Indian J. Nat. Rubb. Res. 2 (1) : 27-37, 1989

WOOD ANATOMY OF *HEVEA BRASILIENSIS* (WILLD. EX ADR. DE JUSS.) MUELL. ARG. 1 : DISTRIBUTION PATTERN OF TENSION WOOD AND DIMENSIONAL VARIATION OF WOOD FIBRES

C. P. Reghu, D. Premakumari and A. O. N. Panikkar

Reghu, C. P., Premakumari, D and Panikkar, A. O. N. (1989). Wood anatomy of *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg. 1: Distribution pattern of tension wood and dimensional variation of wood fibres. Indian J. Nat. Rubb. Res. 2(1) : 27-37.

The distribution and proportion of tension and normal wood, the dimensional variations of wood fibres with emphasis on positional effect and their variation from tree to tree were studied in clone PB 86 of *Hevea brasiliensis.* The formation of tension wood was associated with growth eccentricity. The proportion of tension wood increased with the increase in sampling height. The tension wood fibres (gelatinous fibres) were short and broad as compared to the normal wood fibres. The average fibre length showed significant difference among various height levels of the tree trunk.

Key words — *Hevea brasiliensis,* Rubber wood, Tension wood, Wood fibre, Gelatinous fibre.

C. P. Reghu (for correspondence), D. Premakumari and A. O. N. Panikkar, Rubber Research Institute of India, Kottayam-686 009, India.

INTRODUCTION

Wood is one of the most valuable raw materials, which has a vital role in the economic and industrial development of a nation. Shortage of good quality timber and its ever increasing demand for industrial utilisation drive us for exploring the available sources of wood. Rubber wood has been considered to be a waste product in rubber plantations (Silva, 1970), but this situation is changing rapidly. Rubber plantations in India have vast potentialities in supplying wood for various wood-based industries. The estimated area under rubber cultivation by the close of 1986-87 was 3,84,000 ha (Rubber Board, 1987). About 5,000 ha had been replanted annually during the past five years. It has been estimated that one hectare of rubber plantation will yield 198.22 m^3 of rubber wood at the time of replanting, and with the present rate of replantation 9,91,108 m^3 of wood per annum will be available, of which 60 per cent will be trunk wood, usable for various industrial purposes (Viju Ipe *et al,* 1987).

Our information on the basic structure of rubber wood is very meagre. It was hence thought worthwhile to undertake a study on the structural features of rubber wood. Certain selected wood quality indicators, especially the dimensional aspects of fibres and the proportion of tension wood, were studied.

MATERIALS AND METHODS

Two healthy trees of the clone PB 86 of *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg., about 35 years of age, at the time of felling were chosen for the present investigation. Wood discs of 10 cm thickness were sawn out at 60 cm, 210 cm and

360 cm levels from the bud union. The discs collected from 60 cm and 210 cm heights belonged to the exploited region, whereas the third disc represented the unexploited region. For the brevity of description, hereafter the wood discs cut at 60 cm, 210 cm and 360 cm heights are referred to as disc A, B and C, respectively. Tension wood zones were traced on tracing paper and the area covered by each zone was calculated using ACD (Chavan *et al*, 1979).

Cubic blocks of 2x2x2 cm size were prepared from each wood disc. One cubic block was prepared from the central portion including the pith region and the others at intervals of three cm from this, along the diameter of the discs. As pronounced growth eccentricity was noted, one block was collected from near the periphery of such region of the discs. Thus, from each wood disc ten blocks (Fig. 1) were taken. The blocks thus prepared were fixed in FAA. From each cubic block, wood tissues from a region of 2x2x2 mm were macerated following Jeffery's method (Johansen, 1940) and stained with toluidine blue 'O' (O'Brien *et al*, 1964) in order to differentiate normal wood and tension wood fibres (Reghu, 1983).

