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# THE INTRODUCTION OF NATURAL RUBBER (*HEVEA BRASILIENSIS*) IN INDIA: A SUCCESS STORY

**Y.ANNAMMA VARGHESE AND SAJI T. ABRAHAM**

**Abstract**

The introduction and establishment of rubber tree and the development of rubber plantation industry in India is one of the most remarkable success stories in the Indian plantation sector. *Hevea brasiliensis,* indigenous to the tropical Amazon rain forests was introduced to South-East Asia by the British, who succeeded in transporting *Hevea* seeds from Brazil to Kew Botanical gardens in England with the objective of planting in the then British India. However, after the initial unsuccessful attempts, rubber was reintroduced from the Royal Botanic Garden, Ceylon during 1878-1887 and rubber cultivation in an organized scale was initiated in Kerala (Travancore) in 1902. Though initially the Indian rubber plantations industry was controlled by British companies, progressive Indian farmers had observed the advantages of rubber as a commercially viable crop, that by the first half of the century, three fourth of the rubber area was under the native ownership.

The Government of India through the constitution of Rubber Board in 1947 provided institutional support for the rubber plantation industry. The challenges before the Board were enhancement in production and productivity through R& D, ensuring remunerative returns to growers and quality enhancement of the product. The systematic research on natural rubber (NR) started in 1955 with the establishment of the Rubber Research Institute of India (RRII). The broad research priorities viz., improvement in production and productivity, reduction in cost of

production, achievement in quality competitiveness, supporting extension of rubber cultivation in non-traditional rubber growing areas through research back up, investigations on post harvest technology, product development and marketing were achieved over the years. The most outstanding contribution of RRII towards enhancement of production and productivity is the developments of the high yielding clone RRII 105, which has substantially contributed to the viability of natural rubber cultivation in the traditional rubber growing regions of India. The newly bred RRII 400 series clones (of which 5 are in the planting recommendation currently) are expected to further enhance the average productivity significantly. RRII has introduced about 5000 wild accessions resultant of the International Rubber Research and Development Board (IRRDB) expedition in the Amazon valley for broadening the original narrow gene pool and bringing in further genetic advancement in the crop. Efforts to produce tissue culture derived plants for commercial cultivation has registered significant success and the micro propagated plants are under field evaluation. Appropriate agro-technology has been evolved for rubber cultivation under sub optimal conditions prevailing in the non-traditional areas. Along with the significant strides made in yield increase, integrated approaches to reduce cost of production and improve quality of the product has resulted in the development of a functional system of Discriminatory Fertilizer Recommendation (DFR) based on soil and leaf analysis, effective plant protection schedules for major diseases and pests, suitable latex harvesting systems and appropriate processing technology for latex and dry rubber.

Thus, over the past few decades rubber plantation industry grew up so fast that now India is the fourth largest producer, fifth in area under rubber cultivation and first in the productivity in natural rubber (NR) among all the natural rubber growing countries in the world. India now produces 711650 tones of NR from an area of 5,73,000 hectares with the highest productivity of 1663 kg/ha. Rubber plantations are a source of livelihood to many of the rubber growers as 86% of them are small growers. NR plantation is a self-sustainable ecosystem, which is a renewable non-polluting and environment friendly source of elastomer in contrast to synthetic rubber manufactured from depletable petroleum resources. NR has contributed significantly to the socio-economic development of the people where it is grown in our country. The crop has a very strong future in India, considering the ever-increasing consumption of NR in various rubber-based industries especially the automobile sector besides its uniqueness as a natural eco-friendly product.

**Key words**: *Hevea brasiliensis,* Introduction, plantation development, research and development support, agro-management, processing technology, eco-friendliness

**Introduction**

The para rubber tree of commerce, *Hevea brasiliensis*, produces around 99 per cent of the world's natural rubber (NR) produced mainly from the SE Asian countries. The colonial powers were instrumental in identifying and introducing rubber as a potential plantation agricultural crop in the south East Asia to ensure an uninterrupted supply of raw material to the European rubber industries.

The NR industry owes its existence to the famous collection by Sir Henry Wickham from its native environment in the Amazon rain forests. In 1876 Wickham collected 70,000 seeds of *H. brasiliensis*. About 2,700 of these seedlings were raised at Kew, England, and 1919 of them were dispatched during 1876, mainly to Sri Lanka; a few went to Malaysia, Singapore and Indonesia (Baulkwill, 1989; Dean, 1987). In India, rubber was first received in 1878, from Sri Lanka. In India, the post independence period showed a remarkable and rapid growth in the rubber plantation sector, aided by a number of favorable factors of which the most important was the Government support channeled through the Rubber Board in the form of various incentives, research and development support for cultivation, processing and marketing. Thus rubber has grown as a strong commercially important plantation crop, with the southern states of Kerala, Tamil Nadu, Karnataka and the NE state of Tripura being the main rubber growing states.

The crop has significant socioeconomic relevance, as about a million growers are involved in the plantation industry in India, with a small grower predominance of 91% in production and 88% in total area under rubber besides providing about 350,000 jobs in the plantation sector. From an agro - ecological point of view, rubber is an eco-friendly tree species and reproduces a stable ecosystem similar to natural forest; in addition to giving high economic returns.

**The rubber tree**

*Hevea brasiliensis* belongs to the family Euphorbiaceae. Currently, a total of 10 species has been recognized in the genus *Hevea viz. H. benthamiana, H. camergoana, H. camporum, H. guianensis, H. microphylla, H. nitida, H. pauciflora, H. rigidifolia,* and *H. spruceana.*

The genus *Hevea* occupies the whole of the Amazon River basin in Brazil and extends towards south and north covering parts of Brazil, Bolivia, Peru, Colombia, Ecuador, Venezuela, French Guyana, Surinam and Guyana. All the 10 species grow in Brazil while seven are found in Colombia, five in Venezuela and four in Peru (Wycherley, 1992). *H. brasiliensis* extends about half of the range of the genus, mainly occupying the region south of the Amazon, extending to Acre, Mato Grosso and Parana areas of Brazil, parts of Bolivia, Peru, north of the Amazon to the west of Manaus as far as the extreme south of Colombia (Fig.1).

The species is now grown mainly in the tropical regions of Asia, Africa and America in countries like Malaysia, Indonesia, India, Sri Lanka, Thailand, China, Philippines, Vietnam, Kampuchea, Burma, Bangladesh, Singapore, Nigeria, Cameroon, Central Africa, the Ivory Coast, Ghana, Zaire, Liberia, Brazil and Mexico. However, the major share of total production comes from tropical Asia.

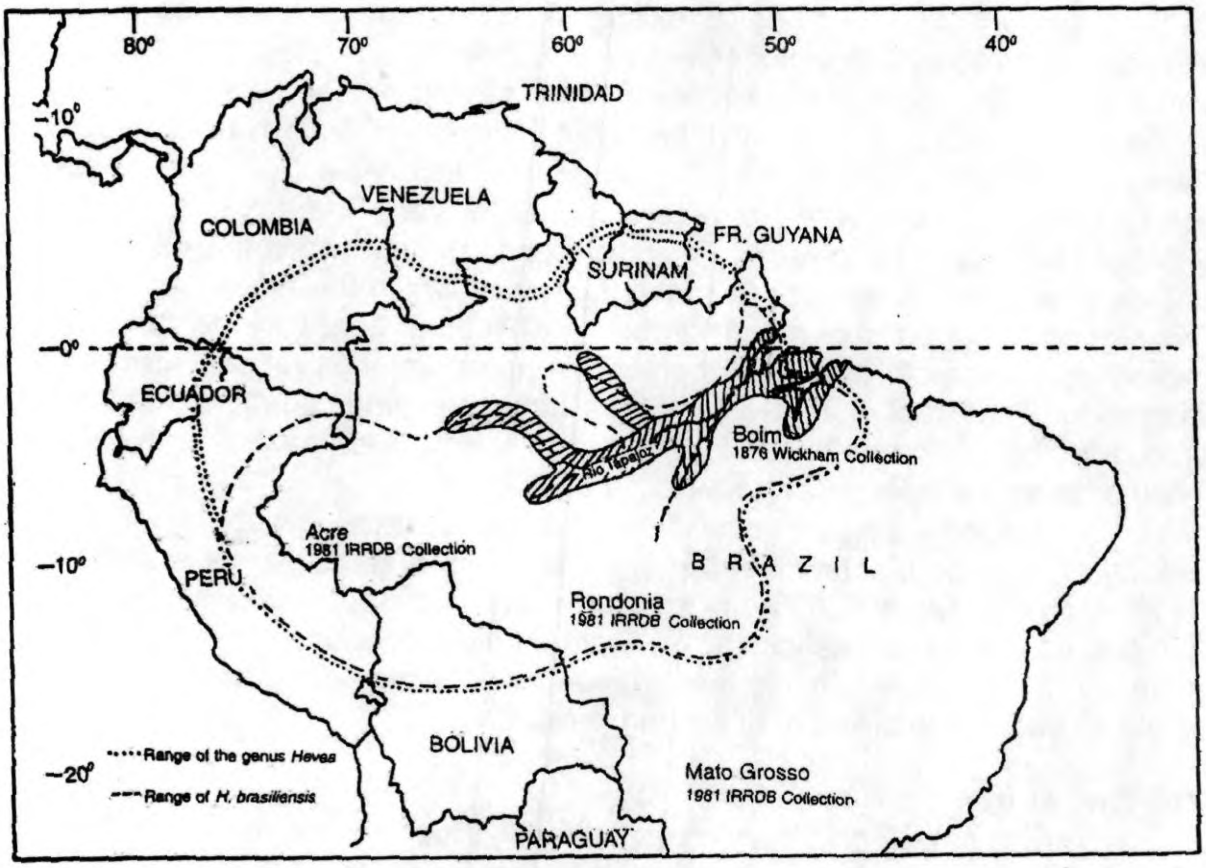


**Fig. 1. Distribution of the genus *Hevea***

## Morphology

The rubber tree is a sturdy, erect perennial, quick growing to a height of about 30 m with an economic life span of over 30 years in plantations (Fig.2). It has a straight trunk with light grey bark and the branches developed to form an open leafy crown. The leaves are arranged in groups or storeys, each storey with a cluster of spirally arranged trifoliate glabrous leaves and extra floral nectaries present in the region of insertion of the leaflets. *H. brasiliensis* and its congeners are uniformly diploids with 2n = 2x = 36 (Majumder, 1964).

