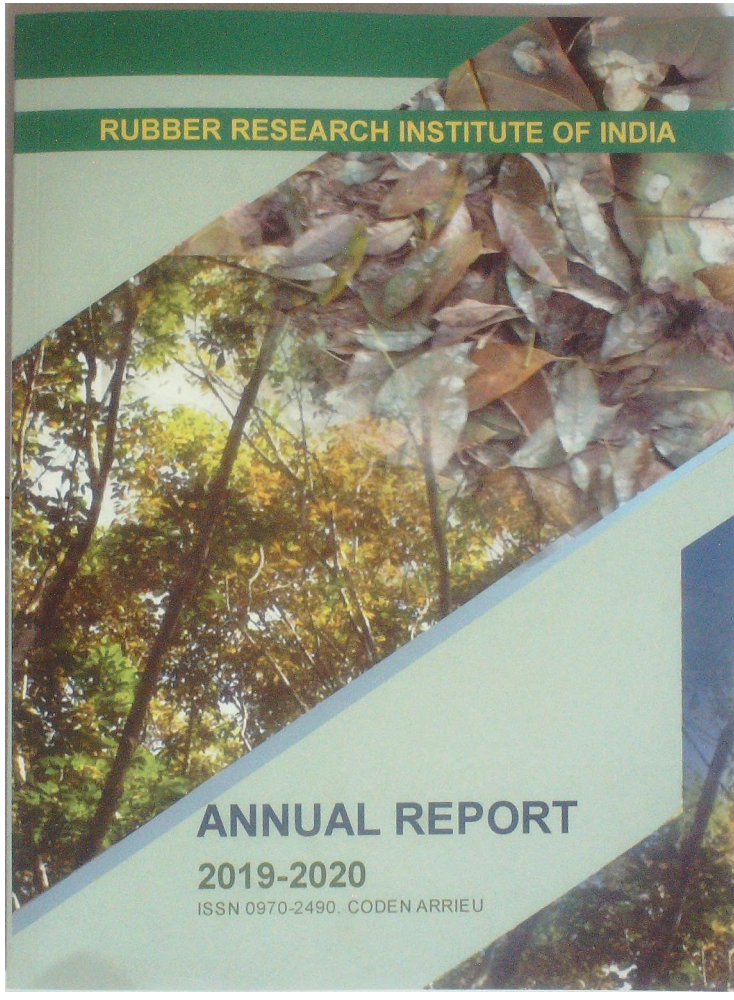

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Rubber Research Institute of India

The Rubber Research Institute of India (RRII), under the Rubber Board (Ministry of Commerce and Industry, Government of India), had its inception in 1955. With a very modest beginning, the RRII is now capable of handling most of the problems associated with natural rubber (NR) production technology, primary processing and product development. The steady growth of RRII in its scientific worth and research contributions has won it the recognition as an International Centre of Excellence in NR research.

Location

The RRII is located on a hillock 8 km east of Kottayam town in Kerala State and is easily accessible by road. Kottayam is connected to all major cities in the country by rail. There are two International Airports, one at Thiruvananthapuram, 160 km south and the other at Nedumbassery, 95 km north of RRII.

Organization

For the efficient discharge of its functions, the RRII has established major research divisions and research supporting sections at its headquarters and regional research establishments at appropriate locations where *Hevea brasiliensis* is commercially grown or is likely to be grown.

Continued on inside back cover

ANNUAL REPORT
2019-2020

RUBBER RESEARCH INSTITUTE OF INDIA
RUBBER BOARD
(Ministry of Commerce & Industry, Government of India)
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CONTENTS

THE RUBBER BOARD

The Indian Rubber Board was constituted under the Rubber (Production and Marketing) Act, 1947, which came intoforce on 18 April 1947. This Act was amended in 1954, 1960, 1982 and in 1994. The Act was further amended by the Rubber (Amendment) Act, 2009 which came intoforce on 22nd January 2010.

Organization

The Executive Director is the principal executive officer and exercises control over all departments of the Rubber Board. The Research Department, (Rubber Research Institute of India) works under the administrative control of the Executive Director.

Executive Director
Dr. K.N. Raghavan IRS

Rubber Research Institute of India
Dr. James Jacob
Director of Research

Crop Improvement
Dr. Kavitha K. Mydin (upto 31.08.2019)
Joint Director

Botany
Deputy Director (vacant)

Biotechnology
Joint Director (vacant)
Dr. R.G. Kala
Principal Scientist (Officer-in-charge)

Genome Analysis
Principal Scientist (vacant)

Germplasm
Joint Director (vacant)

Dr. Jayashree Madhavan
Principal Scientist (Officer-in-charge)

Crop Management
Joint Director (vacant)

Agronomy/Soils
Dr. M.D. Jessy
Joint Director

Fertiliser Advisory Group
Dr. Mercykutty Joseph
Principal Scientist

Plant Physiology
Dr. K. Annamalainathan
Joint Director

Climate Change and Ecosystem Studies
Joint Director (vacant)

Crop Protection
Joint Director (vacant)

Plant Pathology
Joint Director (vacant)
Dr. Shaji Philip
Principal Scientist (Officer-in-charge)

Economics Research
Toms Joseph
Joint Director

Latex Harvest Technology
Joint Director (vacant)
Dr. R. Rajagopal
Senior Scientist (Officer-in-charge)

Rubber Technology
Joint Director (vacant)

Deputy Director (vacant)
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Principal Scientist (Officer-in-charge)

Technical Consultancy
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Deputy Director (vacant)
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Senior Scientist (Office-in-charge)

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Deputy Director

Regional Research Station, Agartala
Dr. Sushil Kumar Dey
Joint Director

Regional Research Station, Nagrakata
Deputy Director (vacant)

Regional Research Station, Tura
Deputy Director (vacant)
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Senior Scientist (Officer-in-charge)

Regional Research Station, Dapchari
Dr. Meena Singh
Senior Scientist (Officer-in-charge)

Regional Research Station, Dhenkanal
Dr. Bal Krishan
Senior Scientist (Officer-in-charge)

Regional Research Station, Padiyoor
Dr. Radha Lakshmanan
Principal Scientist (Officer-in-charge)

***Hevea* Breeding Substation, Kadaba**
Sri. S. Ravichandran
Scientist (Officer-in-charge)

***Hevea* Breeding Substation, Thadikarankonam**
Dr. M. Suryakumar
Scientist (Officer-in-charge)

Administration
Deputy Secretary (vacant)

Finance & Accounts
V. Ganeshan
Deputy Director (Finance)

Instrumentation
Deputy Director (vacant)
M.R. Anilkumar
Instrumentation Officer (Officer-in-charge)

Library & Documentation Centre
N. Latha
Documentation Officer

Statistics & Computer
B. Biju
Assistant Director (Systems)

PREFACE

The major outcomes from RRII during 2019-20 was the release of a cold tolerant, high yielding hybrid clone (RRII 429) for commercial cultivation in Northeastern states of India. This was done at Agartala on 12.02.2020 by Shri. Biplab Kumar Deb, Hon'ble Chief Minister of Tripura. With the release of this clone after more than 23 years of field trials in the region, there are presently two indigenous clones available for large scale commercial cultivation in the North-East. As Northeastern region possesses the largest area for rubber cultivation in future, the two clones will give a major impetus to rubber cultivation in the region. In addition, three high yielding clones introduced from Malaysia in the past (PB 280, PB 314 and PB 255) were also recommended for commercial cultivation in the traditional region. I am happy to learn that more clones are in the pipeline at different stages of field experimentation and still better clones will emerge from these trials in future.

Given the very small size of rubber holdings in the country, the homestead approach being tried by RRII is a welcome step. With a bouquet of grains, fruits, vegetables and fodder crops (both annual and perennials) grown as intercrops, goat rearing, fish farming *etc.* practiced inside immature and mature rubber holdings, the gross revenue from a given piece of land can be increased without compromising on the rubber yield. Such grower-centric approaches are the need of the hour to retain the growers in rubber cultivation. Unlike many other agricultural crops, natural rubber plantations are amenable to homestead farming as established through our field experiments. Planting the right clone for the region, following cost saving management practices and adopting auxiliary income generating activities will decide the ultimate profitability of rubber cultivation.

The National Rubber Policy envisages production of atleast 75 per cent of the domestic requirement of natural rubber within the country itself. To meet this target, it is important that growers continue to remain in rubber cultivation and more areas brought under this crop. I am glad that RRII is using long term climate data, satellite-based remote sensing and other geospatial techniques *etc.* to identify new areas where rubber can be newly introduced in the country. I understand that more regions in Northeastern states will became climatically better suited for rubber cultivation in the coming years.

A close watch on newly emerging as well as endemic rubber diseases seen in India

is most essential. The extent of spread of new diseases, if any, should be systematically monitored and steps taken to keep their spread under check. Developing disease tolerant clones that require little spraying of chemical pesticides should be the ultimate aim of researchers.

There should be greater focus on Research and Development to create value addition at the stage of primary processing of the latex. This will help growers/ processing centers get better price for their produce. I understand that a couple of innovations made in this particular sector, such as deproteinizing latex/dry rubber, various types of latex master batches *etc.* hold considerable potential. Every effort should be taken to take these innovations to a logical conclusion. I also note that there has been considerable increase in the volume of technical consultancy services provided to the rubber products manufactures in the MSME sector. This service needs further strengthening. I appreciate the efforts being taken up to register RRII as a Host Institute of startup programmes under the MSME sector and switching over to the latest NABL regulation (ISO 17025-2017) by the Quality Council of India. A dedicated laboratory to test quality specifications of rubber products imported into the country and a REACH Compliance Laboratory for testing rubber products exported to EU countries will soon be established. These laboratories and further strengthening of R and D and consultancy support for rubber products manufacturing sector can generate a stream of much needed revenue besides providing yeoman service to the entrepreneurs working in area of manufacture of rubber based goods.

I congratulate the Director, Scientists and other officials of RRII for their committed service to the development of natural rubber sector in the country and commend this report for further study.

Dr. K.N. Raghavan
Chairman & Executive Director

DIRECTOR'S REVIEW

Developing region-specific clones and good agronomic practices are the two central themes of agricultural research and during the reporting year the Institute did quite well in both. Releasing an indigenously developed high yielding clone for commercial cultivation in the North eastern states of India was one of the highpoints of this year. After completing more than 23 years of field experiments in the region, RRII 429 was formally released by Shri. Biplab Kumar Deb, the Honorable Chief Minister of Tripura on 12th of February 2020 at Agartala during a special session of the meeting of the R&D Committee that was held for the first time ever outside Kottayam. This clone is tolerant to cold stress and most diseases of rubber. Along with RRII 208 that was released during 2012 there are two RRII hybrid clones now available for exclusive cultivation in the North-East. In addition, three clones imported from Malaysia (PB 280, PB 314 and PB 255) during 1985 were also recommended for commercial cultivation in the traditional regions after completing more than 25 years of field trials. Another two exotic clones (IRCA 130 and IRCA 111) that were imported from Cote d' Ivoire during 1991 were upgraded to Category II of the planting recommendation which is the penultimate stage of commercial release. Phase 6 of the Participatory Clone Evaluation Programme was launched in five locations in the field with 19 pipeline clones. Initial results from the earlier phases of this programme are encouraging.

