KFRI Research Report 82

WATER BLISTERS IN TEAK

Jose Kallarackal
K.K. Seethalakshmi
K.V. Bhat

KERALA FOREST RESEARCH INSTITUTE
PEECHI, THRISSUR

June 1992 Pages: 22

CONTENTS

WATER BLISTERS IN TEAK

ABSTRACT

Water blister in teak was reported as early as 1896. It is a peculiar formation wherein the healthy looking trees, mostly along the riversides, exude a straw-coloured sap which leaves a black discolouration on the surface of the bark. Although the problem is not widespread it is serious enough to cause concern especially in certain localities. This investigation was undertaken to study the possible causes for development of water blisters, and the nature and extent of the resultant damage to the timber. Observations showed that the blister is restricted to tree trunk and is always caused by a radial shake in the trunk wood. The loss is serious in terms of log quality, often resulting in rejection of affected timber for high quality veneer, boards or turnery stock. The blister exudes a straw coloured fluid with a similar chemical composition as that of xylem sap. But the concentration of inorganic salts and pH of blister fluid was very high. The rate of exudation follows a diurnal rhythm similar to root pressure fluid. However, the concentration of salts in blister fluid was higher than root pressure fluid and this accounts for the relatively high osmotic pressure of blister fluid. The flow continues throughout the year and the volume of liquid exuded depends on soil water availability.

1. INTRODUCTION

It was nearly a century ago that the peculiar phenomenon of water blister was noticed in teak plantations of Nilambur (Lushington, 1896). Healthy looking trees, mostly along riversides, were found to exude a light yellow sap which left a black discoloration on the bark surface. Although this peculiar 'disease' generated some curiosity initially, it did not attract adequate scientific attention until 1959 when the first detailed investigation on 'water blister' was carried out by Bakshi and Boyce. They proposed that water blister is a physiological phenomenon caused by root pressure which forced the sap into the crevices of wood resulting from shake. No fungi or bacteria were found associated with the blister. Although this study did not provide a conclusive reason for the development of a shake, it has led to realisation of the substantial damage caused to the timber. Previously, it was believed that the timber was not affected by water blister and the damage was superficial.

Of late, our own survey has shown the water blister problem in several other parts of the State like Pothundi, Peechi, Parambikuiam etc. not only along the rivercourses/reservoirs but also in locations a bit away from them. Although the defect is not widespread, it is serious enough to cause concern especially in certain localities. For example, the well-known Conolly teak plantation in Nilambur shows almost 30 per cent of the trees with water blisters. This has led to a renewed interest on the problem and a need has been felt to investigate the cause of the defect and to find out suitable control measures. It should be noted that teak is currently the major hardwood plantation timber of the State and the blister damage is always caused to the basal part of the bole which is supposed to provide the best timber out of a tree. This preliminary study was undertaken to look into the possible causes of the defect in order to arrive at appropriate control or management strategies.

In this study, we have approached the problem by studying the structure and physiology of the blister mainly in two localities of Kerala, where the problem is prevalent. Although we planned to begin our studies on newly formed blisters or blisters at the initial stages of formation; we found it practically impossible to locate such stages. The problem was externally manifested only at a later stage. Moreover, since teak is a protected plant in the forests and plantations, felling them at will was also not permissible. Hence we have restricted our studies to blisters which are probably several years old. However, from the uniformity in the structure and function of the few blisters we have studied closely, we are confident that their behavior can be generalised in the various areas affected by this problem.

2. MATERIALS AND METHODS

2.1. Material and Locations

Teak (*Tectona grandis*) trees used in this study were located in the Kerala Forest Research Institute (KFRI) campus at Peechi, Valluvasseri and Chaliyarmukku in Nilambur and the teak plantation at Pothundi reservoir. The affected trees in Peechi were growing on a hill slope with an irrigation canal uphill (nearly 10-30 m from the affected trees). The trees in Nilambur were growing at the bank of the river Chaliyar. The trees at Pothundi dam were growing on the edges of the reservoir. Water blisters on the main tree trunk were mostly studied in these locations. A blister developed at the base of a branch was also studied at Peechi.

The survey of the plantation for observing the frequency of the affected trees was conducted at Chaliyarmukku.

2.2. Anatomical studies

Two mature teak trees with water blister in the KFRI campus were felled and cross-cut into serial sections of 5 cm thickness. The extent of the split in each of the disc was noted. The discs were also examined for other injury-related defects. Another tree, oozing from the base of a branch stub was also examined similarly . Part of it was cross-cut and the rest sawn lengthwise. Appropriate portions of wood were fixed in FAA (Johansen,1940) for anatomical studies. Besides, samples were also collected from healthy and affected trees from Nilambur and Pothundi. Transverse and tangential sections of 20 m thickness were cut on a sliding microtome (Reichert, Austria). Sections were stained in 0.5% safranin prepared in 50% ethyl alcohol. Stained sections were dehydrated and mounted in DPX mountant.