*Hevea* is a deciduous tree, which sheds its leaves (wintering- partial or complete) during December - February followed by refoliation and flowering. *Hevea* is predominantly a cross pollinated species. Pollination is by insects and fruits ripen in 5-6 months after fertilization. The plant is monoecious with unisexual flowers produced in pyramid shaped panicles with numerous small male flowers and fewer bigger female flowers confined to the tip of the panicles and their branch lets (Fig.3). Ovary is tricarpellary syncarpous, which on pollination develops in to a three lobed dehiscent capsule (regma) with three large mottled seeds. Seeds contain an oily endosperm.

Fig. 2: Rubber tree

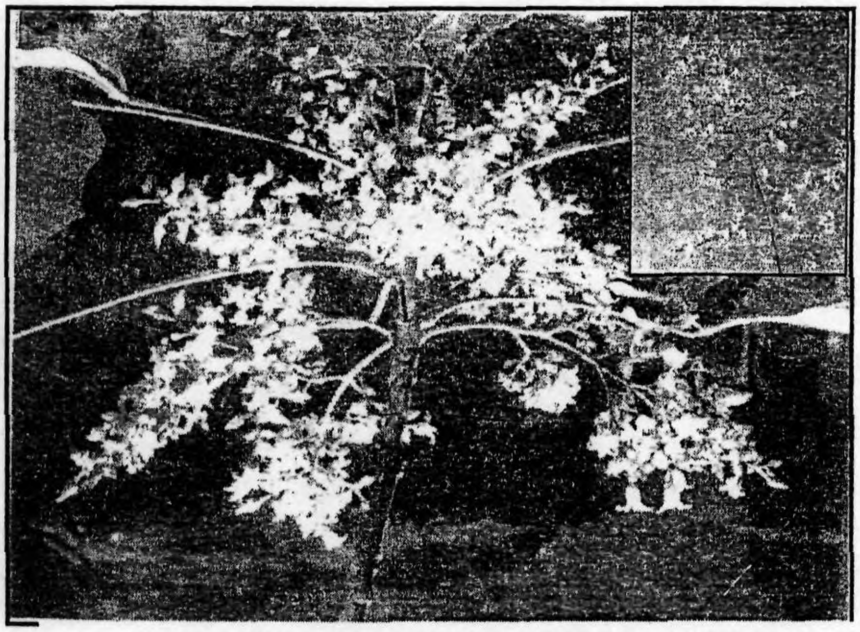

Fig. 3: Inflorescence with a single panicle (inset)

Propagation through generative (seeds) and vegetative (bud grafting) methods is possible in *Hevea*. Vegetative propagation by budding is the commercially adopted method, which results in uniform plantations. Two types of budding adopted in *Hevea* are brown budding, using vigorously growing seedlings of about one year age as stock plants with brown buds collected from mature shoots of same age as scion and green budding using three to five months old, healthy seedlings as stock and tender, green colored buds as scion. The wide spread adoption of vegetative propagation by budding, was one of the contributing factors for the rapid growth of the rubber plantations with genetically improved clones.

**Bark anatomy**

The economic product from rubber tree, latex, is contained in a laticiferous system in the bark differentiated by the activity of vascular cambium. *Hevea* bark has two distinct zones (1) outer hard bast - which is more protective in function with mostly discontinuous and non-functional laticifers and (2) inner soft bast- containing productive and continuous latex vessels differentiated from the vascular cambium (Fig.4). The latex vessels arranged in rows are of articulated anastomising type with vessels of the same

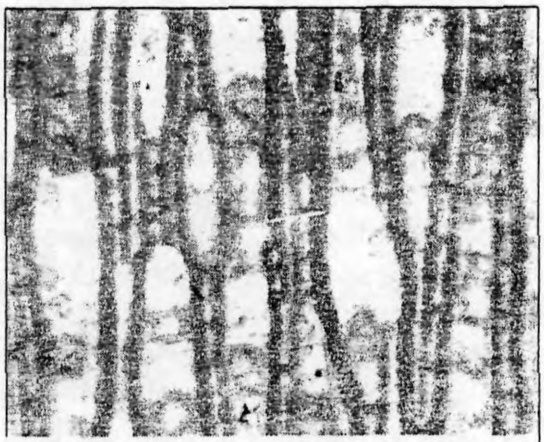

Fig. 4: T.L.S. of bark showing latex vessels

ring interconnected tangentially. The laticifers are generally oriented 3-5° to the vertical, in an anti-clock wise direction.

**Latex biochemistry**

Latex is a specialized form of cytoplasm containing a suspension of rubber and non-rubber particles in an aqueous serum. Besides rubber and water, the other components of latex are carbohydrates, proteins, lipids and inorganic salts and other minor substances (Archer *et al.*, 1963). Rubber particles are the most important constituent in latex making up 30-45 per cent of the volume. Lutoid particles are next in abundance making up 10 to 20 per cent of the volume of latex. Lutoids are sub-cellular membrane bound bodies and encloses a fluid serum known as lutoid serum or B serum, which is a destabilizer of rubber hydrocarbon. Rubber biosynthesis is initiated with the generation of Acetyl-coenzyme A, which is converted to isopentanyl pyrophosphate (IPP), which is then polymerized into rubber. The sustained production of rubber is largely dependent on the latex biosynthetic capacity of a clone for *in situ* latex regeneration between two successive tappings.

**Physiology of latex flow**

Latex flow from a tapped tree is an abnormal physiological phenomenon induced by tapping. When a tree is tapped and the vessel is cut, the very high turgor pressure at the location of the cut is released and viscous latex exudes. This exudation of latex results in the displacement of latex along the length of the latex vessels and laterally, owing to the strong forces of cohesion existing in the liquid phase. This results in a fall in pressure in the vessels leading to entry of water from surrounding tissues making the latex more dilute, which makes the latex less viscous facilitating latex flow. Subsequently disturbances in the osmotic concentration in the vessels damage lutoids releasing a protein' hevein' which forms cross links between rubber particles resulting in coagulation of latex at the cut ends of the vessels. This inherent clotting mechanism within the latex vessels is responsible for the cessation of latex flow (Southern and Yip, 1968) consequent to the plugging of the opened ends of laticifers.

**Tapping of the rubber tree**

Latex is harvested by tapping the bark - a process of controlled wounding of bark to cut open the latex vessels by regularly removing a thin shaving of bark from the surface of the tapping cut at specified intervals. Tapping is done to cut open the latex vessels in case of trees tapped for the first time or to remove the coagulum which blocks the cut ends of latex vessels in the case of trees under regular tapping (Fig.5). Generally tapping is commenced when 70 per cent of the trees in a plantation attain tappable girth of 50cm at a height of 150 cm. One tapping panel covers half the circumference of the tree. The tapping cut should have a slope of about 30° and 25°C to the horizontal for budded and seedling trees, respectively.

Since the latex vessels in the bark run at an angle of 3-5° to the right, a cut from high left to low right of the tree trunk, will open maximum number of vessels. The depth of tapping should be within 0.5 mm of the cambium to get optimum yield without injuring the cambium and regeneration of latex vessels. Tapping should commence early morning, as late tapping will reduce the latex yield due to increased transpiration leading to lower turgor pressure.

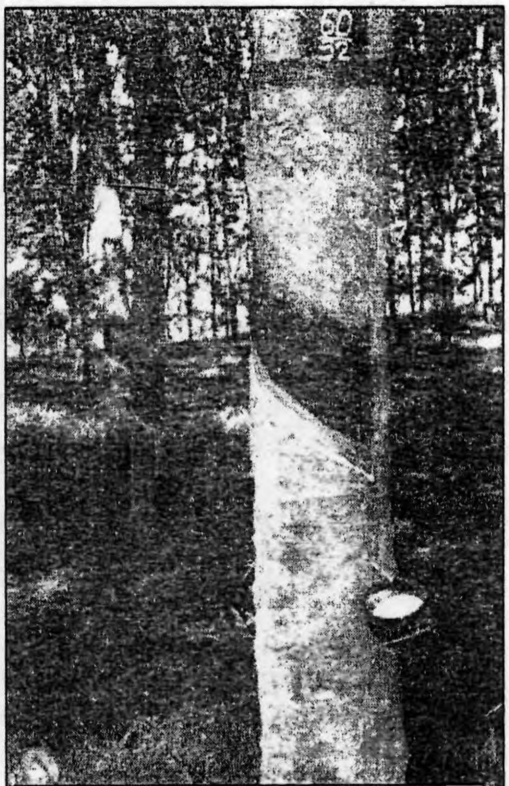

Fig. 5: Tapped tree

The first panel of virgin bark, when the tree reaches maturity is called the BO1 panel, which covers half the circumference of the trunk. The second virgin bark panel is on the opposite side of the first panel (BO2). These panels can be tapped for about five years each. By this time the bark regeneration of the first panel is sufficient to allow tapping again. The third panel (BI1) is the renewed bark of the first panel, and the fourth panel (BI2), renewed bark of the second panel. It takes about 20 years for the complete exploitation of all the four panels.

Conventional tapping systems followed are half spiral alternate days (1/2 S d/2) and half spiral once in three days (1/2S d/3) systems. Still lower frequencies like d/4 and d/7 systems have been experimented and recommended for specific situations. Intensive tapping methods adopted for maximum exploitation before replanting include increased tapping frequency, extension of tapping cut, opening of double cuts and use of yield stimulants. Upper level panel tapping like controlled upward tapping (CUT) is now gaining popularity for longer exploitation of the virgin bark above the lower panel (Vijayakumar *et al.*,2000). The latex yield from trees, vary with clone, age of the tree, fertility of the soil, climatic conditions, tapping system followed as well as skill of the tapper.

