Detailed investigations were carried out on the structure, distribution and formation of tension wood in *Hevea brasiliensis* (wild. ex. Adr. de Juss.) Muell. Arg., with the main objectives: (1) extent of tension wood with special reference to clonal variability; (2) distribution pattern and directional effect on tension wood formation in mature trees; (3) extent of tension wood formation in immature plants; (4) tension wood formation in tissue culture plants and budgrafted plants; (5) role of tension wood in wind damage; (6) distribution and proportion of tension wood in tapped and untapped zones; (7) structural modification of wood elements during tension wood formation and (8) identification and demarcation of tension wood in rubber wood logs through macroscopic staining. The study also aimed at identification of factors affecting tension wood formation in the immature growth phase.

Data were recorded on the distribution pattern, proportion and structure of tension wood in mature trees of four clones *viz.* Tjir 1, GT 1, RRIM 600 and RRII 105, selected from the Central Experiment Station of Rubber Research Institute of India at Chethackal, Ranni. Data were also recorded on the proportion of tension wood in immature growth
phase in ten month old bud grafted plants of 10 clones viz. Tjir 1, Gl 1, GT1, PB 5/51, PB 217, PB 235, RRIM 600, RRIM 623, RRIM 703 and RRJ 105.

Data recorded on tree leaning, growth eccentricity and proportion of tension wood at different height levels of the tree were correlated to ascertain the directional effect on tension wood formation.

Eight month old tissue culture plants and budgrafted plants of the clone RRJ 105 were selected to compare the extent of tension wood formation. Mature trees of RRJ 105 were selected to study the role of tension wood on wind damage. An eco-friendly macroscopic staining procedure, using a combination of Zinc Chloride, Iodine and Potassium iodide, was developed for the easy identification and demarcation of tension wood zones in rubber wood logs.

Four month old seedling plants were used to investigate the causative factors responsible for tension wood formation. Budgrafted plants of the clone RRJ 105 at the age of eight months were used to study the effect of growth regulators on tension wood formation.

Important structural characters recorded were proportion of tension wood, dimensional variation of wood elements, analysis of pores and rays in both normal and tension wood zones. Histochemical localization of starch, lipids, total proteins, cellulose and lignin were also attempted in normal and tension wood zones.

Experiments on the factors affecting tension wood formation includes (1) angle of leaning; (2) angle of leaning with defoliation; (3) gravitational stimulus; (4) exogenous
application of growth regulators such as Indole-3-acetic acid (IAA), 2-3-5-
Triiodobenzoic acid (TIBA) and Gibberellic acid (GA3) on inclined and vertical axes.

The data generated were subjected to detailed statistical analysis viz. Analysis of
variance, (ANOVA), paired t-test and correlation coefficients.

In mature trees, compact arcs of tension wood were formed in both the vicinity
of the pith and peripheral regions of the tree trunk as white wooly lustrous zones. The
proportion of tension wood in all the four clones ranged from 16.75 to 26.49%. The
variation in the quantity of tension wood formed at different height levels of the trunk
was significant only in RRIM 600. However the variation between clones was not
statistically significant. The G-layer of tension wood fibres was well developed in all the
clones and showed partial or total detachment from the adjacent walls.

The proportion of tension wood in 10 clones at the juvenile phase ranged from
14.32 to 49.97%, and the variation among the clones was significant. The study revealed
that the plants at the juvenile stage is more flexible to tissue modification leading to
tension wood formation in *Hevea brasiliensis*.

The correlation studies revealed that the tree height, angle of leaning and pith
eccentricity did not play any significant role in tension wood formation in the mature
trees of *Hevea brasiliensis*. The proportion of tension wood was significantly reduced in
the tapped zones of three clones viz. Tjir 1, RRIM 600 and RRII 105 than the untapped
zone, whereas in GT 1 the trend was just the reverse. The formation of tension wood was
relatively high in tissue culture plants (27.49%) than the budgrafted plants (12.75%) in
the immature growth phase.
Quantitative analysis of tension wood in trunk snapped trees due to wind, revealed that the proportion of tension wood was significantly higher in the zone of wind break compared to the zone below and above the point of break. It may be assumed that the stress exerted by wind blow leads to fibre buckling in the lower side of the inclined trunk followed by the rupture of tension wood fibres in the upper side.