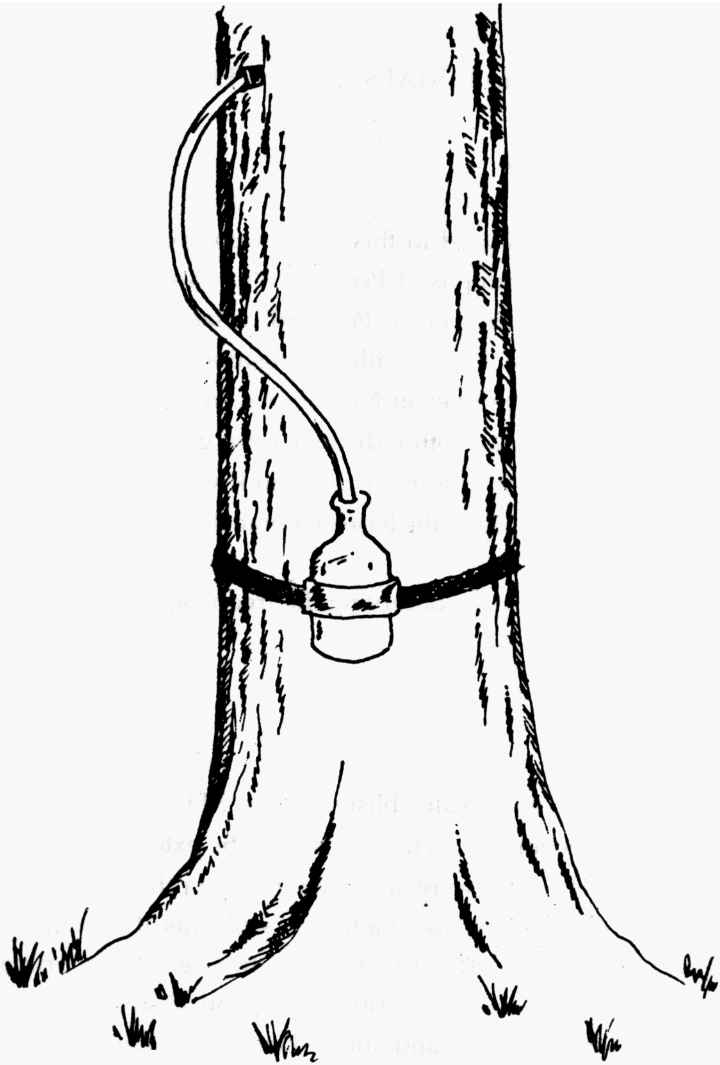

Fig. 1. Method for collection of fluid from blister affected teak trees

2.3. Blister fluid collection

For studying the rate of flow from the blister, the naturally formed hole through which fluid was oozing out was widened using a hand-drill. A short piece of metal tube (3 mm diameter) was inserted into this hole on the tree trunk. Leaks from the contact area was prevented by a quick setting putty (M-seal, Mahindra & Co.). A polythene transparent tube was led from this metal tube to a bottle suitably tied to the trunk of the tree (Fig.1). The exuding fluid was collected in this bottle. The fluid quantity was measured daily, sometimes twice a day to study the diurnal variations.

2.4. Girdling

The trees were girdled just above ground, and below the level of blister opening by removing the bark and sapwood all around.

2.5. Physical and chemical analysis of the fluid

The pH of the fluid was measured using a pH meter. The electrical conductivity of the fluid was tested using a conductivity meter calibrated against potassium chloride solutions of similar concentration. The osmotic pressure of the fluid was measured using a cryoscopic osmometer (Osmomat 030, Gonotec, Germany). Samples of the blister fluid were analysed for C, H and N using an autoanalyser. The inorganic cations, namely, Na^+, K^+, Ca^{++} and Mg^{++} were analysed using an atomic absorption spectrophotometer. The samples had been digested in a triacid mixture for 4-5 hrs until clear. Organic groups like the phenolic hydroxyl and aldehyde were tested by $FeCl_3$ test and 2,4-DNP test respectively.

2.6. Soil moisture

Soil moisture measurements were made in samples collected at two different depths (0-30; 30-60 cm) in areas with blister problem. The samples were sealed in plastic bags in the field. Later, they were weighed to determine the fresh weight, and dried in an oven at 105°C for 24 h. The water content is expressed in mm as soil water deficits. The field capacity of the soil was determined by draining the samples in a filter paper lodged in a funnel.

2.7. Weather data

Data on rainfall, temperature and relative humidity were collected from the KFRI weather station at Peechi. In Nilambur, only the rainfall data was available.

2.8.Plantation survey

The survey of a plantation to determine the frequency of the blister problem was conducted at Chaliyarmukku. Quadrats, 50 m x 50 m were taken starting from the riverbank. The affected trees and the healthy trees in each quadrat were counted.

3. RESULTS AND DISCUSSION

3.1. Morphology and Anatomy

The most apparent sign of water blister problem is a black vertical stripe on the trunk of the tree (Fig.2). This is caused by the continuous oozing of a fluid from a hole on the tree trunk. In some trees, considerable deposition of calcareous substances were also found on the darkened portion of the bark surface, suggesting crystallisation of the dissolved substances from the fluid. The blister could be found at any level of the trunk, usually not above 5 m from the ground. In majority of trees it occurred within 2 m from the ground. The affected trees showed long vertical grooves extending on the bark, mostly on the two opposite sides of the trunk suggestive of the damage inside the trunk. A number of affected trees examined after felling showed that the external grooves on the bark coincided with the internal split. The extent of the split ranged between 1 and 3 m. However, only one opening to the outside was found in all the affected trees.

Less frequently, some trees were found to exude fluids from the base of the decayed branch stubs. Similarly, it was not uncommon to find minor exudation from small crevices resulting from wounds. However, the morphology and origin of these 'blister like formations' were found to be different from the typical water blister reported by Bakshi and Boyce (1959).