## Indian Rubber Plantation Industry

### Introduction and domestication

The domestication of rubber in the East was entirely a project initiated and financed by the then Government of India through the East India Company. Cultivation of rubber in India actually started in 1878 from the rooted cuttings imported from Royal Botanic Gardens, Ceylon (Petch, 1914 and Dean, 1987). During 1878-87, many consignments of seeds and rooted cuttings were sent to

Nilambur, in Malabar and the trees developed from them ensured regular supply of seeds thus accomplishing a successful introduction of Para rubber crop into India.

However, the first attempt to introduce rubber as a forest crop in the teak plantations of Nilambur valley, in Kerala, under the Forest Department of the Government of Madras was not successful since the forest officials considered the rubber planting in Nilambur valley as interference in the teak plantations. Even though these rubber trees were left neglected, Proudlock (1908) found that the Para rubber trees on experimental tapping, yielded latex of excellent quality and recommended its cultivation on an extensive scale on the coastal belts of the country. There are reports of planting of *Hevea* and *Castilla* rubber trees in Howthorne estate, Shevaroy Hills, Salem during 1898 and in the Glenburn estate, Kotagiri in 1902 (Speer, 1953). Para rubber was planted in Ponda, Goa during 1900 and at Aldoma and Margoa in 1906.

**Commercial plantings**

The rubber cultivated during early 1900s grew into the commercial scale with the establishment of several rubber estates. Foreign investors were attracted for investment in rubber plantations in India, by the price boom in that period. Planting in the first rubber estate in, by a syndicate of which J.A.Hunter and K.E.Nichol were the active members (Anon, 1911). In 1904, Mundaykayam region in Travancore could boast of a total of 240 acres of rubber plantations (Speer, 1953). Planting of rubber in commercial scale in South Travancore attained momentum only in 1904 with the establishment of Sittar and Florance estates (Anon, 1911). By 1910, Travancore had become the lead state of rubber planting in India with 18252 acres and Mundakayam became the main centre (Sarma, 1947) of rubber planting with about 10,000acres (4048 ha).

In the erstwhile state of Cochin, development of rubber plantations was mainly on Government owned land and by 1910; Cochin region had a total area of 6800 acres, under rubber (Thomas and Panikkar, 2000). In South and Central Malabar, there were five big companies, with an aggregate area over 6000 acres under rubber cultivation (Anon, 1911).

Rubber had the distinct advantage of a strong support from the government in the early days of establishment in India. The British planters initiated rubber cultivation on a plantations scale and the state administration encouraged them by providing land, labour, capital and trade facilities. There were several steps by the then Government for ensuring the establishment of rubber as a plantation crop. In 1862, a policy for the issue of land suitable for the cultivation of plantation crop was formulated (Anon, 1871). A tremendous boost for the initial growth and expansion of rubber plantations was ensured by the then Travancore-Cochin Governments in 1860s through liberal rules for the distribution of forest waste land, for plantation crops (Anon, 1871; Baak, 1992, 1997). Tax rates were substantially slashed for the government forest lands leased out for the spread of rubber cultivation. Labour control was facilitated through legislations like Criminal Breach of Contract Act, 1865. The Companies Act introduced during 1888 helped in the establishment of large enterprises, which worked on the basis of share capital (Thomas and Panikkar, 2000).

In the initial phase, the rubber plantation industry was controlled by the British companies due to the colonial patronage they got from the British Government and the rubber produced was exported to London. But over the years the steady growth in commercialization of agriculture and successful expansion of area under rubber cultivation with good remuneration, attracted the attention of a host of enterprising native planters in the state of Travancore and Cochin in the mid-19$^{th}$ Century and this period witnessed the emergence of a native planting community who channeled their accumulated surplus from agriculture, trading and banking to prospective plantation agriculture (Thomas and Panikkar, 2000). Rubber naturally became their choice crop during the early 20$^{th}$ century (Baak, 1997). Gradually the Indians managed to consolidate their dominance in rubber plantation sector and by 1947 about 73 per cent of the area under rubber were controlled by Indian companies (Sarma, 1947).

Labour and price components were another two factors that added to the successful establishment and development of rubber plantation industry in India, especially in the state of Kerala. Native labour from the Travancore, Cochin and Malabar regions, took up the new task of harvesting the commercial product- the latex in an efficient manner (George *et al*., 1988). Compared to other less remunerative agricultural jobs, higher and assured remuneration from tapping and the steady expansion of area under rubber attracted more people to the new job sector of tapping in rubber plantations. Europe in the early twentieth century witnessed a price boom in the rubber owing to the very high demand for rubber as a consequence of invention of pneumatic tyres and various other rubber products. This led to an increasing export of rubber from India to Europe, which fetched attractive prices and this high prices along with improvements in agro-technology and availability of cheap contract labour provided a very favorable environment for rubber cultivation and more and more area was brought under rubber cultivation in the subsequent years.

**The present scenario**

Asian countries dominate the natural rubber sector, occupying 93 per cent of the area under rubber cultivation. Natural rubber had a highly appreciable rapid growth in production in India considering the domination of small growers in this plantation sector. Production of NR had a tremendous boost from a very low level of 23,730 tones in 1955-56 to a high of 7,11,650 tones in 2003-2004 (Rubber Board, 2004). The productivity of rubber plantations in the country, increased from 353 kg/ha in 1955-56 to 1663 kg/ha in 2004, highest productivity among NR producing countries. The increase in tapped area and yield per hectare has contributed to this progress in production and productivity. Better domestic and international prices of NR prevailing for the past few years was a main factor that contributed to a resurrection of NR plantation industry from a bad period of low prices. The higher remuneration served as a strong incentive to the small growers of rubber to resume productivity enhancement measures, which had been suspended during the periods of low prices.

In the world scenario, India is fifth largest in terms of area under natural rubber (5,74,000 ha), the fourth largest producer (7, 07,100 tones) with a world share of 8.9 per cent and is fourth in consumption consuming 7,17,000 tones (9.1%) annually (IRSG, 2004). The distribution of rubber cultivation in different states in India is shown in Table 1. Kerala occupies the maximum area of 4,78,402 hectares followed by Tripura (30,271 ha), Karnataka (20,460 ha) and Tamil Nadu (18, 633 ha).

**Table 1: State-wise distribution of area under rubber in India (2003-2004)**

| State/UT | Area (ha.) | % share |
|---|---|---|
| **Traditional Area** | | |
| Kerala | 478,402 | 83.3 |
| Tamil Nadu | 18,633 | 3.2 |
| **Non-Traditional Area** | | |
| Karnataka | 20,460 | 3.6 |
| Andaman & Nicobar | 962 | 0.2 |
| Goa | 755 | 0.1 |
| Orrisa | 480 | 0.1 |
| West Bengal | 461 | 0.1 |
| Maharashtra | 182 | Negligible |
| Andhra Pradesh | 124 | Negligible |
| Tripura | 30,271 | 5.3 |
| Assam | 13,541 | 2.4 |
| Meghalaya | 4,758 | 0.8 |
| Nagaland | 2,091 | 0.4 |
| Manipur | 1,773 | 0.3 |
| Mizoram | 708 | 0.1 |
| Arunachal Pradesh | 379 | 0.1 |
| Total | 573,980 | 100.0 |

**Table 2: State-wise production of NR in India (2003-2004)**

| State/UT | Production (tonnes) | % share |
|---|---|---|
| **Traditional Area** | | |
| Kerala | 655,070 | 92.1 |
| Tamil Nadu | 22,520 | 3.2 |
| **Non-Traditional Area** | | |
| Karnataka | 14,070 | 2.0 |
| Andaman & Nicobar | 389 | 0.05 |
| Goa | 575 | 0.08 |
| Maharashtra | 46 | 0.01 |
| West Bengal | 71 | 0.01 |
| Orrisa & Andhra Pradesh | 40 | Negligible |
| Tripura | 12,755 | 1.8 |
| Assam | 2,581 | 0.4 |
| Meghalaya | 2,812 | 0.4 |
| Nagaland | 396 | 0.1 |
| Others | 325 | 0.5 |
| Total | 711,650 | 100.0 |

(Source : Rubber Board, 2004)

## Rubber cultivation – the success story

### The Rubber Board

After the 2nd world war, there were increasing demands by the growers to setup a permanent organization to look after the rubber industry. Based on the recommendation of an ad-hoc committee, the government passed the Rubber (Production and Marketing) Act, 1947 and constituted the 'Indian Rubber Board', which has been later renamed as "The Rubber Board" functioning under the Ministry of Commerce, Government of India. Appropriate amendments of the Rubber Act was made in 1954, 1955, 1960, 1982 & 1994 defining various functions of Rubber Board for the overall development of rubber plantation industry.

The spectacular growth achieved in the rubber plantation sector in the last five to six decades, has been the result of the strong and effective institutional support extended by the Rubber Board by taking concerted efforts in increasing the productivity and extension of cultivation to non-traditional rubber growing areas, ensuring remunerative and stable prices to the product, and by adopting several measures for value addition to raw rubber by improving quality standards and developing strong marketing channels. Setting up of a pioneer research institute for rubber and a strong extension network ensured advisory and technical services and financial inputs at the door step of the rubber growers. All these efforts contributed for the overall development of Indian rubber plantation sector in the post independence era.

Rubber Board headed by a Chairman appointed by the Government of India has 25 members representing Government/non-Government/Plantation/Industry sectors. There are eight departments in the Rubber Board viz. Rubber Research Institute of India (RRII), Rubber Production (RP), Processing and Product Development (P&PD), Training and Technical Consultancy (T&TC), Administration, Finance and Accounts (F&A), Licensing and excise duty (L&ED) and Statistics and Planning (S & P) Department.

The Rubber Production Department is responsible for planning, formulation and implementation of various schemes for improvement in production as well as expansion of rubber cultivation. The department also undertakes extension /advisory service, supply of inputs and demonstration and training for small growers and rubber tappers.

Training and Technical Consultancy (T&TC) division provides specialized training for the plantation and manufacturing sectors and also provide technical and marketing services like consultancy, and certification and export promotion of natural rubber and rubber products.