The various homestead trials under progress in different regions of the country reflect a clear shift from the traditional rubber-centric approach to a more grower-centric approach which is the need of the hour. Raising the total farm income of the grower from his holding that is fast shrinking in area is crucial to retain the grower in rubber farming. Apart from various types of food and fodder crops inter-cultivated in immature and mature rubber holdings, a variety of other agricultural enterprises such as fish, poultry and cattle farming can be practiced in rubber holdings. In addition to ensuring nutritional security to the family, these activities can provide the much-needed subsistence for the grower when rubber price falls. Digital soil fertility maps of rubber growing soils of Tripura were prepared. The highly acidic nature of these soils which had less organic content than soils of the traditional regions is a matter of concern as this can cause widespread deficiency of essential plant nutrients such as calcium, zinc and boron which are not included in the fertilizer recommendation for Tripura.

A new leaf disease caused by the fungus *Pestaloptiopsis* has been spreading in some

rubber growing countries in South East Asia. Similar symptoms were reported from different parts of Kerala but the causative organism was identified as *Colletotrichum spp.* and the incidence was not as severe as in the other countries.The recently imported international clones through the IRRDB were tested for their reaction to *Colletotrichum* and *Corynespora* and a few were tolerant to the former. Gene expression in response to *Phytopthora* infection was studied. Highly saturated genetic linkage maps were constructed and QTL markers were identified for diseases caused by *Phytopthora*, *Colletotrichum* and *Corynespora*, the major pathogens of rubber in India. These markers together with markers for high yield and stress tolerance will greatly help in developing disease tolerant, high yielding and climate-resilient smart clones. Dependence on chemical disease control measures has to be further reduced. Molecular Biologists, Plant Physiologists, Plant Breeders and Plant Pathologists must work in close unison to realize the smart clone vision which is to release at least one high yielding, fast growing, disease tolerant and climate-resilient new clone every five years or so. Given the large number of pipeline clones at various stages of field trials and the emergence of large number of molecular and physiological markers, this vision can become a reality. However, it remains to be seen what is the theoretical upper yield ceiling in this species and whether we are fast approaching this genetic limit in the available genomic resources in the country.

Somatic embryogenesis and *in vitro* plant regeneration could be obtained from transgenic cells incorporated with agronomically important genes such as *hmgr1* (rubber biosynthesis), *osmotin* (drought stress), *ipt* (cell proliferation and fast growth), and *Hsp31* (stress tolerance) and these are undergoing hardening process.This is a remarkable fete. Efforts to develop antibiotic marker-free GM rubber and homozygous diploids gave promising results. Haploid plantlets of RRII 414 and RRII 105 were successfully developed, hardened and field planted. This is a significant achievement in a highly cross pollinating, genetically heterozygous tree species. Healthy plants were regenerated from cassicolin challenged embryos of RRII 105, a clone that is highly susceptible to *Corynespora* and the regenerated plants exhibited tolerance to *Corynespora* infection. Although highly exciting, this finding defies traditional knowledge of genetics.

Satisfactory growth and yield in rubber with little external fertilizer application known for many years is another observation that defied classical explanations. Transcriptome analyses of roots of rubber showed presence of at least two Arbuscular Mycorrhizal Fungi (AMF) which are known to mobilize mineral nutrients from the soil and make them available for plant growth. This information should be further explored to make rubber cultivation even less dependent on chemical fertilizers. Also, it remains to be seen how far AMF association with the roots of forest trees help them grow naturally with no external fertilizer application. It is time that researchers come out of the box and explore unorthodox avenues and dream a future scenario where rubber cultivation is totally free from chemical fertilizers and pesticides and thus promote the organic farming potential of rubber. This is a challenge that we must face squarely and immediately and this warrants a multi-disciplinary approach.

In addition to independence from chemical inputs for rubber cultivation, our

studies estimated that the net lifecycle emission from rubber plantation is 27 MT CO_2 per ha which is a substantial ecosystem service provided by rubber cultivation.

Optimization and validation of molecular tools for assessment of genetic diversity and evolutionary relationships was continued. Outcome from this work will directly benefit in identifying genetically divergent parents for including in biparental mating programmes which will favor producing genetically more advanced progenies. A total of 829 genes were found differentially expressed among high and low yielders. Similarly, ethylene-mediated signal transduction and ethylene-induced gene expression were studied in high and low yielding clones.

Geospatial techniques, including satellite-based remote sensing were used to map and update area under rubber cultivation in the country. Long term climate data from 372 districts falling in the major rubber growing belts in nontraditional areas were examined and it was found that 65 of them may be suitable for cultivating rubber.

Group approach or collectivism is needed to address several structural impediments in the smallholding sector. There is a felt need to strengthen two-way communication between growers and experts of Rubber Board that is fundamental to seamless diffusion of technology. Timely and precise information and communication are vital for sustaining rubber cultivation even as the world is changing very fast.

In the midstream (primary processing) and downstream (Rubber Technology/ products manufacturing) sectors also the Institute continued to make significant advancements. Deproteinization of latex, making sheet from preserved latex, latex-carbon black master-batches incorporating nano filler *etc.* are some promising areas of work in the midstream sector. Earlier successful devulcanization was achieved at the Institute and storage behavior of devulcanized rubber is now being examined. Cytotoxicity studies with crumb rubber particles obtained from end of life tyres showed no harmful effects on cell line.

In the area of products development, the Institute completed forensic analyses of 42 products and conducted various tests of 649 rubber products mostly from the MSME sector. Detailed project reports were prepared for three large medical gloves manufacturers and conducted a cost-benefit study for the proposed Rubber Park at Kanyakumari. In addition, consultancy and troubleshooting services were given to a large number of rubber industries.

Twenty quality standards for natural rubber latex were revised as per the request of BIS. The Technical Consultancy Division of the Institute is in the process of switching over to the latest NABL regulation (ISO17025-2017) under the Quality Council of India. Steps were taken to register RRII as a Host Institute of startup programmes under the MSME sector. Steps were also taken to commission two laboratories at RRII; one for testing REACH compliance of rubber products proposed to export to the EU and another for testing quality standards of rubber products imported into India.

Despite continuing difficulties with scarcity of funds and large number of vacancies in scientist and other technical cadres, RRII could perform well during the reporting year. This was possible only because of the visionary leadership and support provided by the Chairman and Executive Director which is gratefully acknowledged.

Dr. James Jacob

AGRONOMY AND SOILS DIVISION

Developing good agricultural practices to enhance growth and yield of rubber and sustain soil health, reducing cost of cultivation, mitigating drought, generating additional income and improving biodiversity continued to be the major thrust areas of research of the Division and various experiments with these objectives were continued. A homestead farming project with multiple enterprises was initiated during 2019. Follow up studies of RubSIS on liming and fertilizer skipping was in progress at different locations. Analysis of soil samples for fertility mapping of rubber growing regions of North East India was in progress.

1. Nutrient Management

The experiment on nutrient management initiated in 2016 to revise the current fertilizer recommendation for root trainer rubber plants was continued. The results indicated the superiority of integrated management (cow dung slurry and PGPR) and foliar nutrition for the growth of root trainer rubber seedlings.

The fertigation experiment in root trainer nursery was continued at CN, Karikkattoor. Fifty root trainer plants each were observed under control and fertigation treatments. Considerable savings was noted in water consumed for irrigation *viz.* about six litre of water per plant was used for irrigation under control while it was one litre per plant under the fertigation treatment. The plants under fertigation attained saleable standards by two and a half months while in the control it took three months. The plants under fertigation treatment had significantly higher diameter, height, inter nodal length and number of leaves in the first and second whorls.

Continued the field experiment on target application of water soluble fertilizers in to the root zone of young rubber plants. Girth of plants after two years was not significantly different between the standard practice and water soluble fertilizer treatments. Foliar application of fertilizers also did not indicate superiority over standard practice.

The field experiment started during 2001 at Central Experiment Station (CES), Chethackal to study the effect of long term application of inorganic and organic manures on the growth and yield of rubber and physico-chemical properties of soil was continued without applying fertilizer and FYM. No significant difference was observed between treatments for yield five years after skipping fertilizers. The field trials initiated during 2011 to study the effect of secondary and micronutrients on growth of rubber and soil properties at three locations, *viz.* Cheruvally, Palappally and Thamarassery estates were also continued. Significant difference was not observed between treatments with respect to girth of plants.

In the study on rhizosphere chemistry and adaptations of rubber to acidic soil conditions, the rhizosphere and bulk soil collected from 26 locations in the acidic soils of Kerala showed that the pH, available P,

K, CEC, exchangeable K, aluminium P and calcium P fractions were significantly higher and exchangeable Al was lower in the rhizosphere soil compared to the bulk soil. The pH was near 5.5 in the rhizosphere of young rubber trees. Soil organic carbon status increased in soil with pH 7.4 after the growth of rubber seedlings for eight months compared to soils with pH 5.5 and 4.5.

In continuation of the rhizosphere study, a new trial was initiated to study the rhizosphere chemistry of clones RRII 414, RRII 430 and RRII 105 at two locations in Kerala.

2. Soil and water conservation

The experiment on evaluation of biological/vegetative hedges for soil and water conservation in rubber plantation initiated during 2009 in Mundakayam estate was concluded. The establishment of vegetative hedges did not significantly influence growth of rubber, but stabilized the terraces and reduced soil erosion during initial years.

3. Intercropping and cropping systems

The field experiment initiated in 2018 at CES, Chethackal to find out the feasibility of establishing various crops like coffee (Selection 13), pepper, turmeric, amorphophallus, colocasia and chilli, as intercrops in mature rubber plantation under tapping was in progress. Planting of ginger and turmeric was undertaken and coffee started flowering.

The experiment on development of a multi-species rubber-based cropping system for Tamil Nadu region was in progress. Growth of rubber continued to be significantly higher in intercropped area compared to control plot.

The experiments on intercropping perennial crops with rubber initiated at CES, Chethackal in 2001 were continued and the growth and yield of rubber continued to be not influenced by cultivating coffee or nutmeg as intercrops. Experiment on inter planting of rubber with timber trees *viz.* teak, wild jack and mahogany initiated in 2001 at CES, Chethackal was continued. Growth of rubber was not significantly influenced by row spacing and type of timber intercrops. No significant difference in yield of rubber was observed between spacing, type of intercrops and interactions. Among the timber plants, performance of wild jack continued to be better. The experiment to study the effect of retaining pineapple after the normal intercropping period on performance of rubber and soil properties was in progress at Malankara estate.

