wood density increase from base to top without marked change in the middle position of both branches and stem (e.g. benteak, cashew, coraltree, dhaman, gurjan) and

- wood density decrease from base to top (e.g. dillenia, irul).

In some species like irul, kindal, rubberwood and teak, the patterns are not similar in the stem and branches. However, the analysis of variance reveals that within-stem variation is significant only in three species (dillenia, gurjan and kindal) (Table 4). The wood density variation among the branches, as measured by the coefficients of variation, ranges from 59 percent in kindal to only 17.8 percent in dillenia (Table 5).

Table 4. F-values of ANOVA for the variation in physical properties between (5 trees) and within (3 positions) stems

Timber	Source of variation	Wood density	Bark density	Bark percentage
Benteak	Between	4.78*	26.43**	12.35'''
	Within	0.66ns	2.1 Ins	3.15ns
Cashew	Between	7.61**	5.45*	3.99ns
	Within	0.98ns	1.1 ns	8.11*
Coraltree	Between	1.84ns	8.29*	0.76ns
	Within	0.17ns	0.58ns	0.18ns
Dhaman	Between	3.42ns	2.69ns	5.95ns
	Within	0.75ns	0.52ns	19.06*
Dillenia	Between	25.95**	9.76**	0.53ns
	Within	8.47**	0.05ns	3.06ns
Gurjan	Between	1663.80**	2.42ns	0.19ns
	Within	144.55**	0.41ns	1.53ns
Irul	Between	4.93'	26.81**	1.44ns
	Within	2.68ns	0.10 ns	5.74*
Kindal	Between	2.55ns	0.12ns	3.60ns
	Within	21.02''	0.69ns	0. I2ns
Padri	Between	7.41**	6.82ns	I .22ns
	Within	0.33ns	2.89ns	0.29ns
Rubbcrwood	Between	0.95ns	0.53ns	4.37**
	Within	0.87ns	0.10ns	7.68.
Teak	Betwecn	6.48*	6.05*	4.1 I**
	Within	1.16ns	1.83ns	8.01*

* Significant at **5** percent level
** Significant at I percent level
ns Not significant

Table 5. Coefficients of variation (%) for the variation in properties among branches (within and between).

Timber	Wood density	Bark density	Bark percentage	Fibre length
Benteak	17.0	36.5	41.4	18.8
Cashew	10.6	21.9	25.2	10.3
Coraltree	16.0	30.4	34.8	11.8
Dhaman	16.6	16.3	35.6	6.6
Dillenia	17.8	11.5	38.2	6.7
Gurjan	18.9	5.5	5.9	9.4
Iru!	8.8	15.9	20.8	7.5
Kindal	5.9	5.3	21.9	10.9
Padri	7.4	12.2	27.4	9.0
Rubberwood	7.7	12.8	33.5	15.7
Teak	16.0	17.9	50.6	17.9

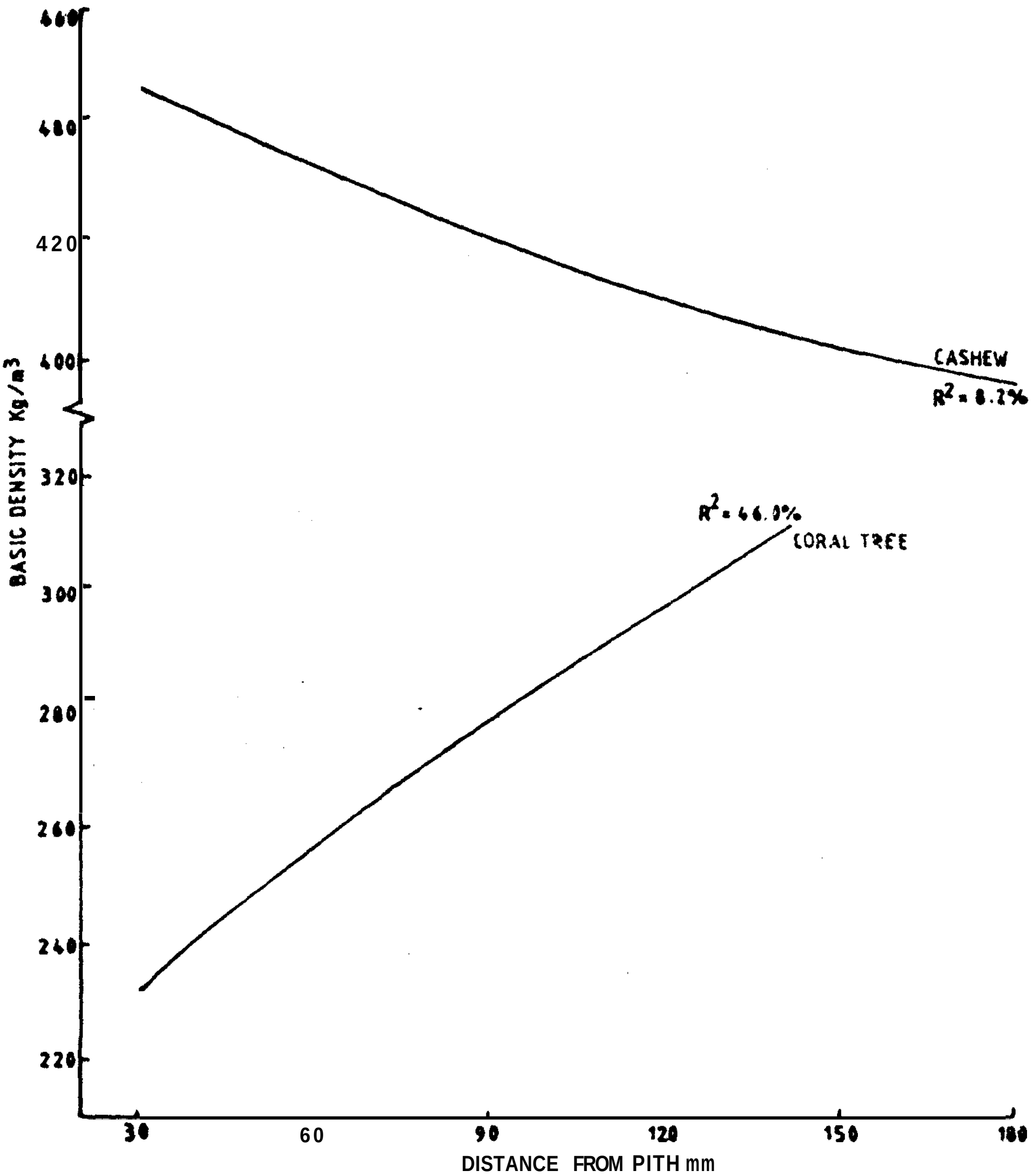


Fig. 2 Wood basic density as a function of distance from pith.

The among-species comparison reveals that coraltree has lowest average value for wood density in both stein and branches (<400 kg/m3). The maximum density noted for this species is 371 kg/m3. Cashew comes under the category of moderately low density timbers (400-550 kg/m3). Rest of the species fall under the group of medium-density hardwoods (550--750 kg/m3), irul being the heaviest timber. The results of weighted t-test show that the differences among the three categories of species mentioned are significant (Table 6).