Processing and Product Development Department (P&PD) provides technical assistance for the operation of the block rubber factories, analytical services and technical advice to natural rubber processors through a Central Testing Lab and implements the scheme for ISI marking of latex concentrates and block rubber in collaboration with the Bureau of Indian Standards (BIS). The Department also offers engineering services for establishing rubber processing and rubber goods manufacturing units.

Licensing and Excise Duty (L& ED) is associated with issue of licenses for all transactions in rubber involving dealers, processors and manufacturers and also facilitates collection of excise duty and cess from the rubber marketed for generation of funds, as prescribed by Government of India.

Statistics and Planning (S & P) Department is entrusted with collection and preparation of statistical data on all aspects of rubber cultivation and manufacturing industry and in publishing the detailed statistical reports.

**Research and development in rubber**

A strong and sustained R&D support is very essential for ensuring steady progress in any crop species and rubber is no exception. Rubber Board had given top priority for establishing a pioneer research institute and a strong extension network with the broad objectives of global competitiveness in quality, cost and also considering the environmental aspects.

**Rubber Research Institute of India (RRII)**

Although rubber cultivation, in an organized scale, was initiated in India as early as in 1902, infrastructure for systematic research on the crop got established only after half a century with the formation of the Rubber Research Institute of India

(RRII) in 1955. Development of clones with high yielding potential to replace the poor yielding seedling plantations, management strategies for maximizing production from existing plantations, evolving crop protection strategies and development of primary processing technology to ensure market acceptability were the research areas initially taken up. Significant achievements were made in all these areas within about 25 years and the most outstanding contribution was the development of the clone RRII 105, which is still one of the highest yielding clones. Through coordinated and committed research over the decades, RRII has been able to come out with agrotechnolgies covering choice of planting material, propagation techniques, planting methods, maintenance of plantation, intercropping, weed management, management of pests and diseases, latex harvesting systems, primary processing and product development.

RRII is headed by the Director of Research with the Head Quarters at Kottayam, Kerala and has nine research stations spread over different regions and eight divisions in the HQ viz. Agronomy, Botany, Germplasm, Biotechnology, Plant Pathology, Plant Physiology, Rubber Chemistry Physics and Technology and Economic Research.

The RRII has been instrumental in India achieving the highest productivity among the major NR producing countries. Major research contributions by RRII in the areas of crop improvement, crop management, disease management, latex harvest, processing and product development besides research on the ancillary products like rubber wood, rubber honey, etc. paved the way for the successful establishment and development of the rubber plantation sector in India.

**Crop improvement**

Systematic breeding and selection efforts by the rubber breeders from different Rubber Research Institutes from South-East Asian countries played a key role in making rubber breeding an outstanding success story. Rubber breeders had prioritized the breeding objectives taking into account both the general and specific needs of the planting community, especially as the majority of them are small growers and considering the wide spectrum of friendly and hostile environments in which rubber is grown.

Genetic improvement of *Hevea*, in spite of being a very elaborate and time-consuming procedure has paid rich dividends in increasing yield by several folds and making available several high yielding clones, for commercial planting. With ordinary seeds as planting material in the initial years of rubber research, productivity was only around 300 kg ha $^{-1}$ yr $^{-1}$. Subsequent selection of high yielding mother trees and multiplication by budding resulted in early primary clones with improved yield potential. Subsequently breeding new clones through hybridization resulted in a series of high yielding hybrid clones of which the most popular clone is RRII 105, which in terms of realized and potential yield, occupy about 85 per cent of the rubber grown area.

**Conventional breeding methods**

The conventional breeding methods in *Hevea* are introduction, ortet selection (mother tree selection), hybridization and clonal selection. Introduction or exchange of available clones among the rubber growing countries in the early years of rubber research constituted the original breeding pool in each country. In India so far, 127 Wickham clones evolved in countries like Malaysia, Indonesia, Sri Lanka, Thailand, China and Ivory Coast formed the exotic component of the gene pool, in addition to the introduction of 7000 accessions of fresh Brazilian germplasm in the last decade of the 20$^{th}$ century (Varghese and Abraham, 2004). The earlier ortet selections or mother tree selections of 46 clones (Marattukalam *et al.,* 1980) and the recent selections of 11 ortets (Saraswathyamma, 2003) are in various stages of evaluation.

The highest productivity now achieved by India can be attributed to the high yielding hybrid clones of which the most popular clone is RRII 105 with a production potential of over 2000 kg/ha/year in farmers plots. The additional yield of RRII 105 over the average annual yield of other popular high yielding clones is an average of 350 kg/ha. With a total tappable area 2,00,000 ha under RRII 105, the total additional production per annum is around 70,000 tonnes giving a net additional revenue of Rs.3500 million per annum.

The current series of hybrid clones developed by the Institute viz. RRII 400 series is another remarkable achievement. Five of these clones viz. RRII 414, RRII 417, RRII 422, RRII 429 and RRII 430 with an yield improvement of 23-46 per cent over the popular clone RRII 105 in the first 8 years of tapping in small scale evaluation trial have been included in the planting recommendation of the Rubber Board. These are potential clones to further enhance the average productivity of rubber plantations in India. In addition,a total of 77 potential clones are in various stages of experimental evaluation (Saraswathyamma, 2003). Concerted efforts are in progress in developing location specific clones for non-traditional rubber growing areas under sub optimal conditions have resulted in identification of clones for the different non-traditional areas (Varghese, 2003).

Programs have also been initiated for incorporation of superior wild accessions as one of the parents in the breeding cycle.

**Approved planting materials in rubber**

In India, a multiclone planting is recommended with the cultivars grouped in to three different categories.

**Category I** (for large scale planting, covering only up to 50 per cent of the total rubber area in a holding)

Clones RRII 105 and PB 260 for the traditional areas and RRIM 600 and GT 1 for the non-traditional areas.

**Category II** (Three or more of these cultivars may be used to plant up to 50 per cent of the total area of any holding).

Clones RRIM 600, GT 1, RRII 5, PB 28/59, PB 217, RRII 203, RRII 414, RRII 417, RRII 422 and RRII 430.

**Category III** (Clones having limited data for restricted planting)

Clones RRII 50, RRII 51, RRII 52, RRII 118, RRII 176, RRII 208, RRII 300, RRII 429, PR 107, PR 255, PR 261, PB 86, PB 5/51, PB 235, PB 255, PB 280, PB 311, PB 312, PB 314, PB 330, RRIM 605, RRIM 701, RRIM 703, RRIM 712, RRIC 100, RRIC 102, RRIC 130, KRS 163, IRCA 111, IRCA 130, SCATC 88-13, SCATC 93-114, Haiken -1, BPM-24 and Polyclonal seeds.

Selections from any of these are approved for small scale planting not to exceed 15 per cent of the total area, in aggregate (Rubber Board, 2005).

**Constraints in rubber breeding**

The constraints which hamper breeding and quick release of cultivars mainly include the original narrow genetic base, heterozygous nature of the crop, seasonal and non-synchronous flowering pattern, low fruit set, long breeding and selection cycle and lack of fully reliable early selection parameters (Varghese and Mydin, 2000).

**Broadening the genetic base**

The genetic base of *Hevea* in the east is reported to be very narrow, limited to a few seedlings originally collected by Sir Henry Wickham, referred to as the 'Wickham base'. (Simmonds, 1989) from a minuscule of the genetic range of the species in Boim, near the Tapajos River in Brazil (Wycherley, 1969). Added to this, there was a further narrowing down of the original 'Wickham gene pool' due to a number of factors, like directional selection for yield, cyclical generation wise assortative breeding pattern and a wider adaptation of clonal propagation by budding leading to more and more genetic uniformity, thus exposing the plantations to the potential threat of diseases and pest epidemics. The parentage of popular clones bred in various rubber-growing countries including India can be traced back to a handful of parent clones (Tan 1987; Varghese, 1992). In *Hevea,* reports indicate instances of less serious diseases becoming more severe (Varghese *et al.*, 1990) and erosion of genes controlling major leaf diseases in the original Wickham material (Wycherley, 1977). South American Leaf Blight (SALB) caused by *Mycrocyclus ulei*, the most devastating disease of rubber (Edathil, 1986) presently confined to the tropical Americas, demands breeding and selection of SALB resistant clones in Asian countries.

Apart from the problem of disease susceptibility, variability for resistance/ tolerance to various abiotic stress situations like drought, cold, high elevations, high velocity winds, etc. assumes significance in the present day context of extension of rubber cultivation to marginal and non-traditional areas. In order to select clones with resistance to highly destructive diseases like SALB, and to develop location specific clones with tolerance to various abiotic stress situations, the base material should contain ample genetic variability and a broad genetic base (Varghese and Abraham, 1999).

**Fresh germplasm- The 1981 collection**

*Hevea* breeders across the world had realized the need for broadening the narrow genetic base through introduction of wild germplasm in to the breeding pool, culminating in a major collection expedition organized by the International Rubber Research and Development Board (IRRDB) and Brazilian Government to the Amazon rain forests in 1981. The team collected 64,736 seeds and budwood from 194 presumably high yielding mother trees not affected by *Microcyclus* and *Phytophthora,* from the states of Acre, Mato Grosso and Rondonia (Ong *et al.,* 1983; Mohd Noor and Ibrahim, 1986). The germplasm centers at Malaysia and Ivory Coast established these and varying proportions of this wild germplasm has been established in different rubber research institutes. In India, a total of 4548 accessions including 126 ortet clones were received from the Malaysian center, which have been established in traditional and non- traditional areas (Varghese *et al.,* 2002b) for conservation, characterization, evaluation and utilization.

Studies for screening of wild germplasm for resistance to major diseases, drought and cold conditions have revealed wide variability for most of traits. Field observations have identified a general field tolerance of the wild germplasm belonging to Mato Grosso provenance to shoot rot disease (Mercy *et al.,* 1995). Preliminary evaluation of the Brazilian accessions in India has revealed wide variability for morphological parameters and juvenile yield and yield contributing traits (Annamma *et al.,* 1989, Abraham *et al.,* 1992, 1994, 2000).