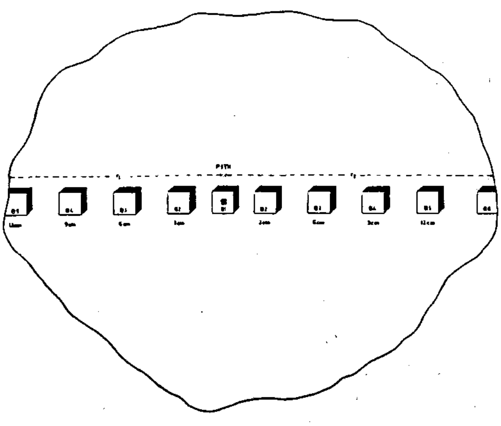

Fig. 1. Diagrammatic representation of wood sampling

Length and width of 25 normal wood fibres selected at random from each macerated sample were recorded. Similarly, measurements of 25 tension wood fibres, wherever available, were also taken. The measurements were taken using a visopan projection screen.

The blocks B2, B3, B4 and B5 belonged to the same relative positions from the pith on radii r_1 and r_2 along the same diameter and hence the values for fifty fibres were considered for working out the mean values. However, for samples B1 and B6 there were only 25 fibres.

For microscopy, sections of 15 micrometer thickness were stained with toluidine blue 'O'. The classification of fibres in terms of length was done following Radford *et al* (1974) and fibres were classified as very short (upto 1000 micrometer), short above 1000 upto 1500 micrometer), long (above 1500 upto 2000 micrometer) and very long (above 2000 micrometer).

Statistical significance was ascertained using 't' - test. Homogeneity of variance of the data was tested and wherever significance in variance was observed, modified 't'-test was applied.

RESULTS

Distribution of tension wood

Wood discs sawn at different heights showed prominent growth eccentricity. Freshly sawn and unpolished discs showed broad lustrous and 'wooly' tension wood zones in contrast to the remaining dull normal wood zones (Fig. 2A). Seasoned and polished wood surface also had visible tension wood zones, but were not very sharp (Fig. 2B).

Tension wood consisted of compact and well developed gelatinous fibres (Fig. 2C). It was mostly concentrated in the central region surrounding the pith. Gelatinous fibres were also seen as broad crescent shaped discrete bands or as isolated patches. The G-layer of gelatinous fibres was convoluted and detached from the adjacent cell wall (Fig. 2D). The normal wood fibres did not show convolutions and their primary and secondary walls were intact (Fig. 2D).

Table 1 illustrates the area occupied by tension wood and normal wood at different heights of the tree trunk . In both the trees the actual area occupied by tension wood and its percentage were high at 360 cm height level, from where it gradually decreased at the lower levels.