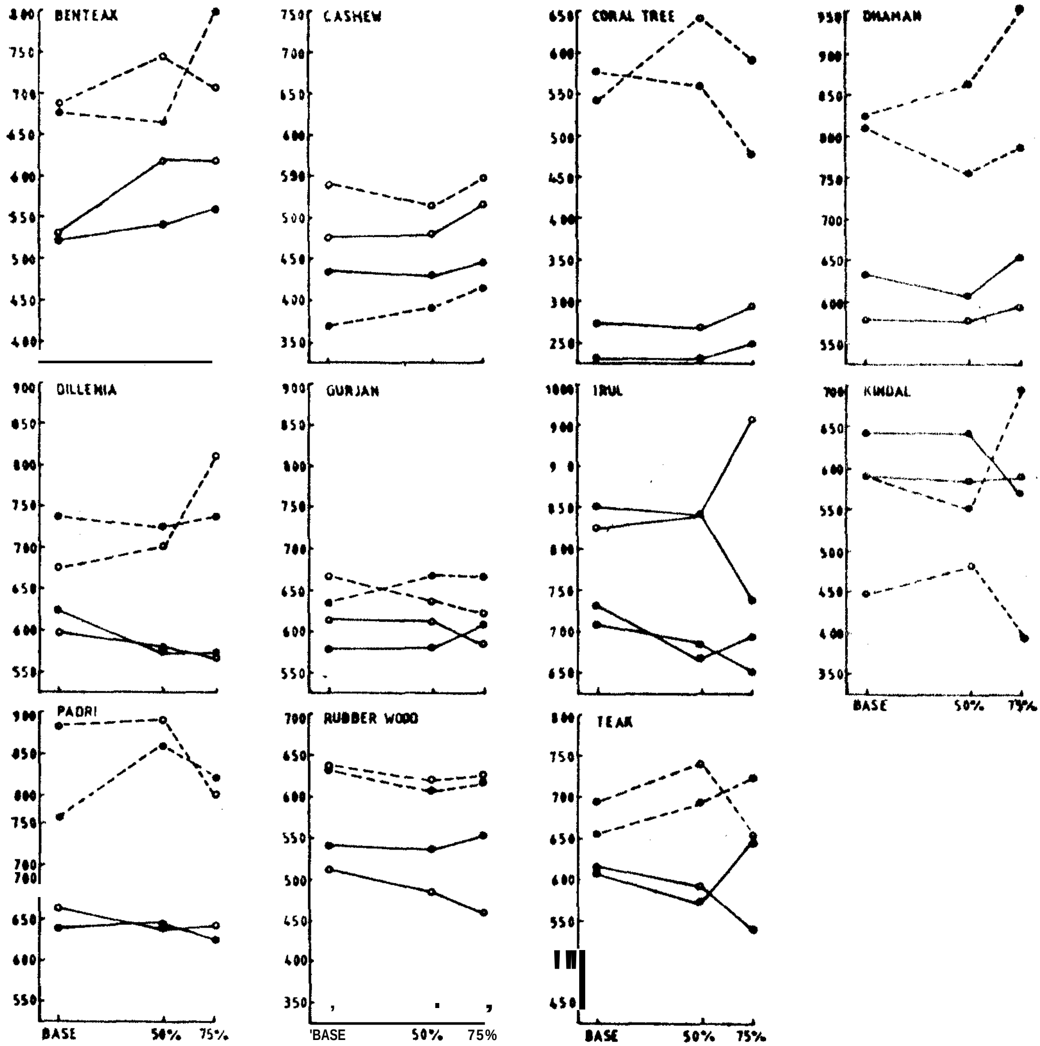


Fig. 3 Relationship of wood (solid line) and bark (discontinuous line) densities (ky/m3 y axis) to 3 positions along the axis in stem and branches. @--Stem; 0— blanch.

5.2 Bark density

Although branches of seven species have greater bark density values than stem statistically significant differences are not noticed with the exception of cashew (Table 7). Bark is denser than wood in both branches and stem of majority of the species (Table 8). On the contrary, wood is significantly heavier than bark in kindal branches. There is no significant difference between bark and wood density in the stem of benteak. cashew, irul and kindal (Table 8). In cashew this difference isnot significant in branches as well,

Table 6, Test of significance of wood density difference between the species (Weighted t-text)

	Benteak	Cashew	Coraltree	Dhaman	Dillenia	Gurjan	Irul	Kinda!	Padri	Rubber-wood	Teak
Benteak	—	*	*	—	—	—	*	—	*	—	—
Cashew		—	*	*	*	*	*	*	*	*	*
Coraltree			—	*	*	●	*	●	*	*	*
Dhaman				—	—	—	—	—	—	—	—
Dillenia					—	—	—	—	—	*	—
Gurjan						—	—	—	—	—	—
Irul							—	—	—	*	—
Kindall								—	—	—	—
Padri									—	*	—
Rubberwood										—	*
Teak											—

* **Significant at 5 percent level**

— **Not significant at 5 percent level**

Table 7. Bark density values (kg/m3) for branches and stem

Trade Name	Branch		Stem		Significance
	Average	(Range)	Average	(Range)	of t-value
Benteak	785.5	(391.5--1028.5)	689.3	(373.5--1045 3)	11%
Cashew	530.5	(383.0-—682.0)	402.5	(314.8- 504.2)	*
Coraltree	581.1	(400.0-833.3)	546.0	(285.7 889.4	ns
Dhman	842.5	(692.3-1 125.0)	793.3	(666.7– 872 2)	ns
Dillenia	674.1	(538.5 –810.0)	733.3	(473.9- 892 3)	ns
Gurjan	649.9	(615.5---704.2)	658.4	(594.9- 724.4	ns
Irul	825.5	(663.0—1002.1)	761.1	(419 8— 1030.0)	ns
Kindal	446.4	(390.2—480.6)	611.3	(522.6 -834 2)	ns
Padri	870.6	(724.1—1133.0)	818.1	(690.8 - 9531)	ns
Rubberwood	632.1	(481.0—902.1)	620.8	(473.0- 891 8)	ns
Teak	690.8	(416.6--875.6)	696.8	(473.2-820. 1)	ns

* Significant at 5 percent level
ns Not significant

Table (1 Comparison of wood and bark density by t-test

Timber	Branch	Stenr
Benteak	B*	ns
Cashew	ns	ns
Coraltree	B**	B**
Dhaman	B*	B**
Dillenia	B*	B **
Gurjan	B*	B*
Irul	B*	n s
Kindal	W**	ns
Padri	B**	
Rubberwood	B**	B**
Teak	B**	B**

B Bark density higher
W Wood density higher
* Significant at 5 percent level
** Significant at I percent level
ns Not significant

Table 9. Correlation coefficients for the relationship between wood and bark density

Trade Name	Branch	Stem
Benteak	**0.967****	**0.509***
Cashew	**− 0.999****	**0.177ns**
Coraltree	**0.875****	**0.892****
Dhaman	**0.056ns**	**0.474***
Dillenia	**0.625****	**0.506***
Gurjan	**− 0.873****	**− 0.621***
lrul	**0.840****	**0.740****
Kindal	**0.801****	**0.886****
Padri	**0.433***	**0.622****
Rubberwood	**0.200ns**	**0.182ns**
Teak	**0.828****	**0.703****

* Significant at **5** percent level
** Significant at I percent level
ns Not significant

The patterns of longitudinal variation observed in bark density are shown in Fig. 3. By and large, they are in accordance with those of wood density, although some deviation5 are noticed. However, the F-values of the ANOVA show that none of the specics has significant within-stem variation although in some species between-sterm variation is significant (Table 4). Among the branches, bark density is more variable than wood density as the coefficients of variation are higher (5.5 percent 36.5 percent) for bark density (Table 5). Further, no consistency is found in the relationship between wood and bark density among the species, although correlation coefficients are highly significant for some species (Table 9). This indicates that at least in some species like benteak, coraltree, dillenia, gurjan, irul, kindal and teak. the possibility exists for predicting wood density, using bark density values.