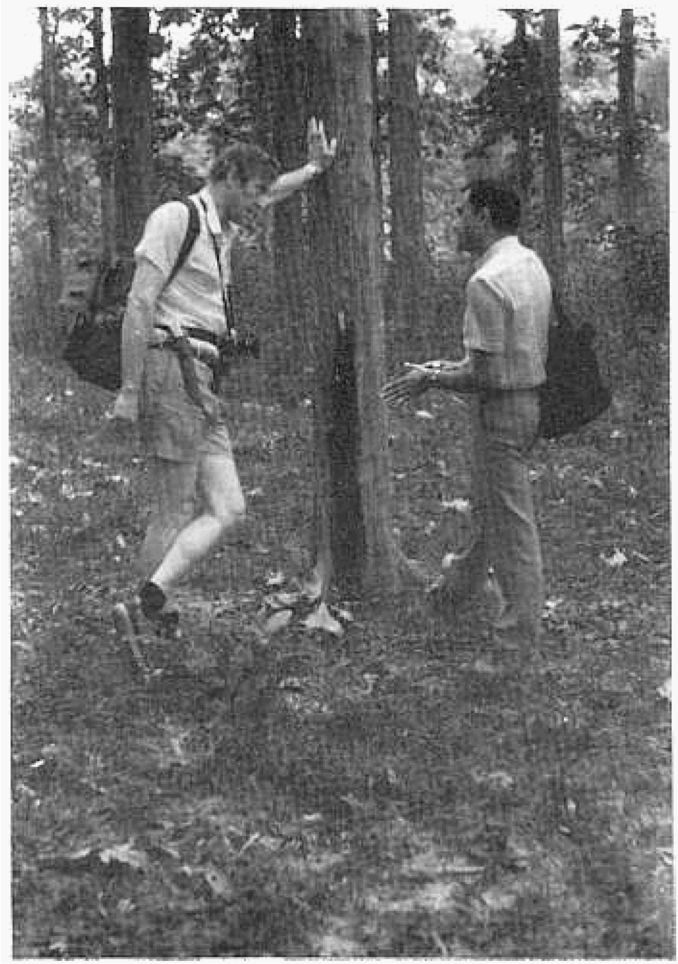

Fig. 2 - Teak water blister problem

A cross sectional disc of the affected tree showed the presence of a major radial shake which passed through the pith and opened to the exterior surface of the wood through a narrow slit (Fig3 a). The cavity resulting from the fissure was the site of fluid accumulation. The shake passed along the direction of rays and extended radially even up to the peripheral sapwood. The wood tissue lining the blister cavity was slightly discolored, so also, the tissue lying at the radial extremity of the split b). The latter resembled the heartwood with which it had almost merged and could not be readily demarcated. It is possible that the discolored portion of wood at the radial ends of the shake included some decayed tissue as evident from its colour variation. Growth rings in this portion were