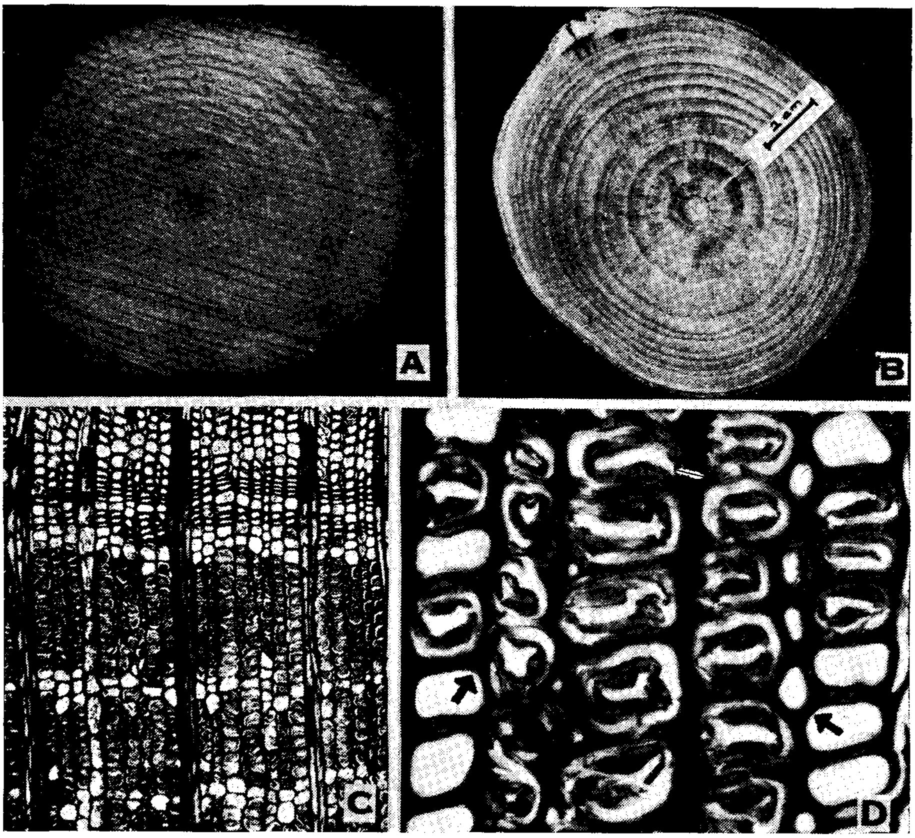

Fig. 2. (A) Green sawn wood disc of *Hevea brasiliensis* showing 'wooly' lustrous tension wood zones. (B) Seasoned and polished wood disc. (C) Cross section of wood showing compact tension wood fibres x 560. (D) Tension wood fibres showing convoluted 'gelatinous' secondary layer and normal wood fibres (at arrows) x 1400.

Table 1. **Surface area of wood disc, area occupied by tension wood, normal wood, pith and their percentages within wood discs at different height levels**

Wood disc	Area of pith (cm²)	Surface area excluding pith (cm²)	Area occupied by tension wood		Area occupied by normal wood	
			(cm²)	(%)	(cm²)	(%)
Tree No. 1						
A	0.45	1182.07	99.87	8.45	1082.20	91.55
B	0.46	774.43	227.46	29.37	546.97	70.63
C	0.95	706.86	251.97	35.64	459.89	64.36
Tree No. 2						
A	0.53	757.64	87.13	11.50	670.51	88.50
B	0.59	731.57	243.03	33.22	488.54	66.78
C	0.67	689.66	249.11	36.12	440.55	63.88

SIZE VARIATION OF FIBRES AT DIFFERENT HEIGHTS

(a) **Length of normal fibres**

Table 2 depicts the mean length of normal fibres (NFL) and gelatinous fibres (GFL) at 60, 210 and 360 cm heights in tree 1 (T1) and tree 2 (T2). The NFL was higher towards the peripheral zones (B5, B6 positions) than the central (B1, B2) and intermediate zones (B3, B4) of all wood discs, in both trees, except disc B of T2 where it was the lowest at B6 position. In discs B and C of T2 the mean NFL showed a gradual increase from B1 to B5. However, in disc A of T1 and T2, B3 position of the former and B1 position of the latter showed less fibre length than the rest. In disc B of T1 the NFL fluctuated from position to position.

In disc A the difference in the average NFL did not show any significant difference between B1-B4, B1-B5, B2-B4, B2-B5, B2-B6, B4-B6 and B5-B6 of T1 and B2-B3, B2-B4, B2-B5, B4-B6 and B5-B6 of T2. Similarly in disc B significant difference in NFL was not observed between B2-B4, B3-B4, B3-B5, B4-B5, B4-B6 of T1 and B1-B6, B3-B4, B4-B5 of T2. In disc C the difference was not significant in B1-B2, B5-B6 of T1 and B1-B2, B4-B5, B4-B6 and B5-B6 of T2.

(b) **Length of Gelatinous Fibres**

The average GFL was low in the central zone as compared to that in the remaining zones of disc C, and disc A (of T2). It was less at B3 position in disc A of T1, whereas, in disc B the mean GFL was less at B5 and B6 positions of T1 and T2, respectively (Table 2).

