Of the ten species of the genus *Hevea*, *Hevea brasiliensis* (Willd. ex Adr.de Juss.) Muell. Arg., the para rubber, is the only species that is cultivated commercially for natural rubber production. The primary center of origin of *Hevea brasiliensis* is the Amazon basin and adjacent areas of Brazil. It has also flourished in certain other countries such as Bolivia, Peru, Ecuador, Columbia Guyana, Surinam and Venezuela.

History says that Sir Henry Wickham, the father of Natural Rubber, made a collection of rubber seeds from the confluence of River Tapajos and the Amazon (Schultes, 1977). Of the 7000 seeds he sent to Kew Garden, London in 1986, 2700 germinated. From these 1919 seeds were sent to Ceylon of which 90% survived and out of 18 seeds sent to Java only two survived (Dijkman, 1951). Another consignment of 22 seedlings was sent to Singapore in 1877 and all of them was reported to have survived. These initial planting materials together with other rubber trees grown in Ceylon were the foundation on which the Malaysian rubber industry is based (Barlow, 1978). The consensus on the history of the source of planting material to the South East Asian rubber plantation is that it had originated from the Wickham collections and from these, rubber cultivation spread to all other Asian countries (Schultes 1977; Simmonds, 1989).
In India, rubber cultivation was started in 1878, in Nilambur, Kerala State, as a forest crop, using the planting materials brought from the Royal Botanical Garden, Ceylon (Petch, 1914; Dean, 1987). However the first commercial rubber plantation of rubber was started in India by European planters in 1902 at Alwaye. The subsequent increase in area under rubber plantations is mainly attributable to the enterprise of a large number of Indian proprietary planters belonging to the former native states of Travancore and Cochin.

1.1 Rubber Tree – An eco-friendly potential source of timber

Rubber tree (Hevea brasiliensis) is a perennial hardwood species belonging to the family Euphorbiaceae, growing to a height of about 30 m. The tree has a straight trunk of 3 to 4 m height, attaining 70 – 110 cm diameter at breast height with profusely branched dense canopy (Reghu, 2002). The trees raised from seedling population show a higher girth compared to those raised from bud grafted planting materials. It has been estimated that at the age of 27 – 30 years, a seedling tree gives 1 m³ and budded tree gives 0.57 m³ timber at the time of clear felling, of which 60% is trunk wood and 40% is branch wood (Haridasan and Sreenivasan, 1985; George and Joseph, 2002). Over the time, bud grafted trees became common in all the major rubber producing countries as the primary objective was to obtain higher level of latex yield than timber. This development had serious implications on the yield of timber per tree compared to the availability during the early times, as the volume of the timber is directly proportional to the girth of the rubber tree.

The prevailing unilateral focus on latex production is at stake in view of the biological and agroclimatic constraints on enhancing productivity of natural rubber (NR) and the growing market uncertainties (George, 2002). In this regard, it will be contextual to examine the latex and timber yield potential of prominent clones developed in Malaysia as
'latex - timber' and 'timber - latex' clones so as to draw certain guidelines specific to the Indian context (Viswanathan and et al., 2002). The reported higher timber yield potential of the latex - timber clones in 14 year old planting in Malaysia varied from 0.81 to 1.87 m³ per tree (MTIB, 1998). The prominent clones identified for higher latex and timber production are from the PB 200 and PB 300 series and RRIM 900 and RRIM 2000 series (Lotfy et al., 1995). Of the RRIM 900 series, 12 clones showed potential for timber production with an average timber volume of 1.09 m³ per tree at the age of 21 years and in RRIM 2000 series, eight clones were identified having greater timber potentiality of 1.23 m³ per tree at the age of 17 years (Ong et al., 1995; MRB, 2003).

The decrease in the area of forests available for logging, shortage of other non-forest traditional timber species etc., led to the exploitation of the potentials of the easily available plantation timber like rubber wood. The distinct features of rubber wood compared to other alternative timber species are:

i. it is a by-product of rubber plantations

ii. it is inexhaustible in supply as rubber plantations are maintained on a sustained crop rotation of 25-30 years and

iii. its effect on reducing pressure on tropical forests enabling bio-diversity conservation, and the reported agronomic sustainability and carbon sequestering effect (George and Joseph, 1993; 2002; George, 2002).

Since rubber is grown as renewable plantations, the eco-friendly nature has become an advantage in promoting rubber wood products in major developed countries, where the “Green movement” is very strong. This led to the enhancement of rubber wood utilization and replacement of other non-renewable forest timber species to a great extent. The total
production of rubber wood is sufficient to meet the global timber requirement to a certain extent. Good quality rubber wood products in the form of furniture, furniture components, treated and processed wood are being exported from major rubber growing countries, particularly from Malaysia to the developed countries like Japan, USA, UK etc.