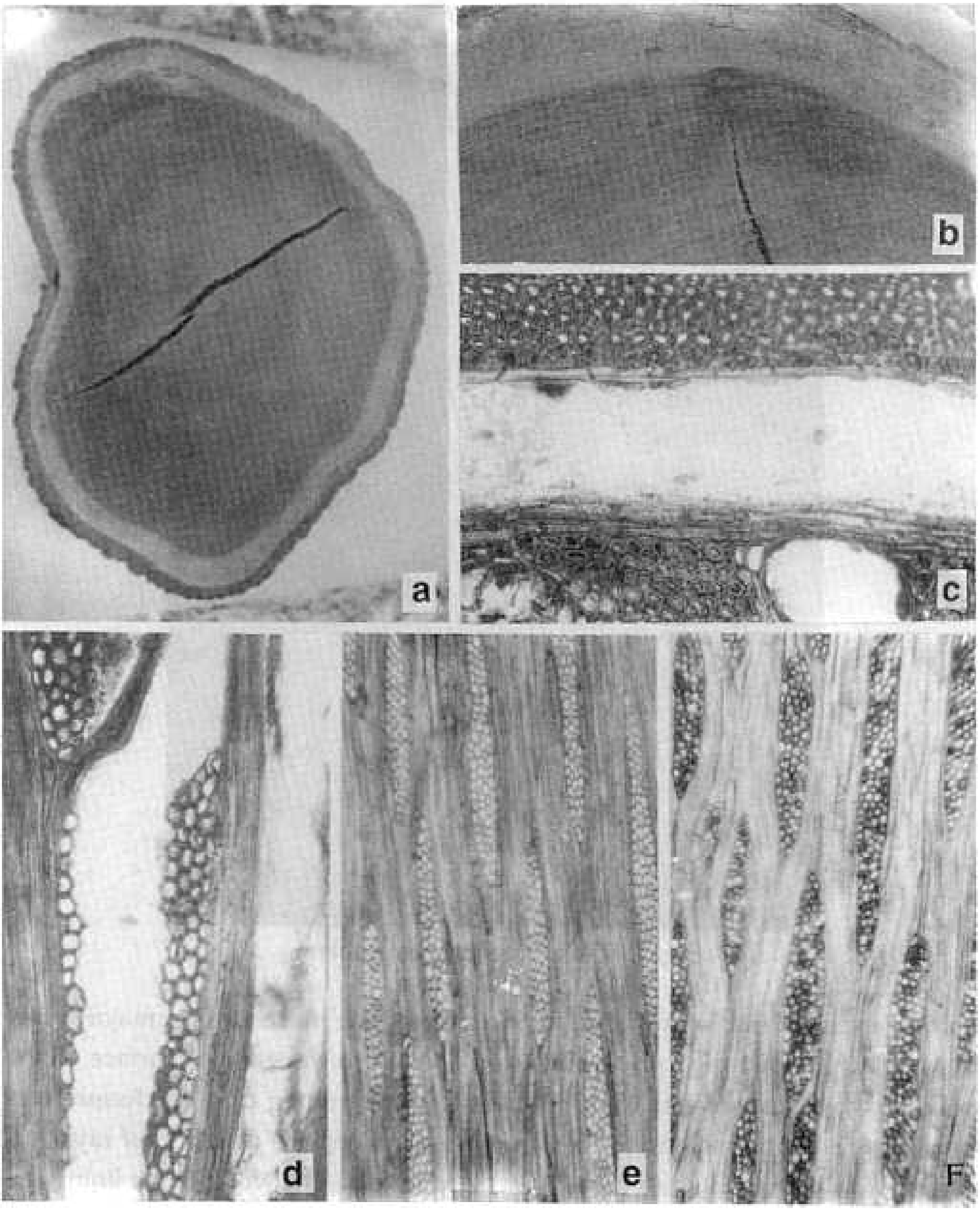

Fig. 3. a. Cross sectional view of a disc cut from a blister affected tree to show the radial shake. b. A portion enlarged to show the discoloration at the radial extremity of the shake. Note the unevenness of rings at this portion. c. Cross section showing the split along the rays. X 120. d. Tangential section to show the splitting through middle lamella of ray cells. X 135. e. & f. Tangential sections showing the common variation in ray morphology between samples. X 70.

irregular; thus indicating disturbance in the normal xylogenesis. The discolouration of the wood could have been caused by the fluid, as the normal shakes in the teak wood does not cause any discolouration. Serial crosscutting of the affected stem further showed that the horizontal dimension of the shake was maximum at the level of the opening and it tapered towards either ends of the stem with the increasing distance from the blister opening. The vertical extent of the shake ranged from 1 to 3 m.

Tangential sections of wood across the shake further confirmed that the split occurred through the rays (Fig.3c and d). The separation was mainly through the middle lamella of ray cells and fibers although a few cells were torn apart in the process. The ray cells and fibers lining the blister cavity had normal structure and showed no signs of any developmental change or histolysis (Fig.3 d). The fact that majority of these dells were metabolically inactive since they were within the heartwood boundary further rules out the possibility of active secretion by these cells. Nevertheless, it is quite possible that considerable amount of heartwood extractives leached out into the fluid accumulated in the blister cavity imparting it a characteristic odour and an yellow tinge.

Occurrence of shakes on standing trees is not an uncommon phenomenon; they have been reported in teak also (Butin and Shigo, 1981). Both radial (heart shake) and tangential shakes (ring shake or cup shake) have been reported in a number of hardwoods (McGinnes, 1965, 1968; Imamura *et al.,* 1974; Butin and Shigo, 1981). Obviously, these are the planes along which wood is generally weaker in mechanical properties and likely to fail under stress. One possible cause of shakes in living trees is said to be growth stresses (Kubler, 1987; Pansin and de Zeeuw, 1980). On the other hand, a number of studies have emphasised that injury to the standing trees and the decay resulting thereby, can initiate the production of shakes (Shigo, 1972; Butin and Shigo, 1981). However, in the present investigation the radial shake in teak was not connected with other wounds as revealed from serial cross sections of affected stems. The affected trees were otherwise sound and vigorous and were devoid of branch stubs or decay columns originating from root zone. Thus injury is unlikely to be a causal factor of water blister. The discolored wood adjacent to the shake is probably the result of the injury caused when the split develops in the tree and not the cause of the split.

Oaks, beech, teak and many other hardwood species in which radial shakes have been reported are timbers having comparatively large multiseriate rays. Thus, in order to examine whether ray tissue differs appreciably between the normal and affected trees of teak a comparison of ray width and seriation was made. It was found that there was no consistent difference. The variation in ray width often noticed between the samples (Fig. 3 e and f) was found to be localised and related to cambial dynamics, position of the sample in the tree, and the disposition of the growth rings. Therefore, these anatomical parameters which have a direct bearing on the strength of the wood across the grain fail to explain why some trees alone develop a shake, and not others.

Anatomical examination of the wood tissue at the radial extremity of the shake indicated that the split often extended up to the cambial zone either during or at some point of time after its formation. Due to cambial damage, the wood produced subsequently had a break ring at this part of the growth rings and the bark had a shallow longitudinal groove on its outer surface. Presence of such a groove on the bark could thus be a reliable external indicator of a radial shake in a standing tree. It could also approximately indicate the longitudinal extent of the shake within the affected stem. Similarly, the number of rings produced after the earliest discontinuous ring could give approximate age of the blister. It was further evident that the tree took an year or more to re-establish the continuity of cambium to produce normal wood thereafter. The alignment of the rings indicated that the continuity of cambial cylinder was established through excessive growth at the flanks of the injured cambium, which gradually minimised the gap and brought the cambia close together. This type of wound closure by compartmentalisation (Shigo, 1985) common to woody dicots and conifers sealed considerable portion of the radial periphery of the blister cavity leaving only a small slit through which the liquid oozed out.