A homestead farming project was initiated at RRII during 2019. Rubber (clone 430) was planted in paired rows at the spacing of 14x4x2.4 m. A control plot was also established at a spacing of 6.7x3.0 m. Perennial intercrops, mango, cashew and jack grafts were established as intercrops.

4. Ground cover management

The field experiment on the effect of legume covers and natural flora on the growth of rubber, soil physico-chemical and biological properties, biomass and nutrient turnover laid out during 2012 at CES, Chethackal was continued. Growth of rubber under both cover crops were comparable and the highest growth was recorded in *Pueraria* established plots. Tapping commenced in the experimental area.

The observational trial to find out the feasibility of establishing *C. caeruleum* under partial shade (after the intercrop pineapple) initiated at Kaliyar estate was continued.

Table Ag. 1. **Soil properties in the *C. caeruleum* established field at Kaliyar estate**

Time of soil sampling	OC (%)	Available nutrients (mg kg^{-1})				pH
		P	K	Ca	Mg	
Initial	1.40	13.8	52.9	33.3	8.7	4.37
After 3 ½ years	1.67	15.0	60.7	55.1	13.0	4.53
t stat	**	NS	NS	**	**	*

*,**significant at 5 and 1 % level, respectively. NS-Not significant

C. caeruleum established well in the field and retained in the field in summer also. Soil pH, OC and available Ca and Mg status significantly improved three and a half years after establishing *C. caeruleum* (Table 1).

The study on differential effect of weed flora on growth of rubber and soil properties initiated during 2017 with soft weeds, grasses, *Mucuna* and natural ground cover was continued.

The study on weed spread of *Mikania micrantha* Kunth from rubber plantations was concluded. The study showed that the rubber plantations infested with *Mikania* were a good source for the weed spread to nearby localities and anthropogenic activities limited the spread and establishment of *Mikania* in Kerala.

The data on distribution of major weeds in rubber plantations of South India collected through visual scoring in 10760 geo-referenced holdings was mapped in GIS. *Axonopus compressus* was the major weed in rubber plantations though regional variations in occurrence were observed. *Chromolaena* was also a major weed in Northern districts of Kerala *viz*. Trissur, Malappuram, Kozhikode, Kannur, Kasaragod, Karnataka and Maharashtra. Association between soil fertility status and weed distribution was observed and available Ca and Mg status of the soil influenced weed distribution.

5. Planting techniques

The field experiment initiated in 2010 to study the impact of mechanized land preparation on soil erosion and growth of plants was concluded. Tilling of the inter-row area for intercropping significantly increased soil erosion up to six years after planting and no significant difference in soil erosion was observed between the treatments.

The experiment to evaluate different planting systems initiated in 2007 at Cheruvally estate was continued. Canopy growth continued to be asymmetrical. Yield of trees in the paired row system of planting was comparable with that of control (square system of planting).

6. Development of agro-management techniques for reducing the gestation period

The experiment to evaluate the field performance of one-whorl, two-whorl and three-whorl polybag and root trainer rubber plants initiated at CES, Chethackal during 2008 was continued. Significant difference in yield was not noticed among different types of planting material.

The field experiment initiated at CES, Chethackal in 2008 to develop an agronomic package to reduce the immaturity period of rubber starting from planting material onwards with combinations of two types of planting material and two management options as treatments was in progress. Direct-seeded green budded plants recorded significantly higher yield compared to green-budded stumps raised in polybags.

7. Stress management

Evaluation of latex coated mulch materials was continued with more layers of newspaper to increase the durability in the field.

The study on high leaf K and drought tolerance was continued with RRII 414, RRII 430 and RRII 105 in the experimental field of RRII and leaf and root zone soil samples were collected for chemical analysis.

8. Soil fertility mapping and soil health monitoring

8.1. Rubber growing regions of South India

Follow up studies of RubSIS were in progress. The block trial studying the effect of liming on growth of immature rubber and soil properties at Thevervelil Estate, Perunadu was continued. The higher girth increment observed in the initial stage for the lime treated plants decreased at later stages. After 27 and 39 months of planting, there was no significant difference between lime applied and control treatments with respect to girth increment. Analysis of soil three months after the fertilizer application indicated that available P, K, Ca and Mg were significantly higher under lime treatments. The trial initiated at Malankara estate, Thodupuzha was also in progress.

The block trial to study the effect of liming on growth and yield of mature rubber and soil properties at Thevervelil Estate, Perunadu was continued. The soil samples collected were analyzed and it was observed that available Ca and Mg were significantly higher under lime treatments, three months after the fertilizer application. The dry rubber yield in the two treatments *viz.* in lime applied and not applied blocks were comparable. The trial initiated at Malankara estate, Thodupuzha was also in progress.

Field experiments initiated at five locations in Kerala during 2018-19 and at one location in Karnataka to study the effect of skipping of fertilizers on growth and yield of rubber and on soil properties were in progress. Another field trial was initiated at TR&T Estate Mundakayam to find out whether application of Mg along with lime will improve performance of rubber.

8.2. Rubber growing regions of North East India

Analysis of soil samples collected (1384) from Tripura was completed for 13 fertility parameters (Soil pH, exchangeable Al, OC, available P, K, Ca, Mg, S, B, Zn, Cu, Fe and Mn) and soil fertility maps were developed with geo-statistical techniques. The soils were either extremely acidic or very strongly acidic in nature. Almost entire rubber growing regions were medium in OC and low in available P status. The available K status ranged from low to medium. Majority of the rubber growing regions were low in available Ca status while medium to high in available Mg status. Most of the rubber growing regions in the state were low in available S. Eighty nine per cent of the rubber area in Tripura was low (< 0.5 ppm) in available B and 97 per cent of the area was low in available Zn (< 1ppm). Analysis of soil samples collected from rubber growing regions of Meghalaya is in progress.

FERTILIZER ADVISORY GROUP

The mandate of the group is to provide soil and leaf analysis based fertilizer recommendation to rubber growers. The services were provided through the soil and leaf testing laboratory at RRII headquarters and seven regional laboratories. Advisories on fertilizer usage were provided to growers by answering the telephonic enquiries or email queries. Of late, the major activity of the regional laboratories was estimation of dry rubber content of latex samples. The sample output during the reporting year is provided in Table FAG 1.

Table FAG 1. **Details on soil, leaf and latex analyses and the revenue**

Sample details	Number	Revenue (Rs./-)
Soil	596	102195
Leaf	506	177711
DRC of latex samples	83049	4585270
Total Revenue		4865176

CLIMATE CHANGE AND ECOSYSTEM STUDIES DIVISION

The major areas of research in the Division are analysis of climate change processes and its impact on rubber cultivation in different rubber growing regions of India. Specific information system on rubber cultivation is being developed using RS-GIS platform to identify areas under rubber cultivation and climatically suitable area for further extension of rubber plantations in non-traditional regions. Meteorological data management system in rubber growing regions is regularly updated to address the climate change issues.

Latest satellite data (March 2019) was used for mapping and updating of natural rubber (NR) plantations acreage in Assam, Karnataka, Kanykumari district in Tamil Nadu and five districts in Kerala. Studies were undertaken to estimate potential areas available for rubber cultivation in the states of Tripura and Assam. Agro-climatic suitability analysis of North estern region of India was completed using area under curve method and climate tolerance limits (CTL) parameters. In the country as a whole, out of 372 districts considered for the study, only 65 (17%) districts were qualified under the normal category having a similar climate to that of Kanyakumari or Kottayam. A total of 82 (22%) and 138 (37%) districts were qualified in the 10 and 20 per cent deviation level categories, respectively. The impacts of El Nino indicators on the seasonal rainfall pattern and temperature were analyzed in rubber growing regions.

1. Developing rubber based information system using remote sensing and GIS

1.1 Geo-spatial mapping and updating of natural rubber (NR) acreage using latest satellite data

1.1.1. Karnataka

Geo-spatial mapping and updating of acreage of rubber plantations in Karnataka was completed. NR acreage in the entire

state was updated using satellite data to be 69,581 ha (age three years and above) as of March 2019. Spatial extent of rubber plantation was the highest in Dakshin Kannada district (46,353 ha) followed by Udupi (13,430 ha) Shivamogga (4,599 ha), Chikkamagaluru (2796 ha) and Coorg (2,403 ha) districts (Table CCES.1).

Spatio-temporal change of NR was analyzed in different districts in Karnataka during 2013 to 2019. Results found that about 38,354 ha of rubber area have been added in the state between the period 2013 and 2019. An average of 6,392 ha of NR area has increased every year in Karnataka during this period.

1.1.2. Kanyakumari district of Tamil Nadu

Natural rubber area estimated from Kanyakumari district as of March 2019 satellite data (Sentinel 2A, 25th March 2019, 10m) was around 21,933 ha (age three years and above) Rubber plantations were distributed in three out of the four taluks in Kanyakumari district, namely Kalkulam (48%), Vilavankode (45%) and Tovalai (7%) taluks. Rubber plantation was not found in Agastheeswaram taluk in Kanyakumari. Tonal variations in satellite data revealed that replantation has taken place in many locations of Kalkulam and Vilavankode taluks in recent years. It was also found that NR area has expanded to southern parts of Kalkulam and Vilavankode taluks.

Table CCES. 1. **Satellite-derived spatio-temporal expansion of rubber plantations in Karnataka (age three years and above) during the period 2013 to 2019**

Districts	NR area (ha)		Expansion (ha)
	2013	2019	
Dakshin Kannada	20413	46353	25940
Udupi	4709	13430	8721
Shivamogga	1589	4599	3010
Chikkamagaluru	2395	2796	401
Coorg	2121	2403	282
TOTAL:	31,227	69,581	38,354

1.1.3. Kerala

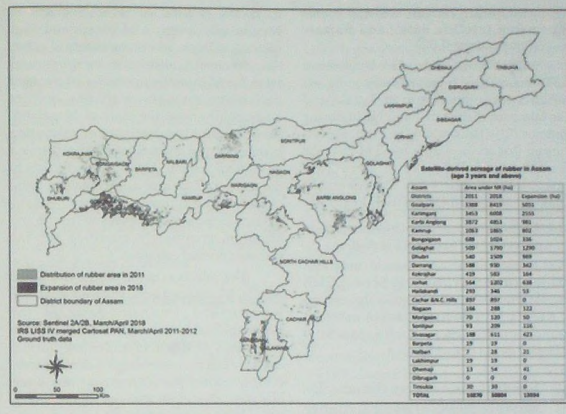
Satellite-based mapping and updating of NR acreage in different districts of Kerala is in progress. As of now mapping and updating of NR acreage in five districts of Kerala was completed (Kollam, Pathanamthitta, Alapuzha, Kottayam and Idukki). Satellite- based NR area statistics in the five districts of Kerala as of 2019 is give below.