Among the species. padri has highest value for bark density, although it is not significantly different from the bark density value of other species except cashew and coraltree (Table 10). As is the case in wood, bark of cashew and coraltree has low drnsity. Between-species difference in bark density is significant only in a few cases (Table 10).

5.3 Bark percentage

The average percentage of bark is greater in branches than in stem. The values of pairedt-test confirm this difference for all the species (Table 11). The highest

Table 10. Test of significance of bark density difference between the species (Weighted t - test)

	Benteak	Cashew	Coraltree	Dhaman	Dillenia	Gurjan	Irul	Kindal	Padri	Rubber-wood	Teak
Benteak	—	—	—	—	—	—	—	—	—	—	—
Cashew		—	—	*	*	—	—	—	*	*	*
Coraltree			—	—	—	—	—	—	*	—	—
Dhaman				—	—	—	—	—	—	*	—
Dillenia					—	—	—	—	—	—	—
Gurjan						—	—	—	—	—	—
Irul							—	—	—	—	—
Kindal								—	—	—	—
Padri									—	—	—
Rubberwood										—	—
Teak											—

• Significant at 5 percent level

— Not significant at 5 percent level

average proportion of bark in branches is 29 percent with 50-55 percent maximum values. Whereas in the stem the maximum bark content noted is only 25 percent.

Table 11. Bark percentage values for branches and stem

Trade name	Branch Average	Branch (Range)	Stem Average	Stem (Range)	Significance of t-value
Benteak	**10.3**	**(4.3—21.0)**	**4.8**	**(2.4—8.5)**	**
Cashew	**28.9**	**(17.8—50.0)**	**16.2**	**(10.5—23.3)**	*
Coraltree	**24.6**	**(16.2—50.0)**	**13.5**	**(6.0—25.0)**	*
Dhaman	**27.5**	**(16.8—50.0)**	**11.8**	**(7.6—24.6)**	**
Dillenia	**15.0**	**(5.2—37.5)**	**9.1**	**(6.0—18.4)**	*
Gurjan	**17.4**	**(9.4-29.1)**	**7.8**	**(6.2-13.2)**	**
Irul	**15.0**	**(10.2—28.0)**	**8.6**	**(6.1—16.2)**	**
Kundal	**15.2**	**(8.5—16.4)**	**9.0**	**(8.0—10.0)**	**
Padri	**17.5**	**(8.3—30.0)**	**12.6**	**(8.8—23.4)**	*
Rubberwood	**14.4**	**(5.2—22.7)**	**7.7**	**(4.0—12.0)**	**
Teak	**28.5**	**(7.1—54.5)**	**10.4**	**(4.0—14.5)**	*

* Significant at 5 percent level
** Significant at 1 percent level

Bark percentage increases from the base to the top of both branches and stem in almost all the species (Fig. 4). The ANOVA confirms that this within-stem variation is significant in most of the species although between-stem differences are mostly insignificant (Table 4). Among the branches. the coefficients of variation range from 5.9 percent (in gurjan) to 50.6 percent (in teak) indicating considerable amount of variation (Table 5).

The highest average value for bark percentage (29) is noted in cashew branches with mean diameter of 6.7 cm (at the base), while the lowest value is 10.3 in benteak branches with mean diameter of 7.7 cm. Similarly, benteak bole has the lowest bark percentage and cashew stem has the highest value. These differences are also found statistically significant (Table 12).

5.4 Heartwood percentage

Of the eleven species studied, five have distinct heartwood. The heartwood percentage is significantly lower in the branches than in the bole in all the five species (Table 13). Heartwood percentage decreases from the base to the top in both branches and stem.

Table 12. Test of significance of bark percentage difference between the species (Weighted t-test)

	Benteak	Cashew	Coraltree	Dhaman	Dillenia	Gurjan	Irul	Kindal	Padri	Rubber-wood	Teak
Benteak	—	*	*	*	*	—	*	*	*	—	*
Cashew		—	—	—	*	—	*	*	—	*	—
Coraltree			—	—	—	—	—	—	—	—	—
Dhaman				—	—	—	—	—	—	—	—
Dillenia					—	—	—	—	*	—	—
Gurjan						—	—	—	—	—	—
Irul							—	—	*	—	—
Kindal								—	—	—	—
Padri									—	*	—
Rubberwood										—	—
Teak											—

* Significant at 5 percent level

— Not significant at 5 percent level

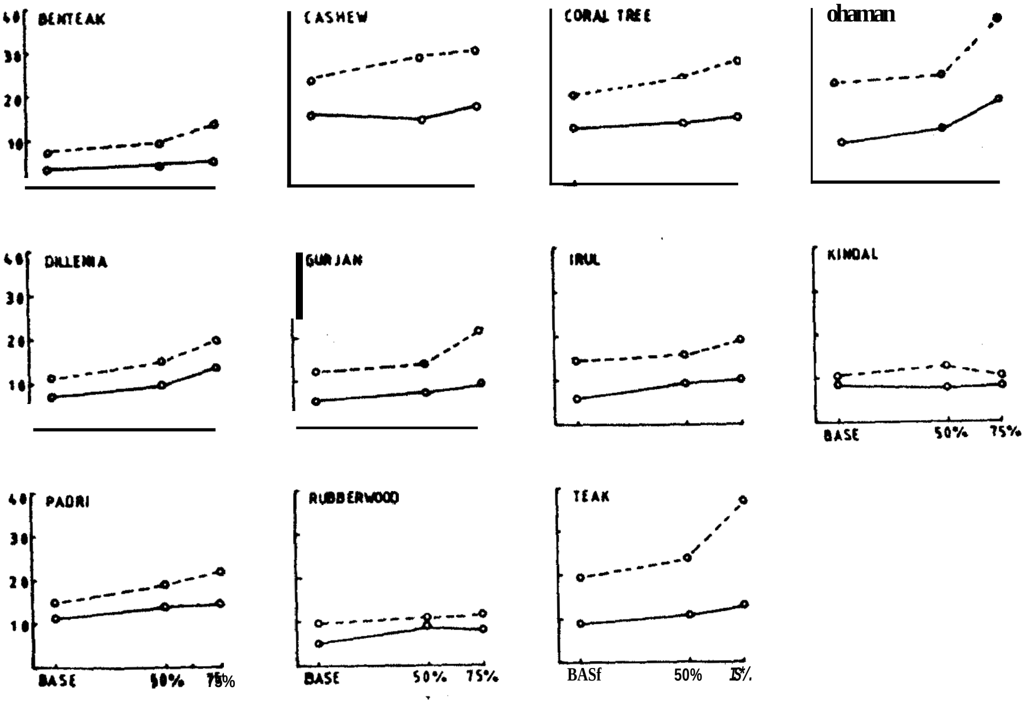


Fig. 4. Average bark percentage (y-axis) at 3 positions along the axis of stem (solid line) and branches (discontinuous line).

Table **13** Average percentage of heartwood in branches and stem.

Trade Name	Branch	Stem	Significance of t-value
Benteak	**29.1**	**72.7**	**
Dhaman	**0**	**61.8**	
Gurjan	**17.5**	**63.9**	**
lrul	**34.0**	**70.3**	**
Teak	**38.5**	**76.6**	**

** Significaat at **1** percent level

Among the species, teak stems with mean diameter of 34.9 cm have the highest value (76.6 percent) and dhaman with mean stem diameter of 28.5 cm have the lowest value (61.8 percent). The branches of dhaman up to 9.1 cm in diameter, have no heartwood at all, while the branches of irul and teak with mean diameter of 7.6 cm and **7.7** cm have 34 percent and 39.5 percent of heartwood respectively.