**Rubber biotechnology**

Advances in rubber biotechnology in India include development of protocols for the micropropagation of *Hevea* through somatic embryogenesis using immature anther and inflorescence explants (Kumari Jayashree *et al.,* 1999). Transgenic plants integrated with SOD gene for environmental stress and TPD tolerance were developed with CaMV 35S and FMV34S promoters and multiplied while transgenic *Hevea* tissues integrated with the gene coding for sorbitol-6-phosphate dehydrogenase (for drought), isopentenyl transferase and antisense ACC (for TPD) and are under different developmental stages (Thulaseedharan, 2003). *β-1,3* - glucanase gene involved in defense to fungal infection in *Hevea* has been cloned and characterized and its involvement in defense against *Phytophthora* infection was studied. It was observed that faster, higher and prolonged expression of this gene during pathogen is involved in disease tolerance (Thanseem, 2005.)

Research initiated on molecular markers in *Hevea* indicated the potential of RAPD markers in various applications in genetic improvement like assay of genetic diversity and genetic analysis (Varghese *et al*, 1997, 2002a, Venketachalam *et al.,* 2002 ). 59 microsatellites were developed for genomic characterization of *Hevea* germplasm (Roy *et al.,* 2004). Species-specific markers [Sequence Characterized

Amplified Region, SCAR] have been developed for identification of the fungal pathogen, *Colletotrichum* (Saha *etal.*, 2002).Studies aimed at identification of molecular markers linked to resistance/tolerance to biotic and abiotic stresses in *Hevea* with an ultimate objective to clone and characterize the respective genes are in progress.

**Crop management**

Reduction of immaturity period, generation of additional income to the farmers especially during the long immaturity period reduction in cost of production and maintenance of sustainable soil health are aimed at, by crop management programmes like nutrient management, intercropping and cropping system, soil and water conservation, fertilizer use efficiency and remote sensing.

Rubber is a long duration crop with a gestation period of seven years under South Indian conditions. The potential of modern high yielding clones can be fully exploited only if scientific management practices are followed in time, aimed at reducing the immaturity period as well as optimizing growth and yield. Various agro management practices for rubber has been evolved and recommended through years of dedicated research.

**Planting material and density**

Studies have shown that good quality polybag plants of uniform size hasten growth and result in uniform plantations. Healthy 2-3 whorled polybag plants are ideal for the successful establishment of a plantation. (Punnoose and Laxman, 2000; Joseph *et al.*, 2001). Best planting season is soon after the rainy season has set in during June-July period. A planting density of 450-500/ ha. is generally acceptable for proper root spread and canopy development leading to high yield per tree and per hectare. Though during the initial four years, plants in the higher density gave better growth, in the subsequent years the trend gradually got reversed indicating the influence of plant competition.

**Soil and water conservation**

The two major factors, which predispose rubber-growing soils to erosion, are the undulating topography and the high intensity rainfall. Only less than 5 per cent of the rubber growing soils comes under level and gentle slope and 5-10 per cent under moderately sloping while the rest comes under strongly sloping –very steep sloping. Sixty seven per cent of the annual rainfall is received during 4 months of the S.W. monsoon. Due to these reasons both soil and moisture conservation is essential in rubber plantations. The practices generally adopted include providing contour terraces and bunds, silt pits, drainage channels, maintenance of ground cover and mulching.

The beneficial effect of silt pits in conserving soil has been quantified and about 250 pits per hectare have been found optimum, particularly in sloppy land. The quantity of soil conserved varied from 5.20 to 10.18 t/ha as the number of pits increased from 100 to 250. Recommendation to grow legume ground cover like *Pueraria phaseoloides* and *Mucuna bracteata* in the early years of rubber plantation helps in minimizing soil erosion.

**Fertilizer management**

Studies on nutritional aspects of rubber have resulted in fertilizer recommendations suitable for different regions. In addition to the general fertilizer recommendations at different growth phases, RRII has evolved discriminatory fertilizer recommendations (DFR) for individual fields by assessing the nutrient status of the trees and fertility status of the soil facilitated through analysis of soil and leaf samples from individual fields. DFR helps to avoid over or under use of fertilizer leading to nutrient imbalances and also economizes fertilizer use. This facility has been made available to the growers at a nominal charge. A survey conducted in smallholdings has revealed that DFR could lead to increased yield up to 200 kg/ha. and a saving in fertilizer cost to the tune of Rs. 400/ha. Regional soil testing laboratories have been established in different rubber growing regions for easy access to the growers. There are also four mobile soil-testing laboratories in the traditional region and one in the northeast, extending this facility to the farmers.

**Inter-cropping/cropping systems**

Experiments on cropping systems have resulted in recommendations on cultivating various annual crops along with rubber. In the first 2-3 years after planting, before the tree canopy closes, it is possible to cultivate a variety of crops in the inter spaces available in the young plantations leading to additional income. Intercropping has been reported to enhance the growth of rubber (Jessy *et al.,* 1996). Pineapple, banana, ginger, turmeric, vegetables and tubers like *Amorphophallus, Colocacia and Diascorea* are popular intercrops of rubber. In mature plantations light availability is limited and only shade tolerant inter-crops can be grown. Experiments on intercropping of tea with rubber are in progress in the tea growing regions in India.

**Crop protection**

The rubber plantations of India,.faces a host of diseases as a consequence of pronounced heavy monsoon rains. The RRII was successful in effective control measures for most of the diseases especially the major disease viz. abnormal leaf fall, powdery mildew, *Corynospora,* etc. which are being practiced in a regular manner in the rubber plantations in India.

Efforts in reducing the cost of chemical control have yielded encouraging results. Control of powdery mildew and *Colletotrichum* leaf disease in disease-prone areas using integrated approaches using systemic and non-systemic fungicides resulted in considerable increase in crop yield. Prophylactic protection either by painting or spraying with copper fungicide reduced the incidence of pink disease. (Jacob, 2003). Management of microorganisms and insect-pests will enhance the productivity of rubber and reduce the cost of production.

Considering the environmental hazards related with chemical control measures, RRII has initiated research on development of biocontrol measures. Due importance is given to breeding programs for development of clones with inherent tolerance/resistance to major diseases.Tapping Panel Dryness (TPD) resulting in the drying up of the bark is one of the complex problems affecting high yielding rubber clones. A solution to this vexed problem is still to evolve inspite of decades of research on the causative factors in all the major rubber growing countries. Management strategies recommended are low intensity tapping and tapping rest. Recent studies at RRII have indicated possible association of viroids with TPD, which need to be further, confirmed.

**Crop Physiology and biochemistry**

Progress has been made in areas like physiology of production, aging and senescence, stock-scion interaction, environmental physiology, physiology of tapping panel dryness syndrome and secondary metabolites. Predictive traits for high yield and high biomass identified are being used to identify latex-timber clones that can produce high latex yield and high biomass at the same time.

Rubber leaves require only half the full sunlight for maximum photosynthesis. Excess light results in the overproduction of reactive oxygen species (ROS) and free radicals (FR) leading to oxidative stress and irreversible damage to cells and tissues (Jacob *et al*., 1999). Based on important antioxidant mechanisms that will scavenge FR and ROS, based on which drought and cold tolerant clones can be identified. In TPD trees, CHOs accumulate due to the inefficiency of the tissues to convert them into isoprene, which is related to reduced supply of ATP. Antioxidants and anti-ethylene compounds have been partially successful in controlling TPD.

Latex diagnosis (LD) studies employ the levels of sucrose, thiol, inorganic phosphorus (Pi) in latex and dry rubber content (DRC) for monitoring the exploitation status of holdings. Based on LD, production metabolism of clone RRII 105 has been characterized as very active and base values were developed for optimum production under 1/2Sd/3 system of tapping.

**Harvesting latex**

Tapping cost contributing substantially to the high cost of production of NR in India, RRII in the last one and half decades has focused on modifying the conventional method with low frequency tapping (LFT), panel change, controlled upward tapping (CUT), mini and reduced spiral tapping cuts, assessment of crop loss due to rain and its recovery through stimulation (Vijayakumar *et al*., 2003). Optimum schedules of etherel stimulation for getting sustainable yield increase in tapping once in three days was evolved for many popular clones.

Among the low frequency tapping systems (LFT), in d/4 system, each panel can be tapped for at least eight years, while under d/6, this is increased to 10 years in comparison to five years in conventional tapping system. Hence, in addition to the obvious advantage of savings in the tapping cost, LFT increases the economic lifespan of the trees also. Controlled upward tapping (CUT) is practiced for the exploitation of the virgin bark above the basal panel using a special long handled modified gouge knife. RRII has also come out with a modified practice of CUT, where the basal panel is tapped with rainguarding during monsoon season and CUT is done during the remaining period, which resulted in sustainable yield increase for many years (Vijayakumar *et al*., 2003).

**Processing and product development**

Utmost importance has been given to evolve technologies and systems for improving quality of the rubber produced in the country and in reducing the cost of processing in order to gear up the industry to meet the present day challenges in international competition.

Latex is collected in the non-coagulate form in collection cups, which constitutes 75-85 per cent of the crop, the rest (15 to 25%) being the field coagulum. Latex can be processed into marketable products viz., (1) ribbed sheets (2) pale latex crepe (PLC) or sole crepe, (3) technically specified rubber (TSR) and specialty rubbers and (4) preserved field latex and latex concentrate and (5) block rubber.

RRII has identified cheaper coagulants like sulphuric acid and sulphamic acid, in place of costly coagulants like formic and acetic acids in the preparation of ribbed smoked sheets, the conventional methods of processing (George *et al.*, 1992, Varghese *et al.*, 1996). Natural rubber usually marketed as either ribbed smoked sheet and crepe rubbers, graded visually quite often failed to meet the specific technical requirements of the end users. This necessitated processing of NR in technically specified block form produced and marketed in India in the name of Indian Standard Natural Rubber (ISNR) which has the distinct advantage of an assured quality for important technical parameters, consistency in quality, convenience in storage, handling and packing.