In disc A, mean GFL did not show any significant difference between B1-B3, B2-B4, B2-B5, B2-B6 and B5-B6 of T1 and B2-B4, B2-B5, B4-B6 and B5-B6 of T2. In disc B of T1 significant difference in the mean GFL

Table 2. **Mean length of fibre within wood disc at different height levels**

Height	Position	TREE 1				TREE 2			
		Normal fibre		Gelatinous fibre		Normal fibre		Gelatinous fibre	
		Mean (μm)	SE	Mean (μm)	SE	Mean (μm)	SE	Mean (μm)	SE
60 cm(A)	B1	1253.56	23.19	1011.08	22.60	1045.80	22.01	1038.24	27.16
	B2	1330.56	16.92	1201.84	16.37	1272.04	15.48	1236.86	23.38
	B3	1129.38	27.40	976.5	27.90	1235.16	21.48	1168.44	19.89
	B4	1292.06	19.90	1155.20	20.99	1319.46	24.01	1245.30	21.14
	B5	1316.14	24.86	1216.04	19.96	1404.48	27.29	1358.12	22.49
	B6	1366.40	29.09	1264.20	37.36	1371.72	32.42	1295.04	30.54
210 cm(B)	B1	1031.80	32.47	1021.16	29.89	1032.92	18.46	1022.84	24.17
	B2	1152.62	23.57	1078.56	21.80	1243.06	20.34	1201.76	18.94
	B3	1251.42	19.12	1108.52	22.89	1365.20	23.60	1263.36	26.68
	B4	1193.78	23.73	1052.10	22.09	1424.22	21.14	1204.56	29.72
	B5	1223.18	24.26	985.04	23.97	1468.74	21.69	1294.58	17.70
	B6	1396.64	25.88	1058.40	28.07	1020.60	28.84	943.32	23.21
360 cm(C)	B1	1063.16	29.91	1049.16	24.58	1187.00	19.54	1172.64	27.57
	B2	1072.26	16.92	1056.72	16.62	1191.06	21.39	1177.96	24.41
	B3	1208.34	19.67	1190.26	26.23	1310.26	20.81	1236.20	18.46
	B4	1302.28	21.59	1262.94	16.57	1423.66	21.45	1358.90	25.17
	B5	1404.20	22.44	1201.20	35.15	1479.94	19.39	1410.64	26.63
	B6	1394.68	39.41	1298.40	25.83	1426.60	31.45	1349.60	21.97

was noticed between B1-B3, B2-B5 and B3-B5 positions, whereas, in T2 except positions B2-B3, B2-B4, B3-B4, B3-B5 and B4-B5, all the other positions showed significant difference. In disc C except B1-B2, B3-B5, B4-B5, B4-B6 positions of T1 and B5-B6 positions of T2 all others were significantly different.

Table 3. **Mean width of fibre within wood disc at different height levels**

Height	Position	TREE 1				TREE 2			
		Normal fibre		Gelatinous fibre		Normal fibre		Gelatinous fibre	
		Mean (μm)	SE	Mean (μm)	SE	Mean (μm)	SE	Mean (μm)	SE
60 cm(A)	B1	22.40	0.19	24.29	0.74	19.04	0.81	24.92	0.70
	B2	21.88	0.61	28.14	0.76	17.29	0.43	25.27	0.38
	B3	18.66	0.54	23.70	0.73	17.92	0.50	26.11	0.51
	B4	19.67	0.57	27.13	0.56	20.23	0.68	27.72	0.47
	B5	20.79	0.61	26.04	0.49	20.44	0.61	28.00	0.49
	B6	21.14	0.80	27.58	0.58	18.62	0.80	27.16	0.89
210 cm(B)	B1	18.90	0.93	21.70	0.67	16.52	0.59	23.10	0.64
	B2	22.33	1.01	27.37	0.71	17.29	0.45	24.78	0.55
	B3	22.39	0.70	27.68	0.67	18.13	0.51	25.76	0.49
	B4	20.44	0.60	27.92	0.68	17.64	0.51	24.64	0.74
	B5	19.89	0.65	29.93	0.95	16.80	0.46	26.10	0.57
	B6	16.13	0.62	29.32	0.75	16.24	0.57	22.82	0.79
360 cm(C)	B1	17.22	0.70	25.48	0.40	18.90	0.67	26.32	0.73
	B2	17.85	0.54	25.69	0.42	19.46	0.54	23.17	0.54
	B3	17.29	0.44	24.22	0.41	18.55	0.51	25.06	0.49
	B4	19.88	0.59	28.00	0.55	19.32	0.53	25.83	0.62
	B5	17.85	0.54	27.86	0.71	21.42	0.69	25.48	0.77
	B6	17.50	0.67	27.58	0.89	19.88	0.80	22.54	0.54