5.5 Proportion of wood elements

The proportions of tissues viz. fibres, vessels, rays and parenchyma observed in branch and stem wood are illustrated in Fig. 5. The t-tests show that significant differences do not exist in tissue percentages between branches and stem. No obvious pattern of variation is noticed either from the base to the top or from the pith to the bark in branches as well as in stem. The average fibre percentage is 60—63 in teak which is highest among the species. The lowest percentage of fibres is in coraltree (Figs. 5 and 6 c) except which all the other timbers have higher percentage of fibres as compared to vessels, rays and parenchyma. In coraltree, total parenchyma (rays + axial parenchyma) proportion is highest. accounting for 65—66 percent. The maximum proportion of vessels is noted in benteak, dillenia and teak (18-23 percent) (Figs. 6a, e and 7e). Ray percentage is rather high in species like cashew and dillenia. Axial parenchyma percentage is greater in coraltree and padri (Figs. 6c and 7c).

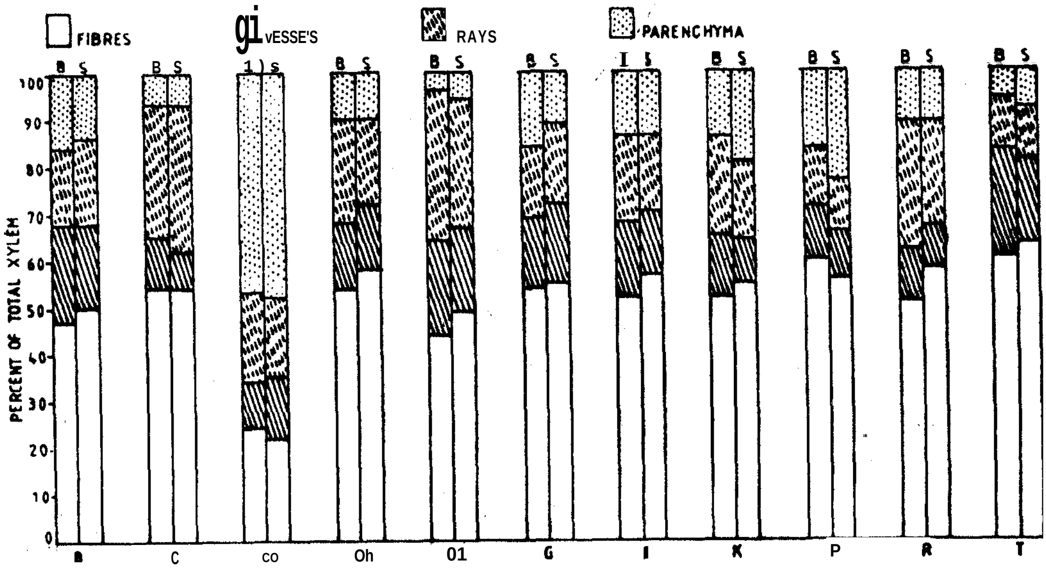


Fig. 5. Average percentages of fibres, vessels, rays and parenchyma of branches (B) and stem (S) in eleven species: (B= Benteak, C= Cashew, *Co*= Coraltree, Dh = Dhaman, Di = Dillenia, *G* =Gurjan, I=Irul, K=Kindal, P=Padri, R=Rubberwood,

5.6 Fibre length

The average, minimum and maximum values for the fibre length are given in Table 14. Branch fibres are significantly shorter than stem fibres in all the species studied. They are 16—20 percent shorter in benteak, cashew and padri whereas in coraltree, irul and rubberwood the difference is only by 5-7 percent. When the species are pooled, the average fibre length is 12 percent lower in branches than in the stem. It is of interest to note that both the shortest and longest fibres of branches are shorter than those of stem in all species.

Table 14. Average fibre length values (mm) for branches and stem

Trade Name	Branch Average	Branch (Range)	Stem Average	Stem (Range)	Significance of t-value
Benteak	0.945	(0.564—1.066)	1.180	(0.676-1.398)	**
Cashew	0.629	(0.558—0.684)	0.749	(0.596—0.8 11)	**
Coraltree	I.491	(1.079- I.654)	1.576	(1.145—2.1 17)	**
Dhaman	1.201	(0.898—1.328)	1.414	(0.958—-1.611)	**
Dillenia	2.376	(2.034-2.605)	2.768	(2.277—3.200)	**
Gurjan	1.317	(1.052—1.547)	1.580	(I .348- 1.840)	**
lrul	1.135	(0.991-1.236)	1.226	(1.026—1.326)	**
Kindal	1.373	(1.009- 1.545)	1.469	(1.294—1.675)	**
Padri	0.8%	(0.724-1.001)	1.075	(0.84 1-1.238)	**
Rubberwood	1.112	(0.808-1.240)	1.176	(1.018-1.357)	**
Teak	1.075	(0.657—1.202)	1.202	(0.739—1.504)	**

* Significant at 1 percent level

The radial pattern of variation in fibre length can be best explained using quadratic regression models presented in Table 3. Fibre length shows curvilinear increase from pith to bark in every species studied. The R2 values of the models range from 21.4 percent (in gurjan) to 61.1 percent (in padri). The fitted curves for cashew, teak and dillenia (representing short, medium and long-fibred species) are given in Fig. 8. As in the juvenile wood of stem, fibres are shorter in branches.

Along the axis. with a pattern of general decrease in fibre length from the base to the top, the longest fibres are present at the basal portion of stem and branches (Fig, 9). However, in rubberwood the maximum fibre length is found in the middle position (50 percent of the length) of stem and branches as reported earlier for some hardwoods (Panshin and de Zeeuw 1980). Further, it is evident from the coefficients of variation (Table 5) that among-branch variation in fibre length is not large.

Among the species, dillenia has the longest and cashew has the shortest fibres. As the weighted t-test reveals (Table 15). the fibre length of these two species is significantly different from that of other species. The fibre length of dillenia is even greater than twice the average fibre length of other hardwoods and is comparable to that of bamboos and pines (Bhat *et al.* 1984). With the average fibre length below 1 mm, cashew comes under short-fibred hardwoods. Rest of the species fall under the group of hardwoods having medium-sized fibres (1-1.5 mm). The t-test values also confirm the differences between the groups of short, medium and long-fibred sample species (Table However, it should be noted that the two species,