Modifications of NR like Oil Extended Natural Rubber (OENR), Thermoplastic Natural Rubber (TPNR) and Deproteinised NR are some of the commercially important materials. Increasing the oil content in the latex in the case of OENR, reduces the tensile strength and resilience, at the same time retaining good tear resistance and having very high wear resistance when blended with polybutidiene rubber (Mathew, 2001, George *et al.,* 2000). Thermoplastic natural rubber (TPNR) blends prepared by blending NR and polyolefines like polypropylene and polyethylene are a new class of materials, possess the processing characteristics of thermoplastics and behavior of vulcanized rubber at room temperature. These are used for applications in footwear, sports goods, seals and also for applications in automobile industry. Deproteinised Natural Rubber (DPNR), is highly suitable for specific engineering applications (George *et al.,* 2000). A laboratory process was reported for the deproteinization of natural rubber latex using a proteolytic enzyme Anilozyme-P. The low protein natural rubber latex could be used to produce dipped goods with low extractable protein content (George *et al*., 2001).

Chemical modification provides for an avenue for evolving new materials from NR, which could be utilized in new frontiers where rubber is not used at present. Similarly blending of NR with other polymers including synthetic rubbers is being focused to design appropriate blends for specific applications (Mathew, 2004).

NR modified bitumen improves the properties of pavements. The advantage of rubberizes bitumen are (i) lower susceptibility to temperature (ii) Higher resistance to deformations/wear and tear, (iii) better adhesion between aggregates and binder, and (iv) increase in fatigue life. The NR added to bitumen as preserved field latex, equivalent to 2 per cent drc on the weight of bitumen, blended at 140 – 160$^{o}$C, in a boiler for about two hours . For consistent availability refinery level production is required. The additional cost involved is about 5-7 per cent only. A preliminary evaluation by Central Road Research Institute of India, New Delhi revealed that the cost of periodic maintenance of rubberized roads can be reduced by about 35 per cent compared to that of ordinary roads considering a design period of about 20 years life. Thus on a long tem perspective, it is prudent to promote extensive rubberisation of roads in our country as it combines savings with safety (Gopalakrishnan, 2004).

**Ancillary income from rubber**

Rubber plantations also serve as a good source to generate ancillary income from three major bye products viz. rubber wood, rubber seed and rubber honey. Rubber wood is the major bye product from the rubber plantation industry, and serves as a major source of additional income during replanting. There is increasing demand for rubber wood as an alternate source of timber for various industrial uses. It has high environmental acceptability both in domestic and international markets. Processed rubber wood has a wide range of applications like furniture, paneling, table top, flooring, household articles, etc.

The average timber yield varies across rubber planting regions from 140 to 200 m$^3$ /ha. It is estimated that in India, the yield of green wood, (including branches of more than 5 cm girth) per hectare is of the order of 180 m$^3$ in the estates sector and 150 m$^3$ in the small holdings (Joseph and George, 1996; Viswanathan *et al.*, 2002). The projected total availability of rubber wood was 2.9million m$^3$ during 2003-2004 of which stem wood account for 60 per cent. The consumption pattern of rubber stem-wood is dominated by packing case sector now (59%) followed by plywood industry (20%). Secondary rubber wood processing sector consumes only 14 per cent of the stem-wood produced (Viswanathan *et al.*, 2002).

Rubber seed is a minor source of non-edible oil in India having commercial application in soap and paint manufacturing industries. The oil content is about 14-16 per centof the total weight of the seed. Rubber seed cake, rich in protein can be used in cattle and poultry feeds up to 20 per cent by weight.

Rubber tree produces nectar from its extra floral nectary located at the point of insertion of petiole and leaflets. Khadi and Village Industries Commission (KVIC) promotes commercial exploitation of honey from rubber plantations in India. The introduction of *Apis mellifera* as an alternative to the Indian honey bee gave a tremendous boost to the Indian rubber honey industry with an average honey yield of 60 kg per hive per year compared to 19.46 kg per hive per year for the popular Indian honey bee (Chandy *et al.,* 1998). Bee keeping in rubber plantations can be economical with a minimum of 15 hives per hectare with a production potential of 182 kg. The estimated production of honey from rubber plantations during 2003-2004 was 6700 MT.

**Green image for rubber**

Rubber, domesticated as a plantation tree crop over 100 years back has already proved its worth as an eco-friendly tree species and an ecologically viable cash crop. Natural rubber, a deciduous forest tree, helps for eco-restoration of denuded and depleted forestlands. With a stand of 450 plants/ha and the canopy closing in less than five years, *Hevea* is a good candidate for afforestation of marginal and denuded soils. Rubber as an eco-friendly crop contributes mainly to soil conservation, nutrient recycling and soil fertility, biomass generation and in providing an alternate source to timber.

The recommended agro-management practices in rubber are aimed at improving soil properties. Soil fertility is sustained through regular application of NPK & Mg during immature and mature phases. The fertilizer inputs are optimized by discriminatory fertilizer recommendation to supply only the required quantity to the soil. Nitrogen fixing cover crops improve soil fertility. Rubber plantations adopting proper agro-management practices help in enrichment of soil organic matter, which consequently improve physical properties such as bulk density, soil porosity, moisture retention and infiltration (Krishnakumar *et al.,* 1990).

Rubber tree is a potential solar energy harvester with an annual bio-mass production potential of around 35 tonnes of dry matter per ha per year, which is comparable with any fast growing tropical forest tree species (Sethuraj, 1996). High biomass production potential of *Hevea* makes it an excellent candidate for energy plantation, source of timber and fuel wood (Jacob, 2000).

The build up of biomass, microflora and understorey vegetation in rubber plantations is comparable to that in teak plantations (Krishnakumar *et al.,* 1991) indicating ecological desirability of rubber in terms of habitat diversity, soil physical properties and nutrient recycling. Considering the energy requirements, energy for production of NR is derived mostly from sun light through photosynthesis while non-renewable energy source is used for production of synthetic rubber, which is about 11 times higher than that for NR (Mathew, 1996). Thus natural rubber has enormous potential in contributing to the cause of solving energy crisis.

Similarly, as an alternative timber source, wood from natural rubber has become the main non-forest timber resource decreasing the logging pressure on natural forests and teak plantations in rubber growing countries.

**Extension and development activities**

During the last five decades, Rubber Board has exercised need based extension and development strategies that were another important input in the overall successful growth registered in the Indian natural rubber sector. The decentralized and integrated extension and development delivery systems ensures informed participation of the growers resulting in higher degrees of adoption of latest technologies, improvement in quality maintenance and primary processing and empowerment of the grower community (Krishanakumar, 2003).

**Rubber plantation development schemes**

Rubber Board introduced its first Replanting Subsidy Schemes in 1957 for popularizing high yielding clones with a provision for financial incentives. This scheme was since then revised periodically, covering new plantings and replanting. Emphasis on institutional development facilitating creation of infrastructure for processing, marketing and technology transfer yielded tremendous progress. Late 1970s and early 1980s witnessed a focus in the rapid expansion of area through supporting new planting and replanting under an integrated scheme called Rubber Plantation Development Scheme-Phases I –IV of which under I-III the participants who were small growers owning up to 5 ha. of rubber in the traditional region and all categories of growers in the NT areas were entitled to receive a planting grant @ Rs.5,000 per ha. in annual instalments spread over 6-7 years of the immature phase. This, even after two and half decades is still undoubtedly the best development program in the agricultural sector (Krishanakumar, 2004). During 1990s primary processing and marketing also received adequate attention by the Board, with a view to enable the small holding sector to keep pace with changes in processing standards and marketing.

**Rubber producers societies (RPS)**

Rubber Producers Society (RPS), a voluntary association registered under the Charitable Societies Act was formed in 1985 in order to promote group approach among rubber small growers. RPSs function on a non profit basis imparting technical and scientific know how to the members aimed at economic and social welfare of the small growers. As a more effective participatory approach, trained and experienced rubber farmers were used as "farmer resource persons" in the campaigns and training programs. Emphasis was also given on women and tribal development by forming women self help groups (attached to RPSs) and providing assistance for income generation activities like establishing handicrafts units and bio-gas plants in Kerala as well as in Tripura.

Special attention was given to utilize rubber as a successful crop in the rehabilitation of tribal shifting cultivators in the North-East India and about 10,000 such families have been benefited in this region and the success of this project is ensured through community participation and motivation of extension machinery.

The receptiveness and adoption of research findings by our farmers have been remarkable. The small growers were more receptive to the developments in research and have adopted the findings promptly resulting in even higher productivity above that of large estates managed professionally in the corporate sector. The small growers also give valuable feed back to the RRII based on their observations, which form the basis for designing new need based research programs..

**Expansion of rubber cultivation to non-traditional areas**

Currently, rubber cultivation has been extended to some 15 new states and Union Territories identified as non-traditional regions. The aggregate extent of plantations raised so far in those regions over the past 25 years comes to 70,000 ha., which accounts for 12 per cent of the total extent of rubber in the country and 5 per cent of the national production. It is poised to rise steadily in the years to come. Cost of production in these areas is low due to cheap land and labour compared to traditional areas. Many thousands of tribal people have ownership over holdings allotted to them out of large block plantations while many among them have earned good employment. Thus the status of rubber as a crop grown only in a smaller corner of the country has been raised to that of one spread far and wide in our contrary drawing national attention and concern.

**International collaboration**

During the course of the last few decades the Rubber Board and RRII have become members of international organizations in the field of rubber, namely International Rubber Study Group (IRSG), Association of Natural Rubber Producing Countries (ANRPC) and International Rubber Research Development Board (IRRDB). Exposure to events relating to rubber at the global level and useful exchange of ideas has helped to pursue research and extension activities in the context of an international scenario. Participation in IRRDB activities has brought about close interaction between the research institutes of member countries and paved way for joint research programmes on various problems commonly confronting member countries. Exchange of newly developed planting materials has been another important benefit.

**Future prospects**

The Indian rubber plantation industry has benefited greatly from a strong R&D support with a good extension network in its growth to the present heights. Improvements in productivity have been achieved through well-defined breeding programs. Identification and incorporation of genes contributing to latex and timber and tolerance to biotic and abiotic stresses are actively pursued. Cost reduction in all aspects of cultivation, harvesting and processing has always received top priority in research.