Table CCES. 2. **Satellite-based NR area statistics for five districts in Kerala**

Sl. No.	Districts	NR area (ha)
1	Kollam	46,935
2	Pathanamthitta	54,468
3	Alapuzha	8,490
4	Kottayam	1,07,708
5	Idukki	37,806

2. Identification of potential areas for rubber cultivation in NE India using satellite data, long term climatic data and soil fertility status

Acreage of rubber (age three years and above) in Assam state updated as of 2018 satellite data and it was 30,804 ha. Results showed that about 13,934 ha of rubber area has increased in the state which indicated that approximately 2000 ha of rubber have been added every year during this period. Between 2011 and 2018 considerable rubber area has increased in the districts of Kamrup, Bongaigaon, Golaghat, Dhubri, Darrang and Jorhat (Table inset in Fig. CCES. 1). However, further area has not been expanded much in Lakhimpur, Dhemaji, Tinsukia, Barpeta and Nalbari districts during the period 2011 to 2018.



Assam	Area under NR (ha)		
Districts	2011	2018	Expansion (ha)
Goalpara	1388	8419	5031
Kamrup	3453	6058	2155
Karbi Anglong	3572	4853	981
Kamrup	1063	1865	802
Bongaigaon	689	1024	336
Golaghat	500	1790	1290
Dhubri	540	1509	969
Darrang	588	930	342
Kokrajhar	419	583	164
Jorhat	564	1202	638
Hailakandi	293	346	53
Cachar &N.C. Hills	857	857	0
Nagaon	156	288	132
Morigaon	70	120	50
Tamlpur	93	209	116
Sivasagar	188	611	423
Barpeta	19	19	0
Nalbari	7	28	21
Lakhimpur	19	19	0
Dhemaji	13	54	41
Dibrugarh	6	6	0
Tinsukia	30	30	0
TOTAL	10879	30804	13994

Fig. CCES. 1. Spatio-temporal expansion of rubber plantations in Assam during the period 2011 to 2018

2.1. Other RS-GIS studies

2.1.1. Identification of potential areas for rubber cultivation in India

Net potential area (NPA) available for rubber plantation expansion in Tripura and Assam was estimated by analysing district-wise data on total cropped area and other major agriculture crops.

2.1.2. Calculation of CO_2 potential of NR plantations in Karnataka

Based on the satellite-based (MODIS) net primary productivity (NPP) annual carbon sequestration potential (as of 2014) of rubber plantations in Karnataka was estimated which comes to about 8.2 tonnes C ha^{-1} year which is equivalent to 30 tonnes CO_2 ha^{-1} $year^{-1}$. The high rate of CO_2 sequestration is an important ecosystem service provided by the natural rubber plantations.

2.1.3. Kavalappara landslide

Due to severe rainfall, a massive landslide occurred in Kavalappara, Malappuram district in Kerala on 8th August 2019. The landslide was studied using pre and post event satellite data and assessed the extent of affected area (13.03.2019 and 18.12.2019, Sentinel 2B, MSI). Satellite data interpretation revealed that nearly 19 ha of sloppy land area was affected due to the massive landslide. The rainfall trend in Malappuram district was also monitored using JAXA global rainfall watch (GSMaP) which indicated that the district received extremely high intensity rainfall on 8th August 2019.

2.2. Monitoring extreme weather events using satellite data Land Surface Temperature (LST)

MODIS based land surface temperature (LST) was analysed to get spatial intensity and variation of temperature in Kerala and Kanyakumari district of Tamil Nadu during summer 2019 (January to May 2019). Results showed that an increasing trend of LST was observed from February to April 2019 especially in districts like Kanyakumari, Palakkad and Northern districts in Kerala.

2.2.1. Preparation of GIS based map on Circular Leaf Spot (CCLS) disease

Prepared a GIS based map on *Colletotrichum* Circular Leaf Spot (CCLS) disease prevalent rubber growing regions in Kerala by plotting disease affected locations in GIS platform for the years 2017, 2018 and 2019 (17 locations).

3. Identification of agro climatically suitable areas for natural rubber cultivation in non-traditional regions of India

The assessment of agro-climatic suitability in areas where rubber is not normally grown in India (Non-traditional regions) was carried out earlier to identify suitable areas in the Left-Wing Extremism (LWE) affected states and the Northeast Region (NER). From a re-analysis made in NER, a total of 35, 43 and 60 districts were selected from the Area-Under-Curve (AUC) analysis and 27, 42 and 43 districts were selected by the Critical Tolerance Limit (CTL) analysis in terms of normal, 10 and 20 per cent deviation categories, respectively. Within the selected Normal category, for the combined (AUC-CTL) method, six districts (Barpeda, Cachar, Bongaigon, Goalpara, Kokrajhar and NC Hills) in Assam were found to be commonly selected in both methods. A total of three districts in Meghalaya, seven in Mizoram and four districts in Tripura were commonly selected. An additional 11 districts in the same states were found suitable up to the 10 per cent variability category with one district additionally from the state of Nagaland. However, the 20 per cent category comprising of mainly seven districts mainly concentrated in Western Assam. None of the districts in the states of Manipur and Nagaland were chosen in the common category. All the districts in the Southern states of Tripura and Mizoram completely qualified for the common normal category.

The selection made on the combined AUC-CTL procedures showed that the western and southern parts of the geographical areas of the NER mainly comprised of districts under the normal category and the eastern region districts were falling within the 20 per cent deviation category. Out of 69 districts in the NER, a total of 42 districts spread over 6 states (Assam-18, Manipur-9, Meghalaya-3, Mizoram-7, Nagaland-1 and Tripura-4) were identified as normally suitable and 53 and 62 districts in the 10 and 20 per cent variability limit, respectively. No districts in the states of Arunachal Pradesh and Sikkim were chosen in the normal AUC and CTL analyses. Districts coming under the same variability category could adopt similar packages and practices for expansion of natural rubber.

In the Konkan area, amongst the 15 Konkan districts taken for the study Thane district of Maharashtra and Uttara Kannada of Karnataka are the two districts which were found less suitable for rubber cultivation. Belgaum has been identified as falling within the 10 per cent suitability through the AUC method of analysis, but it has been identified as normally suitable in the CTL analysis.

In the country as a whole, out of 372 districts considered for the study, only 65 (17%) qualified under the normal category having a similar climate to that of Kanyakumari or Kottayam. A total of 82 (22%) and 138 (37%) districts qualified in the 10 and 20 per cent suitable categories, respectively. Major portions (>85%) of the suitable areas were individually selected from the NE and Konkan regions. Results from this study could be used as a general indication for suitability and further geo-spatial approaches would be required for locating areas conducive for cultivation of NR with greater confidence.

4. Characteristics of rainfall during 2019

The delay in onset and withdrawal of the South West Monsoon (SWM) has resulted in a skewed distribution of rainfall in the rubber growing regions during 2019. The complete withdrawal of SWM 2019 occurred in mid-October and the North East monsoon (NEM) set in without a break. This affected the climate conditions with temperature extremes and dryness in the NR growing belts in the traditional region during summer following until the middle of July in 2019.

5. Climate resource characterisation of rubber growing areas

5.1. Rainfall characteristics of August 2019

The state of Kerala had experienced several landslides and flash floods during the month of August 2019 associated with an extremely heavy rainfall spell which occurred during 08-10 August 2019. The main causative factors for the occurrence of heavy rainfall over Kerala are stronger westerly/south-westerly winds over the Arabian Sea along and off Kerala coast. Usually the strength of this westerly/south-westerly winds increases in association with the formation of low pressure area over northwest Bay of Bengal and their further intensification.

Rainfall over Kerala during southwest monsoon season (1st June to 30th September 2019) has been exceptionally high. Kerala received 2309 mm against a normal of 2049 mm (above normal by 13%). The rainfall over Kerala during the season, June, July, August and September has been -44, -20, 123 and 64 per cent from the normal, respectively. During 1-15 August, 2019 Kerala received 684 mm rainfall against a normal of 238 mm (+187% rainfall departure).

Based on past 143 years of data, it has been found that Kerala received 1132 mm of rain during the month of August in the year 1931 which is the maximum ever recorded August rainfall of Kerala. This year (2019) witnessed the second highest rainfall for the month of August with 950 mm followed by 877 mm in the year 1923 and 851 in the year 1907. The exceptionally heavy rainfall in August (187% above normal rainfall over Kerala during 1-15th August, 2019) can be attributed to one extremely heavy rainfall spell occurred during 08-10th August 2019.

5.2. El nino/La nina episodes and regional climate in rubber growing regions of India

The studies on El nino occurrences and impact on rubber cultivation is continued. Sea surface temperature (SST) of different region (NINO 1, NINO 2, NINO 3.4 and NINO 4 of equatorial pacific was regressed with SW monsoon rainfall of small spatial scale however, no influence

was observed. El nino events with the warmest SST anomalies in the Central Pacific are more effective in drought producing subsidence over India than events with the warmest SST anomalies in the Eastern equatorial Pacific.

It was observed that during 1980-2014, all the six drought events faced by India were El nino years, however, interestingly not all El nino years led to drought incidents in the country. Since 2000, there were four El nino years (2002, 2004, 2006 and 2009), and three of these (except 2006) resulted in to drought years. The year 2006, which was an El Nino year, however, received normal monsoon rainfall. Similarly, year 1997-98 was a strong El nino year but it resulted in excess rainfall in that year. Contrary to this, a moderate El nino phenomenon in 2002 resulted in one of the worst droughts of the country. However, most of the Indian droughts happened in El nino years. If the rainfall pattern analysed for Kerala state alone the annual as well as monsoon rainfall during El nino years was almost normal or little more than normal. Large spatial variability is noticed both in annual and seasonal rainfall during El Nino years in comparison to non El niño years. During strong El nino years, the rainfall towards the end of the monsoon season was observed to be low. However, in moderate El Nino years, the July month has a deficit rainfall indicating a break in monsoon activity.

Annual frequency (1891-2017) of cyclonic disturbances, cyclones and severe cyclones which has a bearing on the seasonal rainfall pattern exhibited significant changes over time. However, it was observed that there was no influence of El nino over the frequency of occurrences of these cyclonic disturbances.