The nature of the split gives some indication that growth stresses have some role in the development of water blister. The shake of the blister occurred mostly at the basal part of the stem which is generally considered to be the region of maximum stresses. Further, the shake always progressed from the centre and occasionally there was a smaller split, in some affected trees, nearly perpendicular to the major split. This characteristic type of splitting is commonly found in shakes induced by growth stresses. It is said that since a shake releases only the stresses in the nearby wood, a second shake develops almost at right angles to the first, to form a simple star shake (Kubler, 1987). However, to confirm the role of growth stresses in the development of water blister in teak actual measurement of stresses is necessary. This requires designing or refinement of appropriate methodology that is suitable for quicker and sensitive measurements of a large number of trees. Similarly, studies are also necessary to examine the role of wind-induced additional stresses in causing radial shakes as the trees on riverbanks are more directly exposed to wind than other trees in a plantation.

It is often said that water blister does not cause serious loss of wood. It is true that the loss is only minimal if assessed in terms of volume of the lumber recovered. Shakes do not appreciably reduce the lumber recovery but to exclude them the lumber has to be sawn into narrower, less valuable pieces (Kubler, 1987). This means that the loss is serious in terms of quality often amounting to rejection of such timber for high quality veneer, boards or turnery stock.

3.2. Fluid Exudation

The dynamics of the fluid flow from the blister was studied to understand the physiology of this peculiar formation in the teak tree. Fig.4 shows the fluid flow monitored daily for 12 months starting from June 1989 from affected trees at Peechi and Nilambur. The results show the similarity in the behavior between the trees in Peechi and the trees in Nilambur which are 140 km apart. The higher volume flow noticed in Peechi trees during December to January is due to the opening of an irrigation canal 20 m. uphill from the experimental trees. The pattern of flow has been found in accordance with soil water availability which can be noticed from both the rainfall recordings and the soil moisture measurements (Fig.5). The flow has been maximum during July to October, when the soil moisture is also maximum. This is mainly because of the operation of the two monsoons in Kerala during these months. The teak trees in the experimental plots started shedding their leaves by the beginning of November and they were in the leafless stage till the middle of March. It may be seen from the results shown in Fig.6 that even leafless trees show enhanced exudation when the soil water is not limiting. Although the monsoon started in June, it took nearly a month to show the enhanced exudation. This may be due to the slow penetration of water into the deeper layers of soil. It has been shown that major portion of absorbing roots

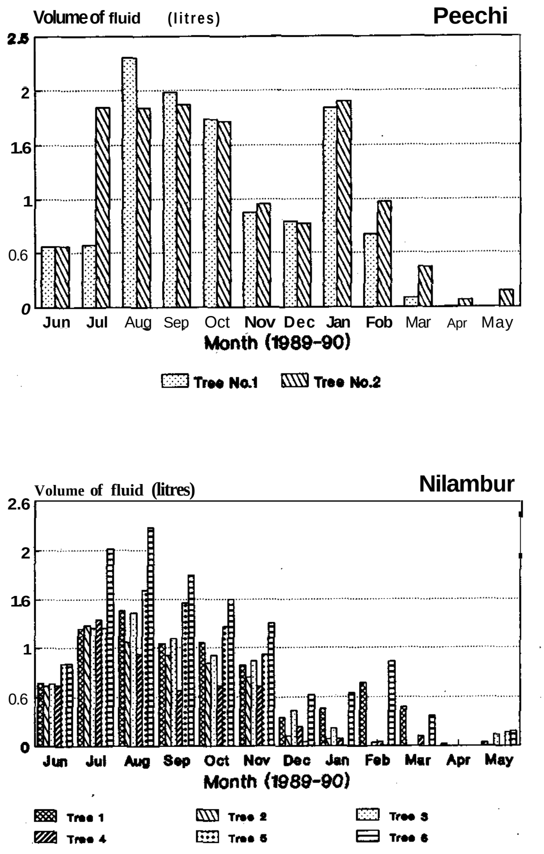

Fig. 4. Volume of fluid collected from blister affected trees at Peechi and Nilambur.

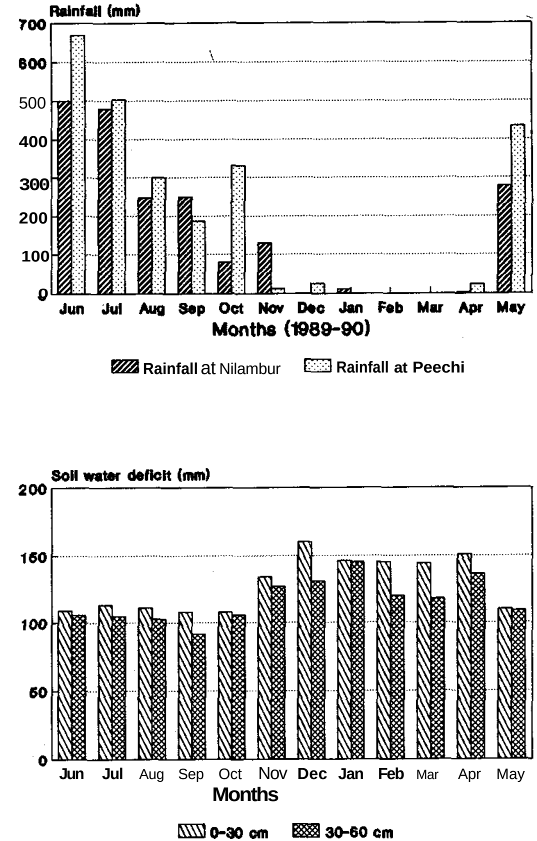

Fig. 5. Monthly rainfall and soil water deficits in the blister affected areas.