(c) **Width of Normal Fibres**

Table 3 illustrates the mean width of normal fibres (NFW) and gelatinous fibres (GFW) within wood discs. In general, both the trees did not show considerable variation in their mean NFW at various distances from the pith. However, significant difference between certain positions was noticed. None of the positions in disc B and C of T2 showed significant difference in their mean NFW, whereas, in disc A of the same tree the NFW was significantly different between B1-B2, B2-B4, B2-B5, B3-B4, and B3-B5 positions. In T1 except positions B1-B3, B1-B4, B2-B3, B2-B4, B3-B5, B3-B6 in disc A; between positions B1-B2, B1-B3, B1-B6, B2-B5, B2-B6, B3-B4, B3-B5, B3-B6, B4-B6, and B5-B6 of disc B and between positions B1-B5, B2-B5, B3-B5 and B4-B5 in disc C, all others did not show significant difference.

(d) **Width of Gelatinous Fibres**

Except some fluctuations among certain positions, considerable variations in the mean width of gelatinous fibres (GFW) were not observed within wood discs of both trees (Table 3). Between majority of positions the difference in the mean GFW was not significant. However, in disc A of T1, significant differences were observed between eight positions (B1-B2, B1-B4, B1-B5, B1-B6, B2 - B3, B3 - B4, B3 - B5 and B3-B6): position B1 was significant to B2, B3, B4, B5 and B6 and B2 was significant to B5 in disc B. In disc C, the mean GFW showed significant difference between eight positions (B1-B2, B1-B6, B2-B3, B2-B4, B2-B5, B3-B6, B4-B6 and B5-B6). In T2 significant difference in the mean GFW was noticed between six positions in disc A (B1-B4, B1-B5, B2-B4, B2-B5, B3-B4 and B3-B5); between five positions in disc B (B1-B3, B1-B4, B3-B6, B4-B5 and B4-B6) and only between two positions in disc C (B3-B4 and B3-B5).

SIZE VARIATION OF WOOD FIBRE AT DIFFERENT HEIGHTS ALONG THE STEM AXIS (disc average).

(a) **Fibre length:** The mean length of normal fibre (NFL) at three height levels along the stem axis did not show any common trend in T1 and T2. In case of gelatinous fibres (GFL), however, the mean length showed significant difference along the tree height, the trend being the same in both T1 and T2. In T1, the mean NFL was lower in disc B than those of other discs with the maximum length in disc A. However, the difference was not significant between disc A and C in their mean NFL, whereas, in T2, the mean NFL gradually increased from disc A to C. However, the difference between disc A and B was not significant (Table 4).

When the disc averages of GFL at different heights were compared, it was the lowest in disc B and the highest in disc C of both the trees and the differences were significant (Table 4).

(b) **Fibre-width:** The mean width of gelatinous fibres was greater than that of the normal fibres at all the positions of wood and their differences were significant except at B1 position in disc A of T1 (Table 3).

In general, at all the three height levels, an increase in length associated with a decrease in width was noticed in normal fibres as compared to those of gelatinous fibres (Table 4).

DISTRIBUTION OF FIBRE TYPES IN TERMS OF LENGTH

Table 5 depicts the frequency of occurrence of very short, short and long fibres in wood at different heights. The frequency of short fibres was the highest and that of long fibres was the least in all wood discs irrespective of the nature of fibres. In disc C of T2, very short fibres were the least as compared to the long ones.