6. Ecosystem studies

6.1. Vegetation dynamics in rubber plantation ecosystems

Spreading of rubber monoculture plantations in Kerala has altered the structure and pattern of natural vegetation in the traditional rubber cultivating region. It is necessary to understand the vegetation dynamics in the rubber growing regions to study the impacts and restoration potential of natural vegetation. In this context, a new field lay out with four experimental plots were established at CES Chethackal during 2018, which include a normal weeded plot, an un-weeded plot, a plot with controlled weeding and an un-weeded plot without rubber allowing natural vegetation. Vegetation survey was conducted in the plots before the planting, following quadrate method. A total of 126 species were identified from the location which comprises of 62 species of shrubs (including small trees) and 64 species of herbs including ferns. Among the herbs, *Spermacoccae spp, M. micrantha* and *C. pubescence* showed highest relative density (ranging from 1.7 to 1.9). *A. brasiliana, C. hirta, M. vitifolia, C. odorata, H. isora, C. infortunatum etc.* are the shrubs distributed with high relative density in the area. Dominance of invasive exotic species such as *Clidemia hirta, Centrosema pubescence, Lantana camera, Alternanthera braziliana etc.* were noticed. High density of exotic species such as *C. pubescence, A. gangetica, A. brasiliana, C. hirta, C. odorata, M. vitifolia etc.* showed the vulnerability of species invasion into the plantation areas after clear felling. Thus a proper land use strategy is required to prevent the exotic species invasion in rubber plantations after clear-felling to conserve the native flora and ecosystem services.

BOTANY DIVISION

Major research focus during the reporting period was on continuing the classical breeding procedures including hybridization, polycross breeding and ortet selection while more attention was paid to developing region/trait specific clones for drought, cold and disease tolerance. Long term performance of hybrids and selections from polycross breeding was assessed in various field trials. Ortets selected from small holdings and large estates were evaluated in small scale and large scale trials. Pipeline clones were evaluated in Central Large Scale Trials and satellite on-farm trials both in traditional and non-traditional regions for selecting superior clones through participatory plant breeding approach. Exotic clones recently imported under the multilateral clone exchange program with IRRDB member countries were planted in large scale evaluation trials to evaluate their suitability to the agro climatic situation in India. Three Prang Besar clones were upgraded to Category I and released for growers. Two IRCA clones were upgraded to Category 2 of planting recommendation. The cold tolerant clone RRII 429 was released formally to the farmers of North East India which has the potential to achieve higher productivity in the cold stress prone regions of India.

1. Evolving high yielding clones for the traditional area

1.1. Hybridization and clonal selection

1.1.1. Small Scale Trials (SST)

In 1999 SST comprised of progenies from 1994 hybridization programme, five selections *viz*. 94/87 (RRII 105 x RRIM 703), 92 (RRII 105 x Mil 3/2), 296 (RRII 105 x RRII 118) and 567 (RRIM 600 x RRII 203) continued to perform as superior clones and were further multiplied to establish bud wood nursery. In 2001 SST A, two high yielding clones *viz*. 95/413 (65 g t^{-1} t^{-1}), 95/425 (64 g t^{-1} t^{-1}) performed well when compared to the check clone RRII 105 (48 g t^{-1} t^{-1}). Two clones *viz*. 95/121 and 95/410 emerged as superior clones among the 29 clones being evaluated in 2001 SST (B and C) with an average dry rubber yield of 60 g t^{-1} t^{-1} and 58 g t^{-1} t^{-1}, respectively, compared to the check clone in both trials (RRII 105 50 g t^{-1} t^{-1}).

In SST 2003 with 36 clones, two hybrid clones *viz*. 96/417 (RRIM 600 x PB 260) and 96/459 (RRII 105 x RRIC 100) registered an yield of 65 and 70 g t^{-1} t^{-1}, respectively when compared to the check clone RRII 105 (62 g t^{-1} t^{-1}). A clonal nursery of Wickham x Amazonian wild germplasm hybrid clones with RRII 105 and RRIM 600 as check clones (2003) is being maintained at Central Experimental Station, Chethackal. It includes many selections that are under large scale evaluation through Participatory Clone Evaluation Programme.

1.1.2. New generation hybrids

Hybridization programme involving different cross combinations were continued in the breeding orchard at RRII, Kottayam. Using 25 parental cross combinations, a total of 6356 hand pollinations were performed in 2020. A total of 382 seedlings which included 132 hybrids and 250 half-sibs were planted in seedling nursery (2019) for further evaluation.

With an aim to develop high-yielding clones through transgressive introgression, hybridizations were carried out during 2011-14 using high-yielding Wickham clones (RRII 105, RRII 414, RRII 429 and RRII 430) as male parents and superior

Wickham / Amazonian hybrids (95/10, 95/34 and 95/274) as female parents. Based on the test tap yield recorded consecutively for two years, 58 high yielding hybrids were selected for clonal nursery evaluation. Similarly, 163 high yielding clones were selected after evaluating the half sibs of RRII 430, RRII 414, RRII 429 and RRII 105.

1.2. Ortet selection

1.2.1. Clonal Nursery Evaluation

Four clonal nursery trials were laid out in CES, Chethackal this year. This includes a) a clonal nursery with 32 high yielding clones that included selected hybrids, polycross progenies and ortets from non-traditional areas b) 58 high yielding hybrids c) 163 high yielding clones, (selection from half sibs of RRII 430, RRII 414, RRII 429 and RRII 105) d) 36 selections from polycross progenies. From a clonal nursery of 2007, four selections were promoted to PCE trial in Phase 6.

In the Andaman ortet clonal nursery trial (2012), And-Or 103/8 and And-Or 88/4 had exhibited better response to ethephon stimulation with over 25 per cent yield than unstimulated yield. Among 21 hybrid progenies under clonal nursery evaluation (2008), six selections *viz*. (02/688, 02/638, 02/690, 02/844, 02/514 and 02/335) registered superior growth and yield performance when compared to check clone RRII 414. The above selections were multiplied and included in Phase VI PCE trials at five locations.

2. Evaluation of clones

Clone evaluation is an important step in crop improvement, wherein lot of time and resources are required. Large scale evaluation of clones (LST) is an important step conducted after preliminary evaluation of clones in clonal nurseries to reconfirm the potentiality of the selected clones. LSTs are either laid out in RRII's experimental stations such as CES, Chethackal, RRII and other stations. In general, each trial can take about 15 to 20 clones and the plot size may vary from 16 to 25 trees/clone with common border and replications in the range between three and seven depending upon the availability of land, planting material and statistical design. Usually it is evaluated in RBD. In order to cut short the evaluation period, the LFTs/OFTs/PCE are laid out concurrently in multiple locations. We currently have nine large scale evaluation and three on-farm evaluation trials in progress.

2.1. Large scale evaluation (LST)

A new LST (2019) with 14 high yielding clones (half-sib progenies from clonal nursery trial), were planted along with three check clones at CES Chethackal. In the LST of ortets selected from Mundakkayam and Koney estates at CES (2005), MO 45 and MO 28 performed well in terms of girth with 68.8 and 68.7 cm, respectively while RRII 430 and RRII 105 attained 64.5 and 60.5 cm, respectively. Clones KO 9, KO 7 and KO 25 were on par with RRII 430. In terms of yield, the clone KO 9 was superior followed by RRII 105, KO 25 and KO 16 with 92.8, 89.9, 89 and 80.8 g t^{-1} t^{-1}. ALF tolerance was significantly higher in RRII 430 (83.3% leaf retention) while ortets MO 12 and MO 45 were on par with it (68.3 and 66.6%, respectively). The check clone RRII 105 showed only 55 per cent leaf retention.

In the LST of nine promising ortets selected from Cheruvally estate (2005), six ortets showed significantly superior girth compared to the check clone RRII 105 (Table Bot. 1). Two ortets showed significantly superior dry rubber yield with that of the check clone RRII 105 in the second year of

tapping in BO-2 panel (Table Bot. 1). Cyo 41 showed significantly superior girth as well as dry rubber yield and very low incidence of ALF disease. Cyo 41 (P 126), Cyo 35 (P 133), Cyo 48 (P 129) are also being evaluated in the PCE trials.

Table Bot. 1. Girth (cm) and yield ($g\ t^{-1}\ t^{-1}$) in ortet clones

Clone	Girth (cm)	Yield ($g\ t^{-1}\ t^{-1}$)* (second year in BO-2)
Cyo 41	77 a	64.7 a
Cyo 18	64.8 bcd	59.7 a
Cyo 43	61.9 cde	51.7 ab
Cyo 35	66.1 bc	48.3 ab
Cyo 30	66.7 b	46.7 ab
Cyo 72	60.2 de	45.0 abc
Cyo 48	78.9 a	44.6 abc
RRII 105	58.5 e	34.0b cd
Cyo 31	64.1b cd	24.4 cd
Cyo 68	53.5 f	19.3 d
CV(%)	4.2	29.4

*Values followed by same letters are not significantly different based on DMRT

2.2. On-farm evaluation

To evaluate the performance of pipeline clones in the South Karnataka region, an on-farm trial was laid out at KFDC, Karnataka with 14 high-yielding pipeline clones and seven control clones. These pipeline clones are also being evaluated in PCE Phases I (2008), II (2010) and III (2012), at various locations. In an on-farm trial of these clones, three pipeline clones exhibited superior performance during the fifth year of planting compared to RRII 430.

3. Polycross progeny evaluation

Twenty one selections from polycross progenies were bud-grafted and root-trainer plants were raised for planting in clonal nursery trial at CES Chethackal. Another set of 64 polycross progeny selections from RES, Nagrakata were bud-grafted at DDC, Dharanggiri (Assam). Poly-bag nurseries of the selections were also established at Regional Experiment Station, Nagrakata for clonal nursery evaluation.

In order to assess pre-potency of PB clones, 337 half-sib seedlings from high yielding PB clones were evaluated for yield by test tapping. Seventy promising half-sibs were selected and pruned for multiplication to proceed further with clonal nursery trial.

In the observational trial of polyclonal seedlings 2005 (Nettana seed garden origin) at CES, Chethackal, three half-sib progenies exhibited superior yield of 197.1, 175.8 and 160.0 $g\ t^{-1}\ t^{-1}$ while fourteen seedlings yielded above 100 $g\ t^{-1}\ t^{-1}$. The check clone RRII 105 had a mean yield of 62 $g\ t^{-1}\ t^{-1}$.

4. Genetic studies and investigations on genotype x environment interactions

4.1. Genetic parameters

In the genetic analysis experiment at CES, Chethackal, parents and progenies were assessed for growth and yield parameters. Among full-sib families, RRII 105 x RRII 118 continued to yield more than 60 $g\ t^{-1}\ t^{-1}$ in the 17th year of tapping. Clone RRII 33 is the lowest yielder (less than 20 $g\ t^{-1}\ t^{-1}$).

4.2. Physiological evaluation of pipeline clones for drought and cold stress tolerance

In continuation of the physiological evaluation of pipeline clones, polybag plants of 35 pipeline clones were planted in the field during July 2019 at CES, Chethackal, RRS, Agartala and Dapchari. Growth and physiological parameters were measured in the plants grown at Agartala and CES, Chethackal during February and March 2020, respectively. In terms of

photosynthesis, the CO_2 assimilation rate (A) varied between 8.7 to 1.3 μmol m^{-1} s^{-1} under low temperature stress condition. Pipeline clones P116 (8.7), P 093 (8.21), Ch 26 (8.21), P 068 (7.94), PB 86 (7.80), P 178 (7.72), P 089 (7.51), P 192 (7.31), RRIM 703 (6.5) and RRIM 600 (6.44) performed very well under cold stress condition. RRII 429 and RRII 105, A was 5.96 and 5.0 μmol m^{-1} s^{-1}, respectively. Under low temperature stress was at minimum in clones like RRIC 100, P 172, P 048, RRII 118 and Gl1 (with 1.30, 1.66, 1.98, 2.21 and 2.85 μmol m^{-1} s^{-1}, respectively).