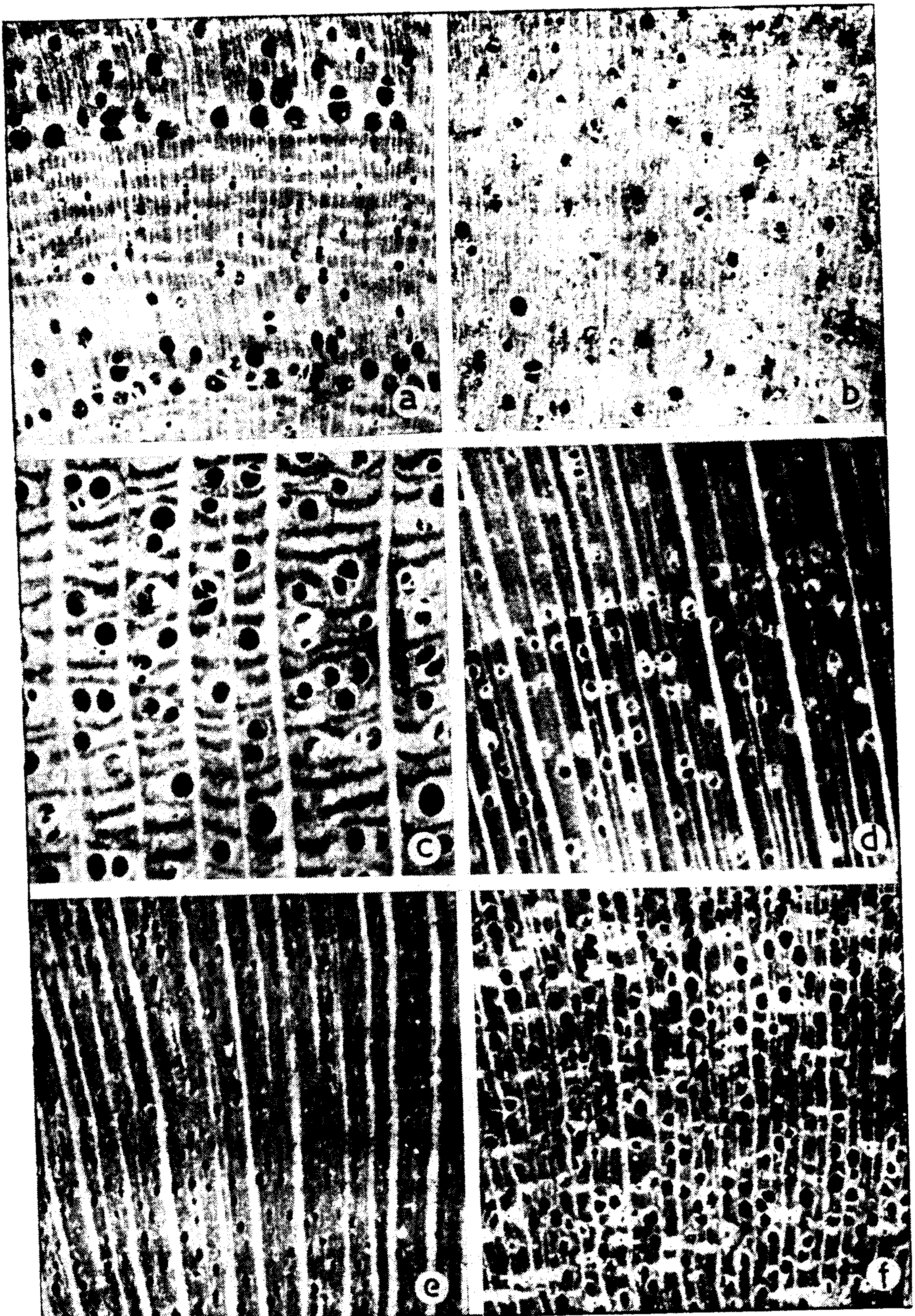


Fig. 6.

Fig. **7.**

Fig. 6. T. S. of branch wood

a. Benteak : Note large vessels. semi-ring porous wood, and aliform-confluent parenchyma

Cashew : Note high proportion of rays.

c. Coraltree : Note exceptionally high proportion of broad tangential parenchyma bands, wide rays, large vessels and low fibre proportion.

d. Dharnan : Note prominent rays.

e. Dillenia : Note vessels and rays.

f. Gurjan : Note vessel volume and white patches of scattered gum canals.

Fig. 7. L.. S. of branch wood

a. Irul

b. Kindal

c. Padri: Note aliform-confluent parenchyma

d. Rubberwood: Note tangential hands of parenchyma and high ray content.

e. Teak: Note high proportion of fibres and vessels.

coraltree and gurjan, with the average fibre length of 1.576 mm and 1.580 mm respectively, have higher than average fibre length for hardwoods. It is also worthwhile to note that the branch fibres of dillenia are longer than the stem fibres of other tropical hardwoods.

5.7 Effect of branch size (diameter) on properties

When evaluating the branches as pulp raw material especially at the time of raw material procurement, it is important to know what happens to the properties

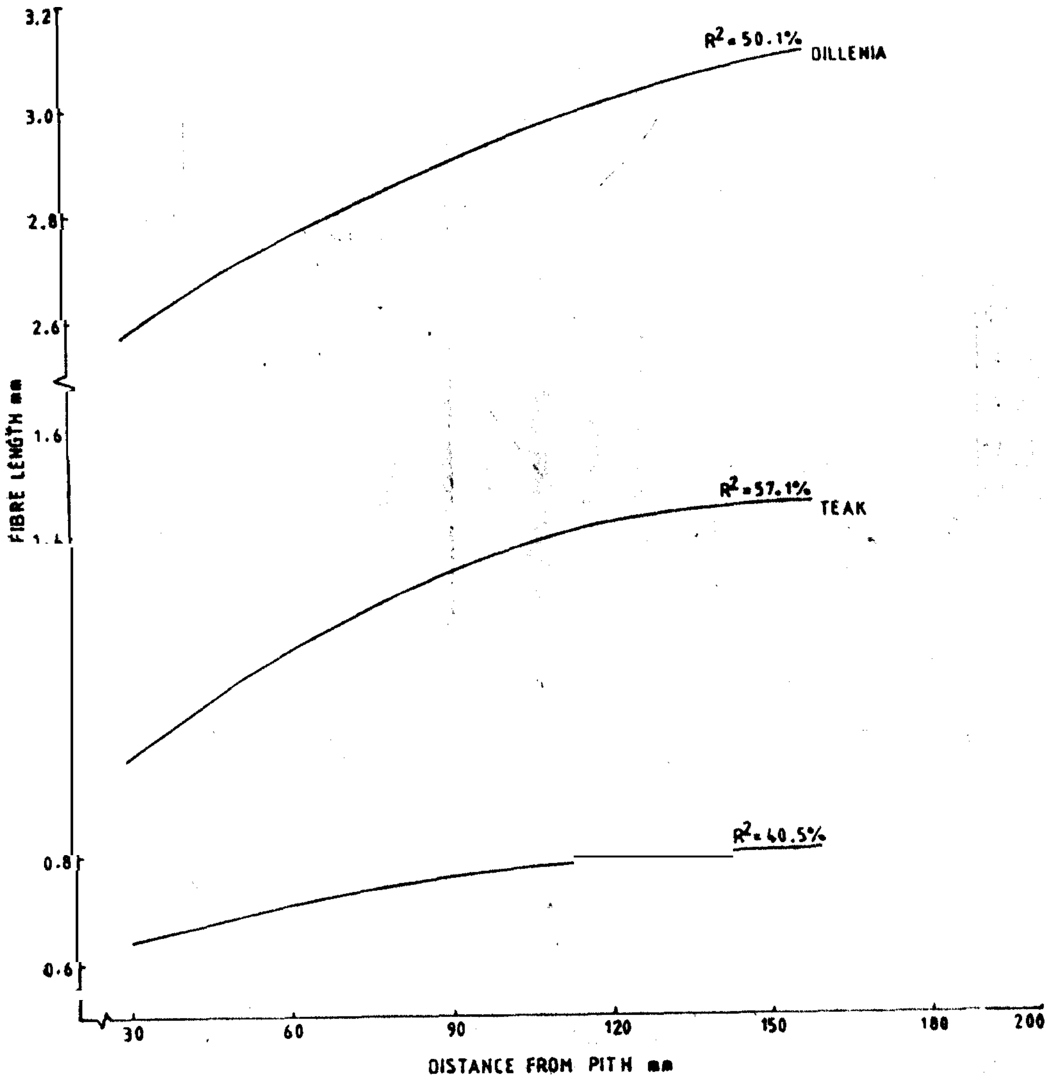


Fig. 8. Fibre length as a function of distance from the pith.