1.2 Availability of rubber wood

Natural rubber cultivation assumes high socio-economic relevance in terms of the geographical concentration of area (87%) and production (78%) in Malaysia, Thailand, Indonesia, India and China (Viswanathan et al., 2003). In India the current estimated average production of rubber wood per hectare is 150 and 180 m$^3$ in small holding and estate sector, respectively (George and Joseph, 2002). It has been estimated that 11 million m$^3$ of rubber wood logs are available worldwide annually (ITC, 1993). The current annual requirement of timber in India comes about 40 million m$^3$ for various industrial applications, whereas the current availability of timber has been estimated to be 29.25 million m$^3$. In India, the projected availability of rubber wood was 2.1 million m$^3$ during 2001-02, of which, sawn timber suitable for secondary processing constitutes about 21%. The potential contribution of rubber wood to the timber industry in India is around 2%. Moreover, rubber wood in India has the potential to conserve more than 20,000 hectares of natural rain forests on an annual basis (George and Joseph, 2002).

1.3 Commercial utilization of rubber wood

The current annual rate of industrial utilization of rubber wood comes about five million m$^3$, of which, Malaysia accounts for two million cubic meters, followed by
Thailand (one million m$^3$) and the rest was utilized by Indonesia, China, India etc. (Viswanathan et al., 2003). In both these countries, rubber wood has become an important raw material for various wood-based industries. The industrial utilization of rubber wood in Malaysia is very efficient due to the adoption of modern technology and better management practices.

### 1.3.1 The Indian scenario

In India the industrial use of rubber wood was started only during 1950s when there was a shortage of species like *Mangifera indica*, *Polyalthia longifolia*, *Ailanthus malabaricus* etc., which were particularly used in match box and packing case industries. India's import of wood and wood products has increased from Rs.15720 million during 1997-98 to Rs. 19943.3 million during 1999-2000. Import of rough wood occupies major share (93%) in the total value of imports (DGCIS, 1998; 2000).

The major portion of rubber wood produced annually in India is not being utilized properly to meet the indigenous timber requirements. The current consumption pattern of rubber wood in India is dominated by packing case sector (56.5%), followed by plywood industry (26.5%). The secondary processing sector of rubber wood consumes only 14 percent of the stem wood produced (George and Joseph, 2002). As compared to Malaysia and Thailand, in India the narrow range of product manufacture increases the recovery loss of rubber wood particularly in the field of value addition. The major factors which retards the development of rubber wood processing industry in India were identified as (i) absence of a statutory agency to monitor and promote the industry; (ii) absence of vertical integration; (iii) lower levels of capacity utilization and value addition; (iv) shrinking supply of quality timber; (v) predominance of intermediaries and the resultant higher raw
material procurement cost; (vi) working capital shortage; and (vii) market access issues (Viswanathan et al., 2003).

1.4 Demerits of rubber wood

Rubber wood is a perishable timber and highly susceptible to biological deterioration. The high deposition of carbohydrates mainly in the form of soluble sugars and starch in the wood tissue makes rubber wood susceptible to fungal and insects attack soon after felling. This biological defect affecting the durability of rubber wood can be properly controlled by adopting appropriate preservative treatments.

Tension wood formation is the most serious natural defect adversely affecting the quality of rubber wood for specific end uses. It is a structural abnormality in wood formed by the development of unlignified or partially lignified specialized fibres called gelatinous fibres or G-fibres. The proportion of tension wood in Hevea brasiliensis may vary from tree to tree, and within the same tree, along the trunk and branches. The occurrence of tension wood restricts the versatile utilization of rubber wood for various applications. The structure, quantity and distribution of tension wood fibres reduce the physical, mechanical and strength properties of rubber wood to a great extent.

Hence to evaluate rubber tree as a potential source of timber for various end uses, the extent of tension wood formation and clonal variability has to be taken into account. As the impact of tension wood on various applications of rubber wood is unpredictable, a better understanding on the structural modifications taking place during tension wood formation as well as the causative factors responsible for tension wood formation in Hevea brasiliensis assumes significance. This would ultimately result in enhanced utilization of
rubber wood by eliminating and / or minimizing the major demerits caused by tension wood, thus facilitating further value addition of rubber wood.

1.5 Relevance of the present study

With the rapid industrialization during the 21st century, the fragile earth is put to tremendous environmental pressure. In this context, protection of natural forest has become a necessity. In the name of conserving forest we can not substitute timber with any other materials. The best and eco-friendly alternative source of timber in place of the depleting natural timber resources is rubber plantations. But substituting rubber wood in place of the depleting quality timber resources necessitate improvement of its quality and durability. It has already been proved that the biological deterioration of rubber wood can be prevented by adopting appropriate wood preservations technologies. However, considerable attempts have not been made so far to ascertain the extent and mechanism of tension wood formation in *Hevea brasiliensis* and to control its negative impact in wood based industries.

In this context a detailed investigation on the formation and structure of tension wood in *Hevea brasiliensis* with special emphasis on clonal variability has been carried out. To understand the mechanism of tension wood formation in *Hevea*, various experiments were also conducted in the juvenile growth phase. The present investigation was carried out with the following objectives:

1. Extent of tension wood formation in *Hevea brasiliensis* with special emphasis on clonal variability.
2. Distribution pattern and directional effect of tension wood formation in rubber
3. Extent of tension wood formation in bud grafted plants and tissue culture plants
4. Tension wood formation and wind damage.

5. Distribution of tension wood in tapped and untapped zones.

6. Structural studies on tension wood.

7. Histochemical studies on tension wood.

8. Identification and demarcation of tension wood zones in rubber wood through macroscopic staining.

9. Factors affecting tension wood formation in *Hevea brasiliensis*.