When A was measured in the plants grown at CES, Chethackal, the clones P 197 (10.7), P 181 (9.6), P 192 (9.13), RRIM 703 (8.4), P 048 (8.4), P 096 (8.4), RRII 208 (8.0), P116 (7.66), P 120 (7.65) and RRII 414 (7.64) performed well while RRII 105, RRIM 600 and RRII 429 had an A of 6.76, 6.6 and 4.53 μmol m^{-1} s^{-1}, respectively. Clones P 116, P 192 and RRIM 703 performed well in terms of A under both drought and cold situations. The instantaneous water use efficiency (WUE) (A/E) under cold stress was better in clones RRIM 703 (12.87), P 116 (7.5), P 197 (7.2), P 178 (7.1) and RRIM 600 (6.4) while it was 5.0 and 3.9 μmol CO_2 per mol^{-1} water in RRII 105 and RRII 430, respectively. Water use efficiency under drought was better in clones P 093 (5.6) and the check clones RRIM 600 (5.2), RRII 414 (5.1), RRIM 703 (4.8), RRII 422 (4.6) and RRII 429 (3.7).

Under low temperature stress period, chlorophyll index (CI) ranged between 44 and 19. Clones P 184, P 179, P 089 had higher CI along with check clones RRII 208, RRII 429 and RRIM 703. Clones P 048, P 089, P 193 had higher CI during drought season at CES along with check clones RRII 429 and RRII 430. Epicuticular wax content (EWC) ranged between 295 and 67.6 μg cm^{-2} and was higher in P 120, P 073, P 193 and in check clones RRIM 600, RRII 430 and RRII 208. Epicuticular wax content was at lowest in P 112, P 172 and in RRII 417. Epicuticular wax content (EWC) ranged between 295 and 67.6 μg cm^{-2} and was higher in P120, P073, P 193 and in check clones RRIM 600, RRII 430 and RRII 208.

Biochemical parameters were analyzed in latex of 17 clones (selection of high and low yielders) in clonal nursery at Agartala during cold stress period after eight years of planting. Under cold stress condition, in terms of dry rubber yield, clones P 20, P 21, P 107 and P 57 performed better than other clones with 41.2, 37.6, 37.4 and 27.1 g t^{-1} t^{-1}, respectively while RRII 430 and RRII 105 yielded 20.7 and 15 g t^{-1} t^{-1}, respectively. Clone P17 was superior to RRII 430 in CES. In terms of girth, clones P 21, P 107, P 17, P 10, P 110 were superior to RRII 430 at Agartala while in CES P 17, P 10 and P 101 were found superior. In terms of ATP, the clones at Agartala (under cold stress) were inferior to plants at CES during March. Clone RRII 430 had highest ATP in latex followed by P 110 and P 102 at CES. Other parameters such as sucrose, thiol and inorganic phosphate were also estimated. The results of the ranking of clones by rank sum method indicated the superiority of P 21, P 20, P 17 and P 107 over clone RRII 430 at cold stress conditions.

4.3. Selection of pipeline clones for adaptability to two divergent environs with cold and drought stress

Forty-five pipeline clones planted in the year 2012 were screened for their adaptability to sub-optimal environs of India *viz.*, Agartala (Tripura State) and Dapchari (Maharashtra State), which experience cold and drought stress, respectively. The pipeline clones were evaluated for their juvenile growth and yield in clonal nurseries at the above two sites

along with a comparative trial in an optimal environ (Chethackal, Kerala). Of the two sub-optimal environs, pipeline clones displayed better growth and yield with better adaptability to cold-stress. Analysis of genetic parameters also supported the above trend. Under cold-prone environ, five pipeline clones *viz*. P 102, P 107, P 021, P 101 and P 059 achieved better or similar girth when compared to check clones, RRII 429, RRII 430 and abiotic stress tolerant clone RRIM 600. Under drought stress environ, two pipeline clones *viz*. P 102 and P 026 gave better girth than drought-tolerant clone, RRII 208. Under optimal environ at Chethackal, check clone PB 260 along with RRII 414 achieved better girth. Six pipeline clones gave girth which was comparable to check clone RRII 430. Regarding mean juvenile yield performance, P 107 gave maximum yield in the cold environ while P 057 was on par with check clone RRII 430. In addition to the above, sixteen pipeline clones performed better than region-specific check clone RRII 429.

In the drought prone region, check clone RRII 430 gave maximum yield. Three pipeline clones *viz*. P 026, P 061 and P 015 yielded better than check clone RRIM 600. Two pipeline clones *viz*. P 027 and P 060 gave better yield that was comparable to RRIM 600. Six pipeline clones yielded better than the region-specific clone RRII 208. Twelve pipeline clones with superior growth and yield were identified as candidate clones for cold-prone environ. Similarly, twelve pipeline clones were identified as candidate clones for drought-prone environ. Eleven pipeline clones were identified as potential candidate clones for the optimal environ. Based on overall performance in terms of juvenile growth and yield as well as stability of these traits under drought and cold environs, four pipeline clones *viz*. P 020, P 026, P 102 and P 107 and the hybrid clone RRII 430 were found potential climate-resilient clones. In addition to the check clone RRII 430, two pipeline clones *viz*. P 020 and P 026 appeared to possess multifarious adaptability for optimal as well as sub-optimal environs.

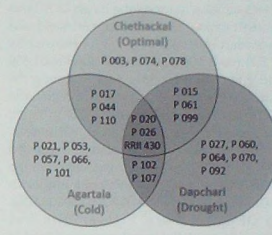


Fig. Bot. 1. Adaptability of pipeline clones under cold, drought and optimal environs based on juvenile growth and yield (2012 planting)

5. Participatory evaluation of rubber clones in the pipeline

5.1. Source Bush Nurseries of Pipeline clones

At the Central Experiment Station, Chethackal, 282 pipeline clones were maintained in 17 source bush nurseries.

5.1.1 Phase 1 (2008)

In the two Central Large Scale Trials at CES, comprising a total of 25 pipeline clones, significant clonal variation in yield was observed in the third year of tapping. In LST 1 (Table Bot. 2), the three check clones *viz*. RRII 414, RRII 430 and RRII 105 had comparable yield. Pipeline clones P 21 (85.3 g $t^{-1}t^{-1}$) followed by P 67 (81.7 g $t^{-1}t^{-1}$) showed significantly superior yield over the highest yielding check RRII 414 (57.4 g $t^{-1}t^{-1}$).

In LST 2 (Table Bot. 3), RRII 414 recorded significantly superior yield than the other check clones. Five clones P 044, P 063, P 064, P 066 and P 070 had yield comparable with RRII 414.

In Batch 1, there are six OFTs at various locations and in Batch 2 there are five locations. Among the Batch 1 OFTs, at Calicut Estate, Mukkom, highest yield was recorded in P 061 (61 g t^{-1} t^{-1}) followed by P 021 (60 g t^{-1} t^{-1}) and check clone RRII 430 (46 g t^{-1} t^{-1}). In Mooply Estate, among the batch 1 clones, P 015 and P 074 registered highest yield (52.1 and 51.5 g t^{-1} t^{-1}, respectively). In OFT at PCK, Athirapilly Estate, highest yield was recorded in P 060 (58 g t^{-1} t^{-1}) followed by the check clone RRII 430 (57 g t^{-1} t^{-1}). DRC was higher in P 010 (35.4 %) followed by RRII 430 (33.8 %). In OFT at Vithura, highest girth was recorded in RRII 430 followed by RRII 414 and P 061. Highest yield was recorded in P 067 followed by P 015 and RRII 430. P 021 and P 076 registered maximum yield (82.4 and 76 g t^{-1} t^{-1}, respectively) in Kanyakumari. In Mundakkayam OFT, among the clones P 067 (33 g t^{-1} t^{-1}) had superior yield compared to control RRII 430 (29 g t^{-1} t^{-1}).

Among the batch 2 (five locations), P 026 (59.8 g t^{-1} t^{-1}) exhibited superior yield at Be Be Estate at Punalur which was on par with RRII 430 (63 g t^{-1} t^{-1}). In the OFT at Perinthalmanna, P 066 (77.7 g t^{-1} t^{-1}) registered highest yield while RRII 414 recorded 49 g t^{-1} t^{-1}. In the OFT at Shaliacary, P 066 (58.5 g t^{-1} t^{-1}) was found superior which was comparable to both the check clones RRII 414 (58.3 g t^{-1} t^{-1}) and RRII 430 (55.7 g t^{-1} t^{-1}). In the OFT at Koottickal estate (2008), P 063 and P 066 performed better than RRII 430 in the third year of tapping. P 063 recorded the highest girth increment rate before (7.6 cm) and on tapping (3.1 cm). In the OFT at Devagiri Estate, Kanjirappally, P 026 showed comparable yield with that of the top most check clone RRII 414.