DISCUSSION

Tension wood formation is considered as a natural defect in wood brought about by growth irregularities and environmental conditions (Isenberg, 1963; Harlow, 1970) and its formation is prevalent in those families where the wood is less specialized (Necessany, 1958; Hoster and Leise, 1966). The degree of modification of wood structure involved in tension wood formation is extremely variable among different families as well as within individual plants of the same species (Cote and Day, 1965). Tisseverasinghe (1970) and Panikkar (1971) reported the occurrence of tension wood in rubber tree. Fisher and Stevenson (1981) classified tension wood under Rauh's model based on its impact on tree architecture. As tension wood has considerable impact on seasoning and industrial utilization, it is necessary to establish its quantity, nature and distribution in rubber wood. The proportion of tension wood in *Hevea* was found to vary in different specimens from the same tree along the length or even in different trees (Vijendra Rao *et al*, 1983), and the proportion was reported to vary from 15 to 65 per cent in the same plank (Sharma and Kukreti, 1981).

The present study on the proportion of tension wood at different height levels in clone PB 86 indicates that it increases from base to top of the tree trunk with the maximum percentage (36%) at 360 cm height level (unexploited and unstimulated region). The percentage of tension wood at 210 cm height level (stimulated and slaughter tapped region) was found to range from 29 to 33 whereas, at 60 cm height level (normally tapped region) it was only 8 to 11.5 per cent.

Table 4. **Mean length and width of normal fibre and gelatinous fibre of wood discs at different heights (disc average)**

Height	TREE 1								TREE 2							
	Normal fibre length (μm)		Gelatinous fibre length (μm)		Normal fibre width (μm)		Gelatinous fibre width (μm)		Normal fibre length (μm)		Gelatinous fibre length (μm)		Normal fibre width (μm)		Gelatinous fibre width (μm)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
60 cm (A)	1275.62	10.91	1138.04	11.37	20.56	0.27	26.19	0.29	1287.98	11.61	1235.07	11.13	18.94	0.26	26.63	0.23
210 cm (B)	1207.04	11.37	1060.33	10.26	20.51	0.34	27.43	0.34	1306.80	13.43	1178.35	12.44	17.25	0.21	24.76	0.27
360 cm (C)	1243.20	12.59	1174.29	11.29	19.63	0.26	24.72	0.26	1342.34	11.55	1275.44	11.60	18.05	0.24	26.30	0.25

Table 5. **Frequency of occurrence (%) of fibre types**

Wood disc	Tree No.	Normal fibre			Gelatinous fibre		
		Very short	Short	Long	Very short	Short	Long
A	Tree 1	7.60	82.80	9.60	21.20	77.20	1.60
	Tree 2	10.80	83.20	6.00	8.40	84.00	7.60
B	Tree 1	14.80	82.00	3.20	33.34	66.66	nil
	Tree 2	10.40	68.40	21.20	13.50	84.50	2.00
C	Tree 1	11.60	78.40	10.00	15.11	80.45	4.44
	Tree 2	2.00	75.20	22.80	5.33	83.55	11.12

The increase in tension wood proportion at 360 cm height may be due to the direct influence of the intrinsic growth response caused by the movement of canopy brought about by various factors like wind, gravity, weight or phototropism as suggested by Dayer (1955), Wardrop (1956) and Reghu (1983). Timber containing tension wood causes problems in utilisation like warping, twisting and collapse. It also causes problems in the field of paper pulp-manufacture as reported by Bland (1961). Therefore, further intensive investigation of tension wood in rubber tree is important, from both practical and scientific considerations.

To evaluate a tree as a potential source of pulp wood, it is essential to know the pattern of fibre length (Denne and Whitbred, 1978). Attempts were also made earlier for the manufacture of paper pulp and fibre board out of rubber wood (Anon, 1956; Guha and Negi, 1969).