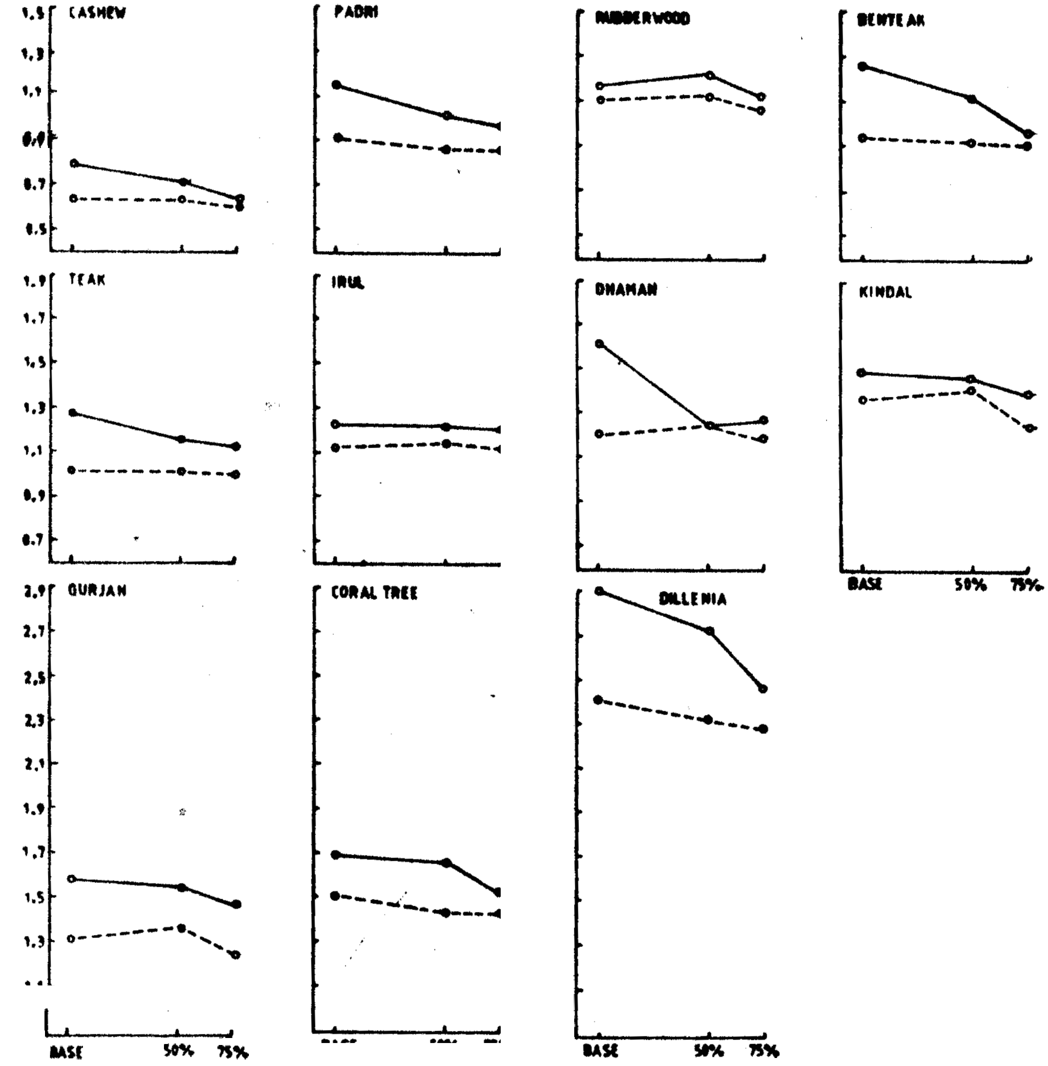


Fig. 9. Average fibre length, mm (y-axis) at 3 positions along the axis, of stem (solid line) and branches (discontinuous line)

when branch size varies. A pertinent question is—to what extent one can include thinner branches in pulping?

In order to know the effect of branch diameter, the average values of the branch properties with branch diameter (at the base) are put in correlation and regression analyses.

Wood density is not significantly correlated with branch diameter in six species (Table 16 and Fig. 10). The correlation is positive in padri. rubberwood and teak in contrast to the negative relationship in benteak and irul. Similarly bark density is

Table 15. Test of significance of fibre length difference between the species (Weighted t-test)

	Benteak	Cashew	Coraltree	Dhaman	Dillenia	Gurjan	Irul	Kindal	Padri	Rubber-wood	Teak
Benteak	—	*	—	—	*	—	—	—	—	—	—
Casbew		—	*	*	*	•	•	•	*	*	•
Coraltree			—	—	—	—	—	—	—	—	—
Dhaman				—	•	—	—	—	—	—	—
Dillenia					—	•	*	•	•	•	•
Gurjan						—	—	—	—	—	—
Irul							—	—	•	—	—
Kindal								—	—	—	—
Padri									—	—	—
Rubberwood										—	—
Teak											—

• Significant at S percent level

— Not significant at 5 percent

positively correlated with branch diameter in kindal, rubberwood and teak ($r=0.838$, $P<0.01$; $r = 0.570, P<0.05$ and $r=0.545$, $P<0.05$ in respective order). In benteak, bark density decreases with an increase in branch diameter ($r = -0.524, P<0.05$). In rest of the species bark density is not correlated with branch diameter.

Table 16. Relationship between branch diameter at base in cm (X) and average branch wood density in kg/m^3 (Y)

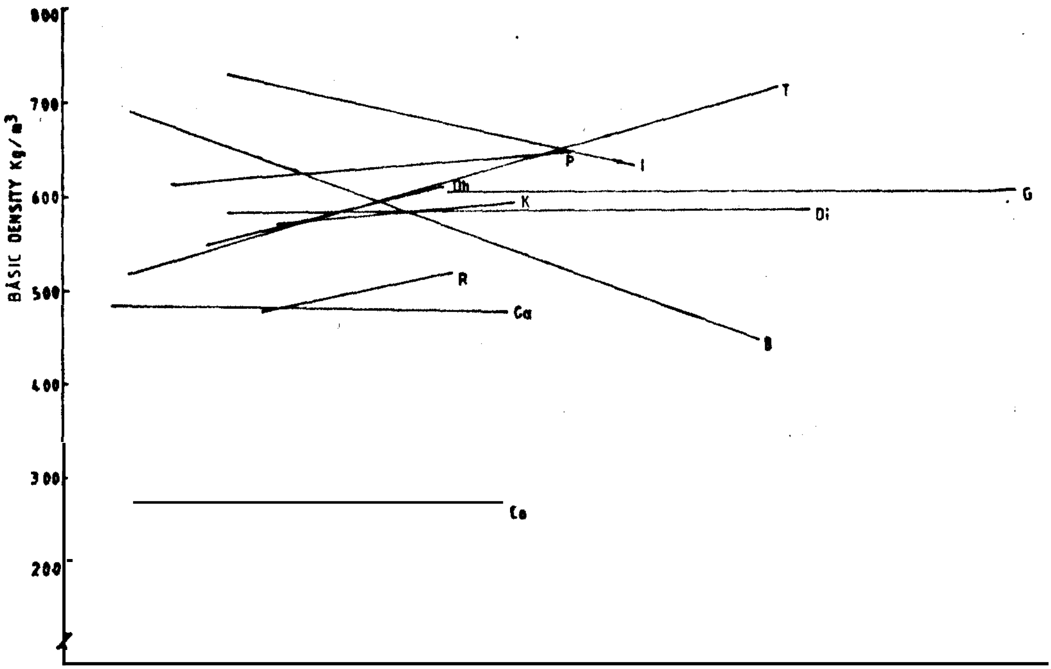
Timber	Correlation Coefficient	Regression equation	r^2 (%)
Benteak	-0.732**	Y = 735.708-18.031X	53.6
Cashew	-0.039 ns	Y = 487.843- 0.708X	0.02
Coraltree	-0.147 ns	Y = 286.703- 2.056X	2.1
Dhaman	0.368 ns	Y = 497.758+12.740X	13.5
Dillenia	0.034 ns	Y = 581.537+ 0.388X	2.1
Gurjan	0.011ns	Y = 606.561- 0.030X	0.001
Irul	-0.566*	Y = 778.996-10.785X	32.1
Kindal	0.257 ns	Y = 550.126+ 4.101X	6.6
Padri	0.569 *	Y = 565.300+14.276X	32.4
Rubberwood	0.586 *	Y = 457.290- 6.762X	34.4
Teak	0.728**	Y = 484.107+14.567X	53.0