The need for further expansion of rubber cultivation to nontraditional rubber growing areas in India, demands the development of location specific clones capable of withstanding various stress situations. The need for identification of sources of durable resistance for major diseases including the potential threat of SALB, has been recognized. The fresh wild germplasm now being characterized and evaluated, is expected to be a rich source of many valuable genes for various biotic and abiotic stresses and also for quality parameters. The conventional procedures are being supplemented with the modern molecular techniques for characterization of accessions at the DNA level, estimation of genetic variability and genetic divergence and identifying markers for characters of breeding value and their application in the large scale screening of germplasm and segregating progenies. Development of biological control measures in lieu of expensive and environmentally hazardous chemical control measures offers much scope for research.

Further research on cropping systems, intercropping, soil and water conservation and integrated weed management offers scope in bringing out still cost-effective cultural practices in rubber. Harnessing modern tools like remote sensing and mapping of rubber diseases from satellite imagery need to be intensified for further advances in agro- management practices.

Prospects for biotechnological interventions in *Hevea* are high and RRII has pioneered in perfecting protocols for genetic transformation of *Hevea* using agronomically desirable genes and has met with success in developing plantlets with specific genes for resistance to drought and Tapping Panel Dryness. Further concerted efforts are essential to perfect these systems on a commercial level. Tapping Panel Dryness Syndrome, seriously affecting the rubber yield poses great challenge in rubber research in spite of decades of research in different countries. Recent studies undertaken at RRII have indicated some association of viroid with this disorder, which however need to be further confirmed. Detailed investigations to elucidate the real cause either biotic, abiotic or both have been undertaken.

Investigations on the physio-biochemical aspects on latex flow, environmental and stress physiology, rubber bio-synthesis and biochemistry and molecular biology of isoprene production are priority areas. Advances in latex harvest technologies will result in reduction of cost of production. Long-term exploitation of high panels is possible through Controlled Upward Tapping (CUT) and low frequency tapping systems are desirable in view of increasing labour shortage. Studies aimed at establishment of latex diagnosis advisory service to rubber plantations need to be undertaken for evolving clone wise tapping recommendations for different agro-climatic and agro-management situations

Having recognized the commercial applications of Rubber wood, the most important ancillary product from rubber tree, research on identification and improvement of timber quantity and quality traits need to be intensified. Desirable selections from the available germplasm could be directly used for raising rubber forests or incorporated in breeding programmes for development of Latex Timber Clones, which is one of the current breeding objectives in rubber. Similarly, perfection of cost effective wood treatment procedures is another area of interest for getting over inherent demerits of rubber wood.

Various . environmental issues related to rubber plantations including possibilities of getting monitory benefit for rubber plantations under the Kyoto protocol, based on their carbon sequestration capacity are being studied. More studies are warranted in generating sufficient data on the environmental impact of natural rubber cultivation on soil, water and to the ecological system in general and thereby project the green image of natural rubber and promote NR as an eco-friendly plantation tree species.

The development of modified forms of rubber including chemical modification and blending of NR with other polymers offers scope for evolving new rubber based products for specific applications. Studies on epoxidation of NR and enzymatic deproteinization of latex have been extended to find new areas of application for the modified rubber. Attempts are also underway to identify allergenic latex proteins and to make allergen free latex products. Successful preliminary attempts in India in developing NR based nano-composites are highly encouraging. Efforts for development of engineering and automotive rubber products need to be strengthened. Technologies to recycle rubber from used waste products (reclamation) and attempts to enhance service life of conventional rubber products could lead to conservation of the polymer in future. In the context of international competition, priority is given for evolving technologies and systems for improving the quality of rubber produced in India and reducing the cost of processing so as to compete with the world rubber market.

In the present global scenario, atural rubber stands to gain from high demand of rubber in the expanding automobile industry besides a host of other industries using different forms of rubber. Meeting the global standards for competing with the world market is the greatest challenge to the Indian rubber industry today. According to the projections by the World Bank, NR prices are expected to increase until 2010 even though at a declining rate. The annual growth rate is forecasted to be 2.4 per cent during 2006-2010. The Rubber Research Institute of India and rubber plantation sector is committed to meet the forthcoming challenges in the natural rubber sector.

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**References**

Abraham, S. T., Reghu, C.P., Madhavan, J., George, P.J., Potty, S.N., Panikkar, A.O.N. and Saraswathy, P. 1992. Evaluation of *Hevea* germplasm 1: Variability in early growth phase. *Ind. J. Natural Rubber Research* 5(1&2): 195-198.

Abraham, S.T., Reghu, C.P., Panikkar A.O.N., George, P.J. and Potty, S.N. 1994. Juvenile characterization of wild *Hevea* germplasm. *Ind. J. Plant Genetics Resources* 7(2): 157-164.

Abraham, S.T. 2000. Genetic parameters and divergence in certain wild genotypes of Hevea brasiliensis (Willd.ex Adr.de Juss.) Muell.Arg. *Ph.D.Thesis* submitted to Mahatma Gandhi University, Kottayam, India. pp121-123.

Annamma, Y., Marattukalam, J.G., George, P.J. and Panikkar, A. O. N. 1989. Nursery evaluation of some exotic genotypes of *Hevea brasiliensis* Muell. Arg. *J. Plantation Crops* 16 (Supplement): 335-342.

Anon. 1871. Rules regarding grant of land for cultivation of coffee. Memorandum of 8 March, 1862; Rules for the sale of waste land on the Travancore Hills, 24 April 1865. *Travancore Almanac* 123-136.

Anon, 1911. Rubber in South India. R. Clay and Sons, London, pp. 11-36.

Archer, B.L., Barnard, D., Cockbain, E.G., Dickenson, P.B. and McMullen, A.I. 1963. Structure composition and biochemistry of *Hevea* latex. In: *The Chemistry and Physics of Rubber Like Substances* (Ed. L. Bateman). Maclaren and Sons. Ltd., London, pp.41-72.

Baulkwill, W.J. 1989. The history of natural rubber production. In: *Rubber* (Eds. C.C.Webster and W.J.Baulkwill). Longman Scientific and Technical, New York, pp.1-56.

Baak, P.E. 1992. Planters lobby in late 19$^{th}$ Century: Implications for Travancore. *Economic and Political Weekly* 27(33): 1747-1753.

Baak, P.E. 1997. Plantation production and political power: Plantation development in the South West India in a long-term historical perspective, 1743-1963.Oxford University Press, New Delhi, 370p.

Chandy, B., Joseph, T. and Mohanakumar, S. 1998. Commercial exploitation of rubber honey in India:Report of a sample survey. *Rubber Board Bulletin* 27(3): 9-15.

Dean,W. 1987. *Brazil and the struggle for rubber: A study in environment history.* Cambridge University Press, Cambridge, 234p.

Edathil, T.T. 1986. South American leaf blight- a potential thread to the natural rubber industry in Asia and Africa. *Tropical Pest Management* 32(4): 296-303.

George, K.T., Haridasan, V. and Sreekumar, B. 1988. Role of government and structural changes in rubber plantation industry in India. *Economic and Political Weekly* 23 (48): M158-M166.

George, P. J. 1989. Need for conservation of crop genetic resources with special emphasis on rubber. *Rubber Board Bulletin* 24(4): 13-17.

George, K.M., Varghese, L. and Mathew, N.M. 1992. Use of suphuric acid as coagulant for natural rubber latex. *J. Plantation Crops* 20(Supplement): 336-341.

George, B., Alex, R. and Mathew, N.M. 2000. Modified forms of natural rubber. In: *Natural Rubber: Agromanagement and Crop Processing*. (Ed. P.J.George and C.Kuruvilla Jacob). Rubber Research Institute of India, Kottayam, pp.453-470.

George, M, K., Rajammal, G., Peethambaran, N.R. and Mathew, N.M. 2001. Enzymatic deproteinization of natural rubber latex. *Ind. J. Natural Rubber Research* 14(1) : 7-13.

Gopalakrishnan,K.S.2004.Natural rubber modified bitumen for high performance roads. *Indian/International Rubber Journal* July-August, 2004 : 46-48.

IRSG. 2004. *IRSG Rubber Statistics Bulletin,* International Rubber Study Group, UK, 58 (10-11): 52 p.

Jacob, J., Annamalainathan, K., Alam, B., Sathik, M.B.M., Thapalial, A.P. and Devakumar, A.S. 1999. Physiological constraints for cultivation of *Hevea brasiliensis* in certain unfavourable agroclimatic regions of India. *Ind. J. Natural Rubber Research* 12 (1&2): 1-16.

Jacob, J. 2000. Rubber tree, man and environment. In: *Natural Rubber: Agromanagement and Crop Processing*. (Ed. P.J.George and C.Kuruvilla Jacob). Rubber Research Institute of India, Kottayam, pp.599-610.

Jacob, C.K. 2003. Management of micro-organisms and insects for cost reduction in rubber plantations. In: *Global Competitiveness of Indian Rubber Industry-Rubber Planters' Conference, India.* (Eds. C. Kuruvilla Jacob and Kurien K. Thomas). Rubber Research Institute of India, Kottayam, Kerala, India. pp 283-297.

Jessy, M.D., Philip, V., Punnoose, K.I. and Sethuraj, M.R. 1996. Multispecies cropping system with rubber: A preliminary report. *IRRDB Symposium on Farming System Aspects of the Cultivation of Natural Rubber (Hevea brasiliensis),* 1996, Beruwela, Sri Lanka, pp. 81-89.

Joseph, T. and George, K.T. 1996. Primary processing of rubber wood in Kerala: Report of a sample survey. *Wood News*, January-March, 1996: 39-43.

Krishnakumar, A.K., Eappen, T., Rao, N., Potty, S.N. and Sethuraj, M.R. 1990. Ecological impact of rubber (*Hevea braziliensis*) plantations in North East India. 1. Influence on soil physical properties with special reference to moisture retention. *Ind. J. Natural Rubber Research* 3 (1): 53-63.

Krishnakumar, A.K., Gupta, C., Sinha, R.R., Sethuraj,M.R., Potty, S.N., Eappen, T. and Das, K. 1991. Ecological impact of rubber (*Hevea brasiliensis*) plantations in North East India: 2. Soil properties and biomass recycling. *Ind. J. Natural Rubber Research* 4(2): 134-141

Krishnakumar, A.K. 2003. A review of extension and development strategies in rubber. . In: *Global Competitiveness of Indian Rubber Industry- Rubber Planters' Conference, India,* (Eds. C. Kuruvilla Jacob and Kurien K. Thomas). Rubber Research Institute of India, Kottayam, Kerala, India. pp 337-349.