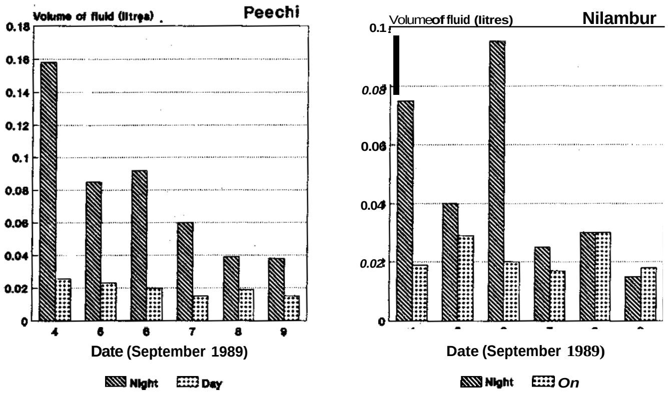

Fig. 7. Volume of fluid collected during day and night separately from teak trees affected with water blister at Peechi and Nilambur

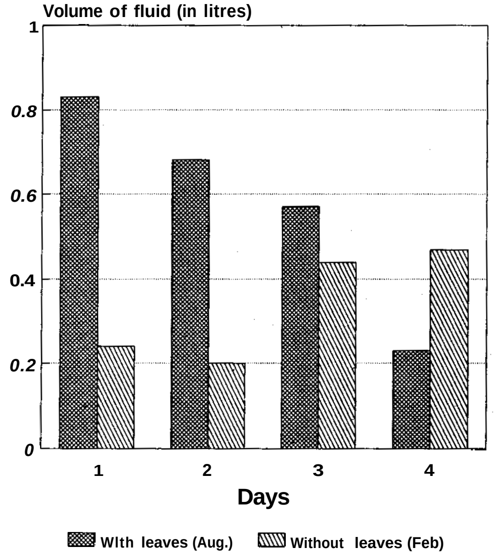

Fig. 6. Volume of fluid collected from affected trees during leafy and leafless stages.

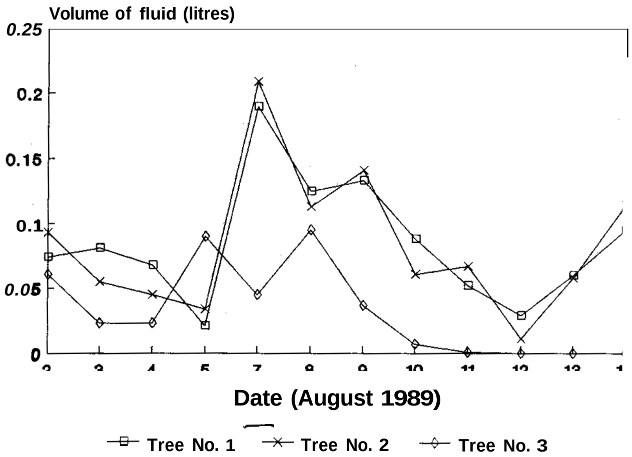

Fig. 8. Effect of stem irdling on the flow of fluid from blister affected trees (tree numbers 1 2 are controls and tree number 3 was girdled on 7 - 8 - '89)

are distributed within 0-60 cm layers of the soil (Alexander *et al* 1981). A slight increase in volume flow noticed in Nilambur trees during February and March is probably due to the summer showers. Between tree comparisons are not meaningful in this study because the volume flow was probably related to the age and size of the cavity inside the trunk.

From the type of fluid flow noticed seasonally, it may be assumed that the flow is basically correlated with root pressure activity. Root pressure is explained as a standing osmotic flow in which salt release to the xylem provides the osmotic pressure for water flow (Anderson ***et al.***, 1970). The equation for this flow is given as

$$J_V = K(\psi_{si} - \psi_{so}) \text{..........(1)}$$

where J_V is the exudation flux, ψ_{si} is the solute potential inside the root cells, ψ_{so} is the solute potential outside and K is a hydraulic constant. Accordingly root pressure will be maximum when the roots are surrounded by more water. This could be the reason for the higher exudation rate from the blisters during the rainy season or when the water is abundant in the soil. However, the root pressure is not as simple as that explained by the equation shown above. Diurnal rhythm in the flow rate exhibited by a detopped root shows that it can be also influenced by temperature, respiration and pressure (Milburn, 1979).

Fig7 shows the diurnal and nocturnal variations in flow rate exhibited by the affected trees in Peechi and Nilambur. Both the figures show the operation of a diurnal rhythm in the flow rate with more fluid flowing through the night than day time. This is very similar to the diurnal flow observed in detopped plants (Milburn, 1979).

The exudation of some quantity of fluid in the leafy stage also indicates that the blister is not getting into the transpiration stream. Since the xylem is mostly under negative pressure during day, the possibility for the blister fluid to enter the tranpiration stream exists.