In *Hevea brasiliensis* Bhat *et al* (1984) reported an increasing trend in the basic density and fibre length from the pith outwards, with an increase in age, although they either remain constant or decrease near the bark region. The present study also shows a similar trend in the case of normal wood fibres except some fluctuations. The length and width of tension wood fibres and the width of normal wood fibres varied from position to position.

Fibre length is inversely related to the rate of radial growth of axis. An increased duration of cambial division brings about the differentiation of longer fibres and eccentricity of radial growth of axis, whereas, an increased rate of cambial division causes the radial growth increment and the differentiation of short fibres (Wardrop, 1964). Taking these into consideration, it appears that the increase in fibre length, associated with growth eccentricity may be due to the increased duration, rather than increased rate of cambial division.

Bhat *et al* (1984) did not observe any statistical difference in fibre length between 0.5 metre above the ground, 50 per cent and 75 per cent of the tree heights in *Hevea*. However, the present study shows significant difference in fibre length between 60 cm, 210 cm and 360 cm height levels from the bud union. One of the trees investigated showed an increasing trend of normal fibre length from bottom to top, whereas, in the other tree 60 cm height has maximum length and 210 cm height has minimum length. The length of tension wood fibres was more at 360 cm height and less at 210 cm height level.

Variation of wood structure between trees of the same species (Dinwoodie, 1961) as well as between different heights (vertical variation) and different positions (horizonal variation) have been reported earlier (Tsoumis 1968). The existence of these variations is reported to be due to the difference in the micro-environment under which each tree grows. Similar variations was also noticed in the length and width of fibres of the clone PB 86 in this study. It is not unlikely that tissue regeneration after tapping, cultural practices such as stimulation, etc, may influence the dimensional characteristics of wood elements.

In general, at all height levels, the fibres of the normal wood were longer and narrower than the tension wood fibres which were comparatively shorter and broader with significant difference between them in most cases.

The frequency of short fibres (above 1000 upto 1500 micrometer) in the present study supports the earlier reports on the average fibre length of rubber wood as 1.50 mm (Silva, 1970), 1.40 mm (Anon, 1956), 1.12 mm (Guha and Negi, 1969), 1.189 mm (Bhat *et al*, 1984) and 1.101 mm (Husain Kazmi and Roop Singh, 1988). The average width of rubber wood fibres reported as 22 micrometer in dry condition (Silva, 1970; Anon, 1956) is also in accordance with this study on fibre width (19–27 micrometer), though the fibre width in dry state was not studied. The results discussed above indicate the need for detailed investigation on the structure of rubber wood.

ACKNOWLEDGEMENT

The authors are thankful to Dr. M. R. Sethuraj, Director of Research for providing necessary facilities and also for timely discussions during this work. Thanks are also due to Shri. G. Subbarayalu and Shri. Tomy Joseph for statistical analysis of the data and to Shri. K. P. Sreeranganathan for the photographs.

REFERENCES

Anonymous. (1956). Rubber wood as a raw material for paper pulp or building material. *Planters' Bulletin. Rubber Research Institute of Malaysia*, **23** : 58–63.

Bhat, K. M., Bhat, K. V. & Damodaran, T. K. (1984). Some wood and bark properties of *Hevea brasiliensis*. *Journal of Tree Sciences*, (1 & 2) : 40–46.

Bland, D. E. (1961). The chemistry of reaction wood. III. The milled wood lignins of *Eucalyptus goniocalyx* and *Pinus radiata*. *Holzforschung*. **15** : 102–106.

Chavan, R. R., Kothari, I. L. & Patel, J. D. (1979). A simple area calculating device (ACD) for biological systems. *Current Science*, **48** : 792–793.

Côte, W. A. Jr. & Day, A. C. (1965). Anatomy and Ultrastructure of reaction wood. In: *Cellular Ultrastructure of Woody Plants* (ed. Côte, W.A. Jr.). Syracuse University Press, Syracuse. 391–418.

Dayer, D. (1955). Artificially induced tension wood in ash, birch and poplar. *Journal of Oxford University Forest Society*, **4**: 19–23.