Tension wood zones turn brownish pink in Zinc-chloro-iodide by the surface application on freshly sawn wood discs. The colour specificity was not observed when this formulation was applied on dried and fungus infected wood discs. Hence this macroscopic staining procedure could be used effectively for the easy identification and demarcation of massive zones of compact tension wood, during primary wood processing such as selective/differential sawing operations to eliminate tension wood.

The length of tension wood fibres was significantly lower than normal wood fibres in all the clones studied. The variation in fibre length at different height levels within trees and between clones was not significant. Width of tension wood fibres was significantly higher than that of normal wood fibres and the variation at different height levels and between clones was significant. The wall thickness of tension wood fibres was significantly higher than that of normal wood fibres. Variation in length of vessel elements with respect to tree height was not significant whereas between clones, it was significant. The variation in the width of vessel elements at different height as well as between clones was not significant. Frequency of pore was reduced in the tension wood zone than normal wood zone but the variation was significant only in RRII 105. The total area occupied by pores per unit C.S. area of wood was also reduced in the tension wood zone and the difference was significant only in GT 1. Reduction in the average
area of pores in tension wood zone was observed in GT 1 and Tjir 1 while in RRII 105 and 600, the trend was just reverse. The frequency and height of rays was increased in tension wood zone than normal wood zone and the variation was not significant. Width of rays was lower in tension wood zone than that of normal wood zone in all the clones and the difference was significant in GT 1, RRIM 600 and RRII 105. The height/width ratio of rays was higher in tension wood zone than normal wood zone and the variation was significant in all the clones except Tjir 1.

The total number and area occupied by starch grains in the parenchymatous tissues per cm$^2$ C.S area was reduced in tension wood zone up to 45% and 26%, respectively compared to normal wood zone. The average area of grains was increased in tension wood zone up to 26.5% than normal wood zone. Localization of lipids and total proteins was negligible in both normal and tension wood zones. G-layer of tension wood fibres was cellulosic and un lignified. The fibre wall except the G-layer of tension wood fibres showed low level of lignification in contrast to the normal fibres.

Seedlings bent at 90$^\circ$ showed maximum tension wood formation (39.6%) and minimum (23.75%) at 45$^\circ$ inclination. Tension wood was formed in the upper side of the axis bent at 90$^\circ$ and 135$^\circ$ whereas its formation was restricted on the lower side of the axis bent at 45$^\circ$ from vertical.

The formation of tension wood was reduced up to 50-75% in defoliated seedlings bent at 45$^\circ$, 90$^\circ$ and 135$^\circ$ from vertical probably due to the inadequate supply of photosynthates required for G-layer formation.
Dense mass of tension wood was formed on the upper zone of the upper and lower parts of the loop under tensile and compressive stresses respectively, indicating the role of gravity on tension wood formation. The causative factors responsible for tension wood formation on the outer zone of the lateral part of the loop may be attributed to the transmission of tensile/compressive stresses from the upper and lower part of the loop.

Application of IAA at 500 ppm concentration on the upper and lower halves of the inclined and decapitated plants inhibited tension wood formation. Similar inhibitory effect on tension wood formation was also observed through the lateral application of IAA on vertical plants. However, application of IAA through bark incision on vertical plants induced tension wood formation. Application of TIBA on the upper and lower halves of the decapitated bent plants also suppressed tension wood formation, but its lateral application in vertical plants induced tension wood formation. Application of GA\textsubscript{3} induced tension wood formation in the upper and lower halves of the decapitated bent plants.

The present investigation indicated that the mechanism of TW formation *Hevea brasiliensis* is related to the influence of various factors at various levels and intensities as follows:

The movement of canopy brought about by various factors like wind, gravity, phototropism etc. makes the axis tilted. The tilted axis generates various internal/external stresses and under this stress condition the rate and duration of cambial activity may vary. Leaning also leads to the variation in the level of hormones/enzymes in the
upper and lower parts of the bent axis. Due to the changed hormonal level the
differentiation and development of wood tissues and metabolism of food reserves may
alter and the variation in the metabolism causes changes in the cell wall formation (the
un lignified cellulosic G-layer ).