Based on the three years data from PCE trials (2008), performance of clones across six locations was summarized. Data on growth, yield and disease tolerance of four pipeline clones P 026, P 015, P 063 and P 066 were found on par with check clones (RRII 414 and

Table Bot. 2. **Girth of clones across locations in PCE OFTs and LST (2008) Batch I**

Clones	Parentage	Calicut	Mooply	Athirappally	Vithura	Kanyakumari	Mundakkayam	CES LST	Mean
P 010	PB 5/51 x RRII 105	54.3	65.3	50.7	61.2	58.6	54.3	59.9	57.8
P 015	RRII 203 x PB 5/51	48.2	57.8	51.5	58.2	50	47.1	54.0	52.4
P 021	RRII 105 x RRII118	59.1	54.4	53.8	63.4	58.8	49.6	62.2	57.3
P 060	RRII 105	42.8	52.1	50.7	57.4	51.7	40.9	45.7	48.8
P 061	PB 28/83	54.5	58.7	57.1	64.5	56.9	52.5	63.8	58.3
P 067	PB 215	48.3	55.3	56.2	62.4	56.7	44.0	55.0	54.0
P 068	RRII 105	51.9	58.4	49.0	63.1	55.9	49.6	56.3	54.9
P 074	PB 5/51	53.2	58.7	54.3	60.4	56.9	51.2	56.3	55.9
P 076	RRII 203 x RRII 105	49.3	49.8	46.4	61.6	54.9	42.6	49.2	50.5
P 084	RRII 105 x PB 86	48.6	60.9	58.8	63.8	52.9	46.1	53.8	55.0
P 088	RRII 105 x RRIC 52	43.7	62.8	51.7	62.3	56.1	46.3	54.8	54.0
RRII 105	RRII 105 (C)	47.5	58.9	56.0	59.9	57.6	46.1	53.7	54.2
RRII 414	RRII 414 (C)	55	60.9	63.1	66.3	58	55.3	60.0	59.8
RRII 430	RRII 430 (C)	52.1	57.3	56.3	68.9	59.4	53.0	57.5	57.8

Table Bot. 3. **Girth of clones across locations in PCE OFTs and LST (2008) Batch II**

Clones	Parentage	Bebe, Punalur	Perinthal-manna	Kootickal	Shaliakary Punalur	Kanjirappally Ranni	CES LST 1	Mean
P 026	PB 242 x RRII 105	60.2	55.3	58.5	58	52.9	58.5	57.2
P 015	RRII 203 x PB 5/51	57.8	56.6	55	62	38.3	54	54.0
P 076	RRII 203 x RRII 105	54.9	50.3	55.1	56.3	42.1	49	51.3
P 078	PB 86 x RRII 203	62.6	47.2	54.2	60.4	31	60	52.6
P 087	RRII 105 x PB 28/59	57.5	59.8	55.4	59.4	49.1	53.6	55.8
P 062	PB 5/51	53.9	48.2	49.2	56.1	39.9	50	49.6
P 063	PB 28/83	65.2	63.6	62.3	68.3	42.6	63.7	61.0
P 065	PB 28/83	54.3	56	53.5	57.8	34.7	56.7	52.2
P 066	PB 28/83	54.3	57.9	54.8	63.8	34	50	52.5
P 069	PB 215	54.8	53.2	56.3	62	41.4	51.5	53.2
P 072	Ch 26	57.2	56.4	56	66.6	50.1	52.3	56.4
RRII 105	RRII 105 (C)	58.5	53.2	56.3	58.1	39.4	54	53.3
RRII 414	RRII 414 (C)	64.3	64.6	62	68.1	57.3	62.5	63.1
RRII 430	RRII 430 (C)	64	59.4	59	63.1	38.7	59	57.2

RRII 430). Interim disease responses indicates clone P 015 to have better ALF tolerance among the pipeline clones which is on par with RRII 430 and RRII 414.

In PCE Phase 1- Batch 1, the clone P 061 (polycross progeny of PB 215 exhibited vigorous growth (54 cm) which is on par with RRII 430 (57.8 cm), RRII 414 (59.8 cm). P 021 (RRII 105 x RRII 118) also showed vigorous growth (57.3 cm) on par with RRII 414 (59.8).

In PCE 1-Batch 2 trial, P 066 (polycross progeny of PB 28/83) registered moderate growth (53 cm) while P 015 (RRII 203 x PB 5/51) also showed a girth of 54 cm when compared to RRII 414 (67 cm).

5.1.2 Phase 2 (2010)

In the LST at CES, P 044 showed comparable girth with RRII 414 (Table Bot. 4). Seven pipeline clones were better than RRII 105. Clones RRII 430, P 70, P 64, and P 19 had lesser ALF infection. RRII 430, P 19 and P 64 had very low ALF infection indicating their *putative* tolerance to ALF.

Though six OFTs were originally laid out (in 2010), two OFTs at Bethany and

Table Bot. 4. **Girth and ALF (%) of pipeline clones in 2010 LST (CES)**

Clone	Girth (cm)	ALF (%)
RRII 414	57	21
P 44	56	25
RRII 430	56	12
P 80	55	25
P 70	54	20
P 54	49	22
P 64	49	17
P 19	48	15
P 53	48	28
RRII 105	47	30
P 27	47	25
P 99	46	58
P 92	43	34
P 47	42	28
P 98	41	31
P 94	40	59
P 57	40	58

Shaliacary estates were discontinued due to Okhi cyclone and land acquisition by the government. In the OFT at Pudukkad, P 044, P 070 and P 019 showed highest girth in the 10th year of planting (Fig. Bot. 2). The trial was opened in 2017 when the trees were

seven years old. Based on overall mean yield over three years (2017-2019), yield of P 092 and P 064 with 59 g t^{-1} t^{-1} was found better than RRII 105 (56 g t^{-1} t^{-1}). P 044 (54 g t^{-1} t^{-1}) was on par with RRII 105. However, RRII 430 maintained its superiority (68 g t^{-1} t^{-1}). In the OFT 2010 at Vaniampara estate, girth of clones varied from 50 cm (P 094) to 64 cm (RRII 430) in the 10th year of planting. Two pipeline clones P 070 and P 080 had comparable girth with check clone RRII 414 (62 cm). The trial was opened for tapping in the 9th year. Yield in the first four months revealed P 99 (82 g t^{-1} t^{-1}) as the highest yielder, followed by P 94, P 47 and P 64 with about 70 g t^{-1} t^{-1} against 67 g t^{-1} t^{-1} for RRII 430. In the Kaliyar OFT, P 044 (55.2 g t^{-1} t^{-1}), P 047, P 074 (61.8 g t^{-1} t^{-1}), P 064 (58.8 g t^{-1} t^{-1}) and P 098 (76.9 g t^{-1} t^{-1}) were found superior in terms of yield while RRII 430 registered 74.5 g t^{-1} t^{-1}. In OFT at Malankara, P 044 (70.9 g t^{-1} t^{-1}), P 064 (74.3 g t^{-1} t^{-1}) and P 099 (95.9 g t^{-1} t^{-1}) registered yield superior to RRII 430 (68 g t^{-1} t^{-1}).

Table Bot. 5. **Girth and ALF (%) of pipeline clones in 2012 LST (CES)**

Clone	Girth (cm)	ALF (%)
RRII 417	43	11
RRII 430	43	7
P 110	40	18
P 104	40	26
P 102	38	20
P 114	38	21
P 101	36	23
P 112	36	44
RRII 105	36	21
P 116	35	9
P 156	35	10
P 158	32	17
P 142	31	21
P 96	30	44

5.3.2 Phase 3 (2012)

In the 2012 LST at CES, six pipeline clones had better growth than RRII 105 of which P 110 and P 104 scored maximum girth (Table Bot. 5). Five pipeline clones were inferior to RRII 105 in terms of girthing. The high yielding RRII 400 series clones exhibited better girth, thus proving their superiority in terms of growth and vigour. These two clones also had very low ALF infection supporting their *putative* tolerance to ALF.

In Phase III, there are OFTs at four locations. In the Cheruvally estate, highest girth was recorded in RRII 430 followed by RRII 417, P 110, P 102, P 101 and P 104. At Calicut Estate, P 110 showed better girth than RRII 430 and RRII 417. Most of the experimental clones were better than RRII 105 in terms of disease tolerance. Initial yield data showed check clones RRII 417 and RRII 430 as the top most yielding clones closely followed by pipeline clone P 110. In the OFT at Kumbazha estate, P 102, P 104 and P 110 were the vigorous clones on par with the check clone RRII 430 (53.5cm) in the 8th year of planting. Tapping was initiated in the 8th year. P 112 and P 104 showed early high yield in the opening year (>60 g t^{-1} t^{-1}). At Shaliacary OFT, clone P 066 (48.3 cm), P 156 (48 cm), RRII 430 (49.4 cm) and RRII 417 (48.9 cm) performed better in terms of growth.

5.3.3 Phase 4 (2014)

In the Phase 4 LST at RRII, three pipeline clones performed better than RRII 105 in terms of girth (Table Bot. 6). All the three RRII 400 series clones performed well in terms of girth.

In the Kailiyadu OFT at Shornur, P 171, P 129, P 168 and P 120 showed superior growth after RRII 414. At Manickal estate, highest girth was recorded in RRII 414

Table Bot. 6. **Girth of pipeline clones in 2012 LST (CES) in phase 4, LST**

Clone	Girth (cm)	Clone	Girth (cm)
RRII 414	48.6	P 171	39.6
RRII 417	46.0	P 71	39.2
RRII 430	44.7	P 168	39.1
P 129	43.6	P 174	38.8
P 181	42.4	P 185	38.2
P 172	41.7	P 48	37.8
RRII 105	41.1	P 178	37.3
P 177	41.1	P 182	37.2
P 133	41.1	P 183	36.8
PB 330	41.1	P 73	36.7
P 180	40.7	P 121	34.5
P 120	40.3	P 93	32.9
P 184	39.7	P 173	32.0
P 179	39.6	Mean	39.7

followed by RRII 430, P 133, P 129, P 168 and RRII 417. At Thiruampady Estate, Kozhikode, four pipeline clones (P 168, P 133, P 126 and P 071) showed better girth compared to RRII 105 and RRII 414 while being inferior to RRII 430 and RRII 417. In the trial at KFDC, Nettana, clones P 126 and RRII 417 with 42 and 37 cm, respectively continued to maintain superior performance in terms of girth while clones P 129, P 133, RRII 430, RRII 105 and RRII 414 followed it with 33.5, 31.0, 30.8, 29 and 26.8 cm, respectively. Clones P 173, P 171, P 177, P 121 and P 093 had minimum girth (19 to 20 cm). In OFT at Bethany estate, Kanyakumari, the trees that got bent due to the Okhi cyclone were fully straightened by providing proper staking. Growth of trees in all the plots during the sixth year after planting was good. Among the check clones, RRII 430 and RRII 105 exhibited a maximum girth of 50 to 51cm while P 071 (selection from polycross progenies), P 133 (ortet selection) and P 177 (WxA hybrid) had maximum vigour among the pipeline clones. At RPL, Kulathupuzha, initial establishment was very poor and the sample size has got reduced due to wild animal attack.

5.3.4 Phase 5 (2016)

In the 2016 OFT at Paalali Estate, Tamil Nadu, early growth performance of pipeline clones and check clones was assessed. Four pipeline clones exhibited superior girth to the top performing check clone RRII 105. In the 2016 trial at KFDC, Nettana, clone RRII 105 was found superior in terms of girth with 25.5 cm while the clones that followed it were P 200, P 226 and P 205 with a girth of 18.8, 18.2 and 17 cm, respectively. Clones RRII 430 and P 218 were the poor performers with 11.2 and 9.3 cm girth, respectively. In the 2016 trial at SFCK Punalur, four plots were badly damaged due to fire outbreak. The check clones RRII 105 and RRII 430 showed comparable girth of 21 cm. Clones P 126 and P 202 showed vigorous initial growth comparable to RRII 430. Five pipeline clones (P 21, P 26, P 64, P 70 and P 81) and seven popular clones (RRII 105, RRII 414, RRII 417, RRII 422, RRII 429, RRII 430 and PB 330) are being evaluated in the trial. In the 2016 OFT at Cherupittakavu Estate, Punalur, RRII 430 was the superior performer (25 cm). P 200 and P 207 had better girth than RRII 105.