Denne, M. P. & Whitbred, V. (1978). Variation in fibre length within trees of *Fraxinus excelsior*. *Canadian Journal of Forest Research*, **8** : 253–260.

Dinwoodie, J. M. (1961). Tracheid and fibre length in timber: A review of literature. *Forestry*, **34** : 125–144.

Fisher, J.B. & Stevenson, J.W. (1981). Occurrence of reaction wood in branches of dicotyledons and its role in tree architecture. *Botanica Gazette*, **141** : 82–95.

Guha, S. R. D. & Negi, J. S. (1969). Pulping of rubber wood. *Indian Pulp and Paper*, **24** (3): 1-3.

Harlow, W. M. (1970). Inside wood: Masterpiece of nature. American Forest Association, New York.

Hoster, H. R. & Leise, W. (1966). Ueber das Vorkommen von Reaktios-gewebe in Wurzeln und Aslen der Dikotyledonen. *Holzforschung* **20**: 80–90.

Husain Kazmi, S. M. & Roop Singh. (1988) Wood anatomy of exotics grown in India. I. *Hevea brasiliensis* Muell. Arg. (Euphorbiaceae). *Journal of the Timber Development Association of India*, **34**(2) : 18–21.

Isenberg, I. H. (1963). The structure of wood. In: *The Chemistry of Wood* (ed. Browning, B.L.). Inter Science Publishers. John Wiley New York.

Johansen, D. A. (1940). Plant microtechnique. McGraw Hill Book Company Inc., New York. pp. 104.

Necessany, V. (1958). B-indolacetic acid on the formation of reaction wood. *Phyton Aires*, **11** : 117–127.

O'Brien, T. P., Feder, N. & McCully, M. E. (1964). Polychromatic staining of plant cell wall by toluidine blue 'O'. *Protoplasma*, **59** : 367–373.

Panikkar, A. O. N. (1971). Occurrence of tension wood in *Hevea*. *Rubber Board Bulletin*, **11**(2): 55–58.

Radford, A. E., Dickison W.C., Massey, J. R. & Bell, C. R. (1974). Vascular plants systematics, Harper and Raw Publishers, New York.

Reghu, C. P. (1983). Structural studies on tension wood of some broad-leaved trees. Ph.D. Thesis. Sardar Patel University, Gujarat.

Rubber Board (1987). Indian Rubber Statistics. 1987-88. The Statistics and Planning Division, Rubber Board, p. 18.

Sharma, S. N. & Kukreti, D. P. (1981). Seasoning behaviour of rubber wood. An under utilized non-conventional timber resources. *Journal of the Timber Development Association of India*, **27**(2) : 19–29.

Silva, S. S. (1970). Industrial utilization of rubber for wood-based panel products. *Rubber Research Institute of Sri Lanka Bulletin*, **3 & 4** : 40–53.

Tisseverasinghe, A.E.K. (1970). The utilisation of rubber wood (*Hevea brasiliensis*). *The Ceylon Forester*, **9** (3 & 4) : 87–94.

Tsoumis, G. (1968). Wood as a raw material. Perga-mon Press, Oxford–London, pp. 123–138.

Vijendra Rao, R., Dayal, R. & Sharma, B. (1983). Studies on the nature and pattern of distribution of tension wood in *Hevea brasiliensis*. Muell. Arg. (Rubber wood). *Indian Forester*, **109(5)** : 286–291.

Viju Ipe, C., Reghu, C. P. & Haridasan, V. (1987). Rubber wood consuming units in Kerala : Technical facilities and problems. *Rubber Board Bulletin*, **23(1)** : 22–25.

Wardrop, A. B. (1956). The distribution and formation of tension wood in some species of *Eucalyptus*. *Australian Journal of Botany*, **4** : 152–166.

Wardrop, A. B. (1964). Reaction anatomy in arborescent angiosperms. In : *Formation of Wood in Forest Trees*. (ed. Zimmermann, M. H.). Academic Press, New York, pp. 405–456.