3.3. Girdling experiments

From some of the observations in the previous paragraph it may be reasonably assumed that the blister fluid is being accumulated as a result of root pressure. However, the pathway of loading the root pressure fluid into the blister cavity is to be found out. One of the affectedtrees already under observation was girdled for this purpose by removing the bark and sapwood just above the ground level. Fig.8 shows the flow of fluid from this tree before and after girdling. It can be seen that the fluid flow from the blister did not stop suddenly, but came to a stop gradually. This probably shows that the loading of the root pressure fluid does not occur in the trunk portion, but rather below. The complete stoppage of the flow four days after girdling would be the result of root disfunction. In the present study we were unable to point out the exact location where the fluid enters the blister cavity. The cessation of the blister flow after girdling certainly shows that the filling of the blister cavity is not by simple physical phenomena, but rather a physiological phenomenon is involved. It is possible that the root pressure pushes the fluid into the cavity at the base of the crevice in the trunk.

The girdled tree started showing symptoms of wilting in a week and later it dried up. No further exudation of fluid from its blister was noticed.

3.4. Physico-chemical properties of blister fluid

Table 1 shows the physical properties of the blister fluid collected by the method described above. The fluid was collected at different months to see if there were variations in their physical properties. However, the variations were found to be insignificant.

Table 1 shows the analysis for some of the inorganic cations in the fluid. The divalent cations Ca^{++} and Mg^{++} are present in incredibly high quantities, contributing to the high osmotic pressure of the fluid. The analysis for Carbon, Hydrogen and Nitrogen yielded 0.9%,10.2% and 0.0% respectively.

To understand the nature of the blister fluid, it is interesting to make some comparative study with other plant fluids like xylem fluid, phloem sap, latex, etc. Such a comparison is presented in Table 1.

Table 1. Chemical properties of teak blister fluid in comparison with xylem sap, phloem sap, and latex from other plants

Substances	Blister fluid	Xylem sap*	Phloem sap'	Latex$
Sodium (mol m^{-3})	6.0	2.0	2.0-12.0	3.0
Potassium (mol m^{3})	3.0	5.2	58.9-1 12.8	89.0
Calcium (mol m^{-3})	35.0	4.7	0.5-2.3	2.6
Magnesium (mol m^{-3})	93.0	1.4	4.5-5.0	39.0
Phosphorus (mol m^{-3})	NA	2.2	14.0	NA
Sulphur (mol m-3)	NA	1.4	4.3	NA
Chloride (mol m^{-3})	NA	1.8	3.9-8.9	80.0
Phosphate (mol m^{-3})	NA	NA	7.6-27.9	3.5
Sulphate (mol m^{-3})	NA	NA	25.8	NA
Nitrate (mol m^{-3})	NA	NA	ND	11.2
Malate (mol m^{-3})	NA	NA	5.2-8.8	NA
Sucrose (mol m^{-3})	ND	ND	233-310	ND
Reducing sugars	ND	NA	ND	ND
Amino compounds(ppm)	NA	283	10808	NA
PH	7.1-7.6	5.6-5.9	7.8-8.2	4.8-5.0
Osmotic pressure (MPa)	0.63-0.69	NA	1.41.5	0.7
Dry matter (mg ml^{-1})	NA	1.1-1.2	100-125	NA

NA = Not analysed; ND = Not detected +Hocking, 1980;* Smith & Milburn, 1980; Hocking, 1980; Komor *et al.*, 1989
$ Baker et al., 1990

Note : The above table is not presented for any direct comparisons because the other fluids are not from teak. However, it is believed that since blister fluid is a relatively unknown fluid, the above comparison will give some idea to the readers on its relative cornpositon.

From the comparison it is clear that most plant fluids are acidic except the phloem sap which is slightly alkaline. The blister fluid shows a neutral pH with a tendancy towards the alkaline range. The osmotic pressure of the blisterfluid is approximately 1.0 MPa which is close to the value of phloem sap. However, in the phloem sap, most of the osmotic pressure is contributed by the sugars, whereas in the blister fluid the inorganic ions contribute to the solute potential.

It may be seen that the inorganic cations present in the xylem sap and the blister fluid are the same although there is immense variation in their quantities. When the osmotic pressure of xylem fluid is ca. 0.01 MPa, the blister fluid is several orders of magnitude higher. It is also interesting to note that when the pH of the xylem fluid is acidic, the blister fluid shows a more or less neutral nature with a slight alkaline tendency.

As described in some of the following paragraphs, the problem of water blister is more prevalent in plantations raised on river banks. Hence it was thought that due to the high water table in these localities, the root system would be subjected to much anaerobic conditions and blister formation could be a manifestation of the plant's reaction. However, the analysis of the blister fluid for functional groups like phenolic hydroxyl ($FeCl_3$ test) or aldehyde group (2,4-DNP test) did not reveal any positive result.

While the blister is exuding through the hole, frequent occurrence of bubbles have been noticed. At times, when no fluid is coming out through the tube, numerous bubbles alone are seen passing through the tube. When these bubbles are led through clear calcium hydroxide solution, it changed into a milky white precipitate indicating the presence of carbon dioxide. There could be several other gases present in the system, we have not made any further analysis of the gas.

3.5.Plantation survey

Table 2 presents the frequency of water blister problem in a teak plantation at a river bank in Nilambur. By examining a few quadrats it is apparent that the prevalence of the blister can be as high as 30%, within 50 m of the river bank. As one moves away in a transect the frequency of the blister affected trees gets reduced. Beyond the 350 m mark from the river bank, the blister problem was negligible.