* Significant at 5 percent level
** Significant at 1 percent level
ns Not significant

Bark percentage decreases sharply as branch diameter increases (Table 17 and Fig. 11). The determination coefficients for the dependence of bark percentage on branch diameter range from 35.5 percent (in dhaman) to 82.3 percent (in gurjan). It is therefore evident that branch diameter is an important source of variation in the bark content of branch raw material.

Heartwood percentage increases with an increase in branch diameter of gurjan and teak (Table 18). The correlation is not significant in benteak and irul as the heartwood formation has not taken place in many branch samples. Similarly, in dhaman the branches of even 9 cm diameter have no distinct heartwood although the heartwood percentage of stem is 61.8.

Another property that is influenced by branch diameter is fibre length. It is positively correlated with branch diameter, with r^2 values ranging from 24.3 percent to 95.3 percent (Table 19 and Fig. 12).



Timber	Correlation coefficient	Regression Equation	r²(%)
Benteak	— 0.873**	Y = 17.361 — 0.843 X	76.2
Cashew	— 0.764**	Y = 41.013 — 1.910X	58.4
Coraltree	— 0.856**	Y = 35.131 — 2.023 X	73.3
Dhaman	— 0.588 *	Y = 36.605 — 1.510 X	34.5
Dillenia	— 0.744**	Y = 22.506 — 0.760 X	55.4
Gurjan	— 0.960**	Y = 22.808 — 0.480 X	92.3
Irul	— 0.599 *	Y = 23.127 — 0.770 X	35.9
Kindal	— 0.927**	Y = 30.210 — 2.538 X	86.0
Padri	— 0.643**	Y = 24.202 — 0.957 X	41.4
Rubberwood	— 0.850**	Y = 24.837 — 1.849 X	72.3
Teak	— 0.849**	Y = 42.445 — 2.150 X	72.1

* Significant at 5 percent level
** Significant at 1 percent level
ns Not significant

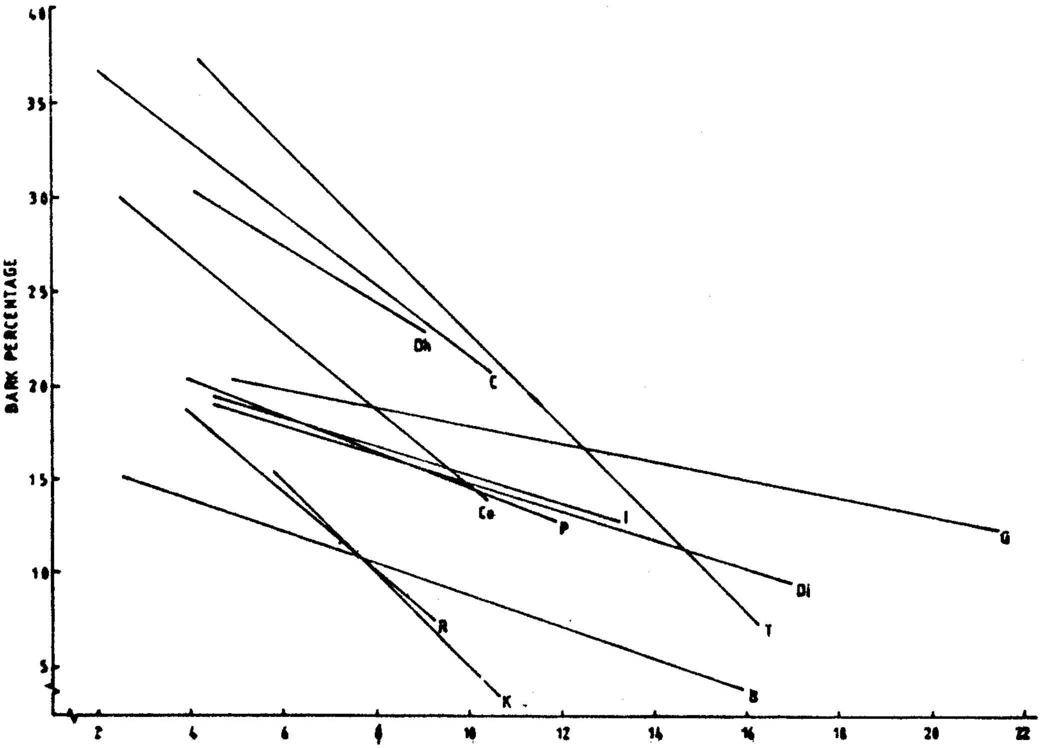


Fig. 11. Bark percentage as a function of branch diameter; B=Benteak, C =Cashew, Co= Coraltree, Dh =Dhaman, Di =Dillenia, G - Gurjan, I =Irul K =Kindal, P=Padri, R= Rubberwood, T = Teak.

Table 18. Relationship between branch diameter (cm) and average heartwood percentage (Y)

Timber	Correlation coefficient	Regression equation	r^2(%)
Benteak	0.353ns	Y = 14.864+ 1.635X	12.5
Gurjan	0.964**	Y = 10.805+4.410X	93.1
Irul	0.205ns	Y = 20.500+2,427X	4.2
Teak	0.813**	Y = 2.482+6.184X	66.1

**Significant at 1 percent level

5.8 Relationship between stem and branch properties

In order to examine the association of branch and stem properties, correlation coefficients are computed using the pairs of average values (Table 20). The correlation analysis reveals that the branch properties are, by and large,