Krishnakumar, A.K. 2004. Participatory approaches in rubber development programmes - A review. *Indian/International Rubber Journal*, July-August, 2004, pp. 30-35.

Kumari Jayasree, P., Asokan, M.P., Sobha, S., Sankari Ammal, L., Rekha, K., Kala, R.G., Jayasree, R. and Thulaseedharan, A. 1999. Somatic embryogenesis and plant regeneration from immature anthers of *Hevea brasiliensis*. *Current Science* 76(9): 1242-1245.

Majumder, S.K. 1964. Chromosome studies of some species of *Hevea*. *J. Rubber Research Institute of Malaya* 18: 253-260.

Marattukalam, J.G., Saraswathy Amma, C.K. and George, P.J. 1980. Crop improvement through ortet selection in India. *International Rubber Conference*, Kottayam, India.

Mathew, N.M. 1996. Natural rubber and the synthetics: Energy, environment and performance considerations. In: *Natural Rubber: An Ecofriendly material*. Rubber Board, Kottayam, pp. 77-99.

Mathew, N.M. 2001. Natural rubber. In: *Rubber Technologist's Hand book.* (Eds. J.R.White and S.K.De). Rapra Technology Ltd, UK. pp. 1-41.

Mathew, N.M. 2004.Trends in rubber research. *Indian /International Rubber Journal*, July-August, 2004, pp.38-45.

Mercy, M. A., Abraham, S.T., George, P.J. and Potty, S.N. 1995. Evaluation of *Hevea* germplasm: Observations on certain prominent traits in a conservatory. *Ind. J. Plant Genetic Resources* 8(1): 35-39.

Mohd Noor, A.G. and Naimah Ibrahim. 1986. Characterisation and evaluation of *Hevea* germplasm. *IRRDB Symposium*, 11-13 Nov 1986, Malaysia.

Ong, S.H., Ghani, M.N.A., Tan, A, M. and Tan, H. 1983. New *Hevea* germplasm: Its Introduction and potential. *Proceedings of the Rubber Research Institute of Malaysia, Planters Conference*, 1983, Kuala Lumpur, Malaysia, 3: 3-17.

Petch, T. 1914. Notes on the history of the plantation rubber industry in the east. *Annals of the Royal Botanic Gardens, Peradeniya* 5: 440-487.

Proudlock, R.L. (1908). Report on the rubber tree at Nilambur and at Calicut, South Malabar. Government Press, Madras.

Punnoose, K.I., Kothandaraman, R., Philip, V. and Jessy, M.D. 2000. Field upkeep and intercropping. In:*Natural Rubber: Agromanagement and Crop Processing*. (Ed P.J.George and C.Kuruvilla Jacob). Rubber Research Institute of India, Kottayam, pp.149-169.

Rubber Board 2003. Indian Rubber Statistics Vol 26. pp 1-9.

Rubber Board, 2004. Rubber Statistical News, Vol 63, No 7.

Rubber Board. 2005. Rubber and its cultivation. In: *Rubber Grower's Companion 2005*. Rubber Board, Kottayam, India. pp 1-106.

Saha, T., Kumar, A., Ravindran, M., Jacob, C.K., Roy, B. and Nazeer, M.A. 2002. Identification of *Colletotrichum acutatum* from rubber using random amplified polymorphic DNAs and ribosomal DNA polymorphisms. *Mycological Research* 106(2): 215-221.

Saraswathyamma, C.K. 2003. Advances in crop improvement in *Hevea* in the traditional rubber-growing tract in India. In: *Global competitiveness of Indian Rubber industry- Rubber Planters' Conference, India*. (Eds. C. Kuruvilla Jacob and Kurien K. Thomas). Rubber Research Institute of India, Kottayam, Kerala, India. pp.101-116.

Sarma, P.V.S. 1947. A short note on the rubber plantation industry in India. India Rubber Board, Kottayam, 16p.

Sethuraj, M.R. 1996. Impact of natural rubber plantations on environment. In: *Natural rubber: An ecofriendly Material*. Rubber Board, Kottayam, pp.55-59.

Simmonds, N.W. 1989. Rubber Breeding. In : *Rubber* (Eds. C.C. Webster and W.J. Baulkwill) Longman Scientific and Technical, New York, pp. 85-124.

Southern, W.A. and Yip, E. 1968. Latex flow studies: 3. Electrostatic considerations in the colloidal stability of fresh *Hevea* latex. *J. Rubber Research Institute of Malaya* 20(4): 201-215.

Speer, S.G. 1953. UPASI 1893-1953. United planters' Association of Southern India, Coonoor, 452 p.

Tan, H. 1987. Strategies in rubber tree breeding. Improving vegetatively propagated crops. (Eds. Abbot and Atkin). Academic Press, London, pp. 27-62.

Thanseem, I. 2005. *Isolation and molecular characterization of β-1,3 glucanase gene and its role in combating abnormal leaf fall disease in rubber tree (Hevea brasiliensis*, Muell.Arg. ). *Ph.D Thesis*. M.G.University, Kottayam, Kerala. 149p.

Thomas, K.K. and Panikkar, A.O.N. 2000. Indian rubber industry: Genesis and development. In: *Natural Rubber- Agromanagement and Crop Processing* (Ed P.J.George and C.Kuruvilla Jacob). *Rubber Research Institute of India*, Kottayam, pp.1-19.

Thulaseedharan, A. 2003. Biotechnological approaches of crop improvement in natural rubber at RRII. Present status. In: *Global Competitiveness of Indian Rubber Industry- Rubber Planters' Conference, India,* (Eds. C. Kuruvilla Jacob and Kurien K. Thomas). Rubber Research Institute of India, Kottayam, Kerala, India, pp.135-140.

Varghese, Y. A. 1992. Germplasm resources and genetic improvement. In:*Natural Rubber: Biology, Cultivation and Technology* (Eds. M.R. Sethuraj and N.M.Mathew). Elsevier, Amsterdam, pp. 88-115.

Varghese YA Mercykutty VC Panikkar AON George PJ and Sethuraj, M.R.1990 Concept of clone blends: Monoculture Vs multiclone planting. *Rubb. Board Bull.* 26(2):13-19.

Varghese, Y. A., Knaak, C., Sethuraj, M.R. and Ecke, W. 1997 Evaluation of random amplified polymorphic DNA (RAPD) markers in *Hevea brasiliensis. Plant Breeding* 116: 47-52.

Varghese, Y.A., Saraswathyamma, C.K. and Sethuraj, M.R. 1996. Rubber breeding in Kerala. *Proc. Seminar on Crop Breeding in Kerala*, University of Kerala, Trivandrum.

Varghese, Y.A. and Abraham, S.T. 1999. Germplasm conservation, utilisation and improvement in rubber. *In: Improvement of Plantation Crops.* (Eds. M.J. Ratnambal, P.M. Kumaran, K. Muralidharan, V. Niral and V. Arunachalam). Central Plantation Crops Research Institute, Kasaragod, pp. 124-133.

Varghese, Y.A. and Mydin, K.K. 2000. Genetic improvement. In:*Natural Rubber:Agromanagement and Crop Processing* (Eds.P.J.George and C.Kuruvilla Jacob). Rubber Research Institute of India, India, pp. 36-46.

Varghese, Y.A., Abraham, S.T. and Reghu, C.P. 2002a. Genetic resources management of *Hevea brasiliensis* in India: Application of molecular markers. *6th Gatersleben Research Conference on "Plant genetic resources in the Genomic Era,* Institute for Plant Genetic and Crop Plant Research, Gatersleben, Germany.

Varghese,Y.A., Abraham, S.T., Mercy, M.A., Madhavan, J., Reghu, C.P., Rao,G.P., Ammal, S.L., Idicula,S.P. and Joseph, A. 2002b. Management of the 1981 IRRDB germplasm collection in India: *Paper presented in the IRRDB Joint Workshop on Plant Breeding, Agronomy and Socio-Economics* held in Malaysia and Indonesia 28.08. to 07.09.2002

Varghese,Y.A. 2003. Crop Improvement in the non-traditional rubber growing areas in India. In: *Global Competitiveness of Indian Rubber Plantation Industry – Rubber Planter's Conference,* India 2002 :117-131

Varghese, Y.A. and Abraham, S.T. 2004. Rubber. In: *Hand Book of Industrial Crops* (Eds. V.L. Chopra and K.V. Peter) Haworth Reference Press Ch.10.

Vijayakumar , K.R., Thomas, K.U. and Rajagopal, R. 2000. Tapping. In: *Natural Rubber: Agromanagement and Crop Processing.* (Ed P.J.George and C.Kuruvilla Jacob). Rubber Research Institute of India, Kottayam, pp.215-238.

Vijayakumar, K.R., Thomas, K.U.,Rajagopal, R. and Karunaichamy, K. 2003. In: *Global competitiveness of Indian Rubber industry- Rubber Planters' Conference, India,* (Eds. C. Kuruvilla Jacob and Kurien K. Thomas). Rubber Research Institute of India, Kottayam, Kerala, India, pp.155-162.

Viswanathan, P.K., Reghu, C.P. and George, T.K. 2002. From latex to timber: The Indian perspective. In: *Proceedings of Rubber Planters' Conference*, India, pp.252-266.

Wycherly, P.R. 1969. Introduction of *Hevea* to the Orient. *The Planter* 44: 127- 137.

Wycherley, P.R.1977 Motivation of *Hevea* germplasm collection and conservation. *Workshop on inter-collaboration in Hevea breeding and the collection and establishment of materials from the neo-tropics*, Kuala Lumpur. 5p.

Wycherly, P.R. 1992. The genus *Hevea*-Botanical aspects. In: *Natural Rubber: Biology, Cultivation and Technology*. (Ed. M.R.Sethuraj and N.M.Mathew). Elsevier, Amsterdam, pp.50-66.