Table 2. Percentage of blister affected teak trees in a plantation at Chaliarmukku, Nilambur

Distance from the river (m)	Percentage of affected trees Transect 1	Transect 2	Transect 3
0-50	25	22	30
50-100	**0**	25	10
100-150	8	7	10
150-200	6	3	12
200-250	9	**7**	13
250-300	8	5	14
300-350	0	3	5

A distance of 100 m was given between two transects.
• Teak interplanted with Mahogany was encountered in this quadrat

From the survey, it becomes apparent that blister problem has some relation to the proximity of the trees to the river. In Peechi where the same problem was noticed, the trees were located downhill an irrigation canal which operates intermittently in summer months. We could not locate a single blister affected tree uphill the canal. This raises the question whether the problem is the result of abundant water in the soil during the leafless stage of the tree. As well known, teak is a deciduous tree and is in a leafless stage in the experimental site from November to beginning of March of the following year. It is reasonable to assume that leafless trees require very little water to carry out the routine metabolism. If excess water is supplied to such trees, it could upset the water transport metabolism, giving rise to high root pressure. When the root pressure fluids accumulate in small crevices of the trees resulting from shakes they develop pressure and causes the crevices to widen. If we assume that the above hypothesis is correct, then the only problem is to explain how such incredibly high salt concentration has come in the blister fluid. This high concentration can build up a lot of osmotic pressure within the crevices, creating more damage to the tree trunk. The question why all the trees on the river bank are not affected also remains open.

4. CONCLUSIONS

4.1. Water blister is a problem restricted to the main tree trunk of the teak trees. Morphologically similar structures found on the branch of some teak trees are functionally different.

4.2. Blister formation is not fatal to the trees. However, it affects the quality of timber extracted.

4.3. The percentage of trees affected with the blisters are certainly high near the river banks, reservoirs and irrigation canals. However, isolated trees can be found in other areas.

4.4. The crevice inside the tree trunk is always caused by a radial shake in at least 25 trees examined. This split extends across the heart and sapwood reaching upto the cambium.

4.5. The blisters exude a straw coloured fluid throughout the year. The quantity exuded is mainly depended on the soil water availability.

4.6. The fluid exudation from the blister follows a diurnal rhythm similar to that of root pressure exudation. However, the solute concentration of the blister fluid is several orders of magnitude higher than the root pressure fluid. The relatively high osmotic pressure of the blister fluid is contributed by inorganic ions.

4.7. The chemical composition of the blister fluid is comparable to the xylem fluid. However, its concentration and pH are dissimilar. The inorganic cations show an extremely high concentration in the blister fluid.

REFERENCES

Alexander, T.G.; Balagopalan, M.; Thomas P. Thomas and Mary, M.V. 1981. Properties of *soils under teak*. KFRI Research Report No. 7:13 p.

Anderson, W.P.; Aikman, D.P. and Meiri, A. 1970. Excised root exudation: A standing gradient osmotic flow. *Proc. Royal Soc. London Ser. B. Biol. Sci.* 174 445-458.

Baker, D.A.; Kallarackal, J. and Milburn J.A. 1990. Water relations of banana. II Physicochemical aspects of the latex and other tissue fluids. *Aust. J. Plant Physiol.* 17 69-77.

Bakshi, B.K. and Boyce, J.S. 1959 Water blister in teak. *Indian For. 85:589-591.*

Butin, H. and Shigo, A.L. 1981. Radial shakes and 'frost cracks' in living oak trees. *USDA Forest Service Res. Pap NE-* 478: 21p.

Imamura, H., Nomura, K., Hibino, Y. and Ohashi, H. 1974 A new type of flavanol in the 'shake' of merbau wood. *J. Jap. Wood Res. Soc.* 20:143-144.

Johansen, D.A. 1940 *Plant Microtechnique*. McGraw - Hill, New York.

Hocking, P.J. 1980. The comparison of phloem exudate and xylem sap from tree tobacco (*Nicotiana glauca* Grah.) *Ann. Bot.* 45:644-643.

Komor, E.; Kallarackal, J.; Schobert, C. and Orlich, G. 1989. Comparison of solute transport in the phloem of the *Ricinus communis* seedling and the adult plant. *Plant Physiol. Biochem.* 27:545-550.

Kubler, H. 1987. Growth stresses in trees and related wood properties. *For. Abstr.* 48:131-189.

Lushington, P.M. 1896. Report and working scheme of the Nilambur teak plantations.(c.f. Bakshi and Boyce 1959).

McGinnes, E.A. Jr. 1965 Extent of ring shakes in Missouri oaks. *For. Prod. J.* 15:190.

McGinnes, E.A. Jr. 1968 Extent of shake in black walnut. *For. Prod. J.* 18:80-82.

Milburn, J.A. 1979. *Water Flow in Plants*. Longman, London.

Panshin, A.J. and de Zeeuw, C. 1980 *Textbook of Wood Technology* IVth Ed. McGraw-Hill, New York .

Shigo, A.L. 1972. Ring and ray shakes associated with wounds in trees. *Holzforschung* 26: 60-62.

Shigo, A.L. 1985. Compartmentalization of decay in trees. *Sci.Am.* 252:96-103.

Smith, J.A.C. and Milburn, J.A. 1980. Osmoregulation and the control of phloem-sap composition in *Ricinus communis* L. *Planta* 148: 28-34.