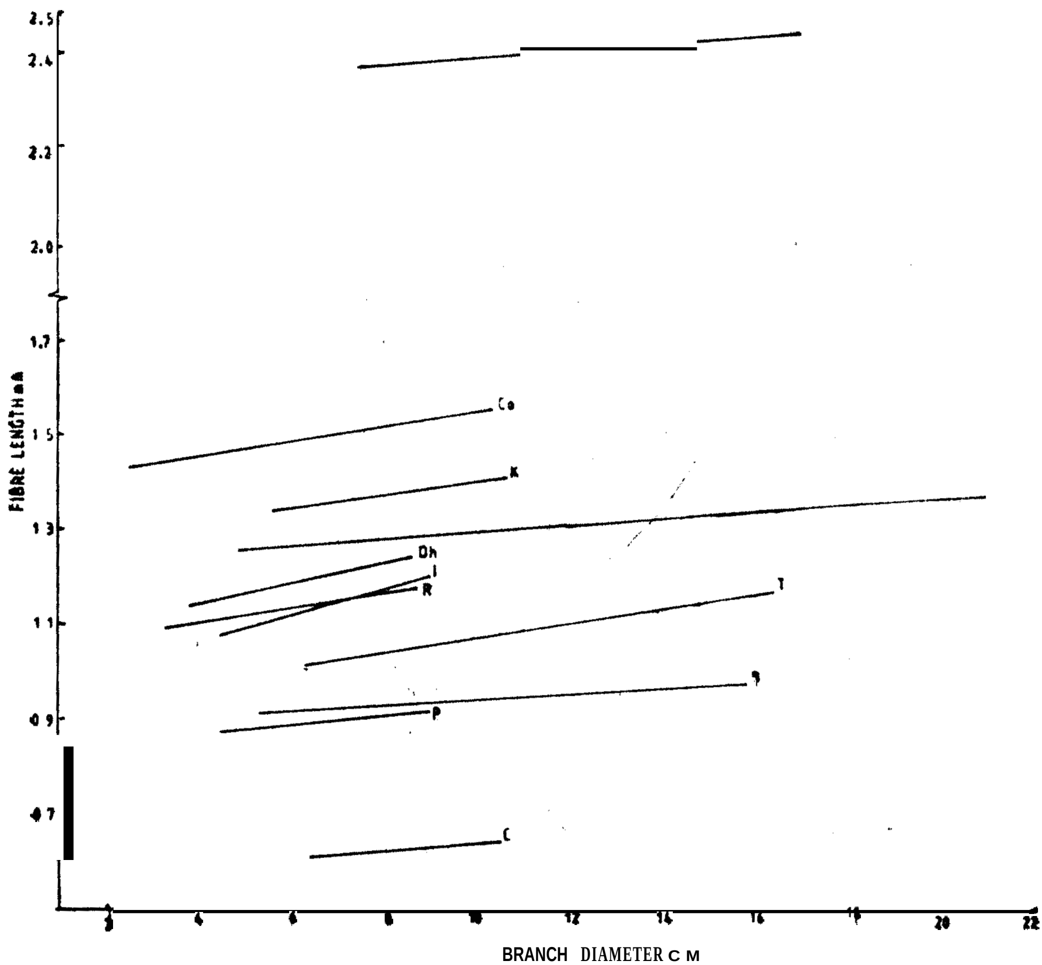


Fig. 12. Fibre length as a function of branch diameter; B= Benteak, C = Cashew, Co=Coraltree, Dh=Dhaman, D= Dillenia, G=Gurjan, I =Irul, K-Kindal, P-Padri, R=Rubberwood, T=Teak.

dependent on stem properties. For some properties, branches are independent of stern as factors like branch size have greater efftct.

5.9 Implications of the results

One interesting finding of this investigation is that the branches of majority of the species studied are not significantly different from the stem in wood and bark .density and fibre percentage. This implies that the pulp yield from branches is not necessarily low as compared to that from stem. Branches can often be superior to the stem for two reasons ascertained in the present study.

- The heartwood percentage, a property known *to* affect the pulp wood quality is much lower in branches, as observed in certain species like benteak, dhaman, gurjan, irul and teak.

Table 19. Relationship between branch diameter (cm) at the base and the average fibre length (mm)

Timber	Correlation coefficient	Regression Equation	r^2(%)
Benteak	0.493ns	$Y = 0.898 + 0.005X$	24.3
Cashew	0.727**	$Y = 0.557 + 0.008X$	52.9
Coraltree	0.880**	$Y = 1.396 + 0.016X$	77.5
Dhaman	0.738**	$Y = 1.058 + 0.022X$	54.5
Dillenia	0.862**	$Y = 2.144 + 0.020X$	14.3
Gurjan	0.976**	$Y = 1.217 + 0.008X$	95.3
Irul	0.839**	$Y = 0.960 + 0.027X$	70.4
Kindal	0.806**	$Y = 1.273 + 0.013X$	65.0
Padri	0.779**	$Y = 0.829 + 0.010X$	60.7
Rubberwood	0.729**	$Y = 0.729 + 0.014X$	53.2
Teak	0.627**	$Y = 0.925 + 0.015X$	39.3

** Significant at I percent level
ns Not significant

- Some species likev cashew have higher density branch wood as compared to stern wood.

On the other hand, lower pulp yield is expected when lower density branches (e.g. dillenia) are pulped as against stem. Furthermore, the higher bark content noted in branches of all the eleven species advocates that branches have to be debarked before pulping in order to maintain the standard in pulp yield and quality. However, it cannot be an impediment in pulping because of the fact that of the eleven species, only four (cashew, coraltree, dhaman and teak) have branches with more than 20 percent bark, and generally up to 20 percent bark is permitted in the chips in order to increase the fibre content. When the branches have more than 20 percent bark, they can be utilised in fibreboard and particleboard industries. Another notable difference which might affect the paper quality, if branches are used, is in fibre length. Because of shorter branch fibres, the paper made from branches is expected to have lower tear strength. But the results show that the overall difference when species are combined, is not more than 12 percent. This difference cannot be overemphasised as many pulp mills today use mixed tropical hardwoods in pulping, where hetween-species differences can be even greater.

Table 20. Correlatiqn coefficients for the relationship between stem and branch properties

Timber	Wood density	Bark density	Bark percentage	Heartwood percentage	Fibre length
Benteak	0.699**	0.979**	0.982**	0.750**	–0.194ns
Cashew	0.886**	0.904**	0.261ns		0.905**
Coraltree	0.725**	0.994**	0.238ns		0.981**
Dhaman	0.055s	-0,289ns	-0.400ns		-0.684*'
Dillenia	0.966**	0.944**	—0.631*		–0.257ns
Gurjan	- 0.128ns	0.453 ns	-0.090na		—0.506ns
irul	0.187ns	0.863**	0.940**	0.904**	--0.579*
Kindal	-0.510ns	0.670**			-0.725**
Padri	0.882**	0.704**	-0.275 ns		-0.407ns
Rubberwood	-0.222ns	0.689**	0.463ns		--0.264ns
Teak	0.823**	0.899**	0.735**	0.633*	0.97l**

* Significant at 5 percent level
** Significant at 1 percent level
ns Not significant

Another point of interest revealed in the present investigation is the presence of long fibres in dillenia, an indigenous hardwood, found in dry and mixed decidious forests and grasslands almost throughout India. Considering the severely limited supplies of locally grown long-fibred timbers, dillenia deserves attention in afforestation programmes for the creation of indigenous long-fibre resource.

The data for tissue proportions imply that coraltree has lower pulpwood value in terms of high proportion of thin walled cells (ray and axial parenchyma), as large portion of parenchyma and ray tissue can cause problem in paper-making. Furthcr-more, fibre proportion of this species is as low as 20 percent in contrast to 48 -62 percent of other hardwood species.

6. CONCLUSIONS AND RECOMMENDATIONS

1. Branches are not identical to stem in all the technical properties but the difference between the two is not so large as to treat the branch material separately in the manufacture of pulp, paper and boards. It is therefore suggested that branches can be accepted as an additional raw material particularly in the current situation of raw material shortage.

2. Branch diameter is an important raw material quatity parameter as it influences many properties like bark percentage heartwood proportion, fibre length and wood and bark density of some species.

3. ***DilIenia pentagyna*** merits attention in establishing the plantations of long-fibred indigenous species in order to meet the minimum long-fibre needs of paper industry.

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