5.3.5. Phase 6 (2019)

In the latest phase of participatory trials (Phase 6, 2019), planting of LST comprising 19 pipeline clones and three check clones was completed in CES. A total of 1360 plants were planted with a plot size of 8 and six replications. Planting operations were also completed in four OFTs at Kanyakumari, Punalur, Padiyoor and Nettana. A polybag nursery of these clones was also established at RES, Nagrakata to lay out a clonal nursery in this region.

6. Breeding for other specific objectives

6.1. Breeding for drought tolerance

In the LST at RRS Dapchari established for screening for drought tolerance drought influenced, leaf drying was recorded. Clones such as P 114, RRII 430, P 192, P 200, P 68, P 63, P 225 and P 83 showed comparative tolerance in the first exposure the drought. In an attempt to develop drought tolerant clones for the non-traditional area, the drought tolerance capacity of the selected progenies, developed through hybridization between high yielding clone (RRII 105; female parent) and a drought tolerant clone (PB 280; male parent) and the reciprocal crossing (PB 280 x RRII 105), were evaluated in a clonal nursery trial in RRS, Dapchari. In a trial with 40 experimental clones and nine control clones, six hybrid clones exhibited consistently superior juvenile yield than the check clone RRIM 600 during the peak yielding season. Three clones with superior yield performance in the peak yielding season also exhibited superior yield during summer. The highest yielder 96/69 exhibited highest girth as well.

6.2. Breeding for disease tolerance

A clonal nursery was planted with imported clones, pipeline clones and other *Hevea* species along with epiphytotic clones (spreaders) for disease tolerance screening as well as yield.

Under breeding programme for evolving high yielding clones RRII 105, RRII 414 and RRII 430, with tolerance to different diseases, hybridization between susceptible high yielding indigenous clones with tolerant germplasm accessions including other species *H. spruceana* and *H. camargoana* and two wild germplasm accessions *viz*. RO 380 and RO 2871 was attempted over a period of three years. In addition to the above, half-sibs were collected from a disease tolerant Brazilian clone Fx 516. All these progenies were evaluated for juvenile growth and yield at the age of three years. In terms of girth, family RRII 430 x RO 380 (mean, 29 cm), followed by RRII 430 x *H. spruceana* (23 cm) performed well. Families RRII 105 x *H.camargoana* and RRII 430 x *H.spruceana* showed comparatively lesser growth. With reference to juvenile yield, family RRII 414 x RO 380 showed maximum yield (mean, 65 g t^{-1} t^{10}) followed by RRII 430 x RO 380 and RRII 430 x *H.camargoana* (15 g t^{-1} t^{10}). Progenies of remaining cross-combinations had poor mean yield (7-9 g t^{-1} t^{10}). The maximum individual progeny yield (191 g t^{-1} t^{10}) was obtained from the cross RRII 414 x RO 380, followed by a progeny of RRII 430 x RO 380 (54 g t^{-1} t^{10}). Half-sibs of Fx 516 had a mean yield of 17 g t^{-1} t^{10} with maximum individual yield of 56 g t^{-1} t^{10}. In the first phase of the breeding programme, several interspecific and half-sib selections possessing better growth and yield potential were identified. These selections will be evaluated for mature yield and tolerance to major fungal diseases.

7. Anatomical investigations

7.1. Wound callus as explant for tissue culture

Callus tissue developed at the root apex during the hardening process of root trainer plants have immense potential in tissue regeneration and is being utilised for root architecture modification. Structural organisation and metabolic status of this starved tissue may have immense potential to be used as explant in tissue culture experiments. Root system of three clones with known genetic identity was developed through layering and transplanted into root trainer cup for the production of callus

through hardening process. *In vitro* tissue regeneration from this callus in the lab is underway.

7.2. Petiolar anatomy for identification of *Hevea* clones

Detailed anatomical studies on distal pulvinus of *Hevea* leaves indicated maximum diversity in structural traits with reasonably good stability for characterizing the RRII 400 series clones. Structural traits *viz*. inter-vascular continuity, shape of vascular bundles, xylem characteristics and proportion of tissues in the stele were examined for characterisation of eight Vietnam clones introduced through IRRDB clone exchange programme. A systematic key was formulated based on structural and morphological traits for clone identification.

8. Studies on propagation

8.1. Drought tolerant rootstocks

A study was initiated at RRS, Dapchari with an aim to develop drought tolerant rootstocks for the non-traditional areas by evaluating drought tolerance capacity of the seedlings in comparison with the seedlings from traditional areas. The trial was abandoned due to damage by rodent infestation, majority of field plants were damaged and hence.

8.2. Modified root trainer plants (MRTP) for disease control through crown budding

Root trainer plants with modified root architecture (33 nos.) were raised in a nursery. Crown budding at the height of eight feet was carried out and transplanted into the field among which six plants developed into healthy scion. Crown budding with Fx 516 was carried out in 300 field plants at RRII.

8.3. Leaf as explant for plant propagation

A new nursery experiment was initiated with rubber leaf as explant. More than 300 explants were planted in polybag and kept in polyhouse with mist blower. Few set of leaves greenness and maintained for more than two months indicating scope for modifying the methodology further. The work is in progress.

9. International Clones

9.1 Large Scale Trials

Two large scale trials (LST) were established at CES, Chethackal with clones imported from Thailand (RRIT 226, RRIT 251, RRIT 408, RRIT 3604 and RRIT 3904), Indonesia (IRR 5, IRR 104 and IRR 119), China, Vietnam and Cambodia. Bud grafting (250) of six imported clones from Cote d'Ivoire and Myanmar was undertaken to raise sufficient planting material to establish Source Bush Nursery (SBN) and International Clone Museum. SBNs of other imported clones from Thailand, Indonesia, Philippines and Sri Lanka *etc*. are also being maintained at CES, Chethackal.

9.2. International *Hevea* Clone Museum

The International *Hevea* clone museum, consisting of high-yielding as well as SALB-resistant clones imported from different IRRDB member countries is being maintained at RRII Main Campus.

10. Arboreta of *Hevea* clones and forest species

The arboretum of *Hevea* consisting of 55 clones as demonstration-cum-research plot is being maintained at RRII Main Campus, Kottayam. An arboretum planted in the RRII Main campus during the year

2014 with 63 assorted forest plant species along with *Hevea* is also being maintained.

11. Upgradation of Prang Besar Clones to Category 1 and release for cultivation in the traditional region

An evaluation of long term performance of PB clones in comparison with the RRII 105 across 10 field trials over a period of 25 years has proved the superiority of clones PB 280, PB 255 and PB 314. These clones have demonstrated yield over 2500 kg ha^{-1} year^{-1} in station trials and above 2000 kg ha^{-1} year^{-1} in on farm trials thus indicating their superiority over RRII 105 in both the stages of evaluation. These three clones therefore merit upgradation to Category 1 and release for cultivation in the traditional region. However, a large scale evaluation trial of these clones for the non-traditional regions also have to be initiated.

11.1. Region specificity of the promising Prang Besar clones

11.1.1. Clone PB 280 proved to be the superior clone among the three clones with 3123 kg ha^{-1} year^{-1} in Station Trials and 2162 kg ha^{-1} year^{-1} in On Farm Trials. Clone PB 280 topped the list with 2642.5 kg ha^{-1} year^{-1} in terms of mean ranking across trials. PB 280 is known to be drought tolerant and has exhibited specific adaptation to South Kerala (Punalur), and Karnataka (Nettana) and Central Kerala (Chethackal and Kottayam). Though susceptible to *Phytophthora* and *Oidium*, this clone is tolerant to Pink disease, Tapping Panel Dryness and *Corynespora*. Clone PB 280 is also promising in terms of timber yield.

11.1.2. Clone PB 255, the highest girthing clone, though third among the three selected clones in terms of mean yield across locations (2304 kg ha^{-1} year^{-1}) was superior in terms of rubber yield in Kanyakumari, Nettana, Padiyoor and Kottayam indicating specific adaptation to South Tamil Nadu, South West Karnataka, North Kerala and Central Kerala regions in the traditional belt. Exceptionally high yield of this clone in Kanyakumari is noteworthy. This clone is tolerant to *Corynespora* with a low incidence of pink disease and moderate incidence of TPD.

11.1.3. Clone PB 314 was the second highest rubber yielder with 2414.5 kg ha^{-1} year^{-1} and was also the second highest girthing clone across 10 locations. This clone was the highest yielder in one location and the second highest yielder in five of the remaining nine locations. However, the secondary characteristics of this clone are not very promising. This clone shows specific adaptation for high yield in South Tamil Nadu, Central Kerala and North Kerala.

12. Upgradation from Category 3 to Category 2 of IRCA clones

Category 2 of the planting recommendations includes clones of proven high yields over long term in large scale trials. These clones are recommended for planting in combinations of two or more covering up to 50 per cent of the total area of a large holding. Considering the high yield and growth over long term in statistically laid out large scale station trials at Kanyakumari, Chethackal and Padiyoor, clones IRCA 130 and IRCA 111 were found promising. Accordingly, they were upgraded from Category 3 to Category 2 of the planting recommendations for the traditional region.

13. New Projects

13.1. A project on 'Alternative sources of Natural Rubber: Studies on the feasibility of cultivation of Guayule Rubber (*Parthenium argentatum*) as an alternative source of NR in arid/semi-arid areas and marginal lands of India' has been initiated.

The Government of India has been approached to include Guayule in the import permit list.

13.2. With regard to the newly initiated project on population improvement for enhancement of yield in *Hevea brasiliensis*, arrangements have been made to establish 'Polycross Seed Gardens' with about 21 elite and promising pipeline clones in an area of 20 ha at Arasu Rubber Corporation, Kanyakumari District of Tamil Nadu. Planting materials were prepared and a polybag nursery of selected clones is maintained for planting in the year 2020.

14. Supplementary research for clone evaluation trials

14.1. A method for accurate yield determination from clone evaluation trials

Estimation of yield in experimental trees was a matter of concern due to various factors. A simple, rapid and accurate method has been standardized to estimate DRC. In this method, instant coagulation was demonstrated through a reverse coagulation procedure. This enables to address quick method can be implemented in all the clone evaluation trials that require an accurate data recording method. Using this method, yield recording from experimental trees including LSTs and PCE trials of Botany and Germplasm Divisions was carried out successfully.

14.2. Metallic labeling for experimental trees

Paint marking for retaining the identity of experimental clones is expensive as it is to be carried out annually in all the trees of various field trials. For reducing the cost, durable and legible aluminium metallic labelling was introduced and installed in 3000 trees of three PCE trials.

GERMPLASM DIVISION

Three gene pools-the domesticated gene pool, the wild germplasm belonging to the 1981 IRRDB collection, and the collection of other *Hevea* species, make up the genetic resources of *Hevea* being conserved at RRII. The focus of the Division is on the management of the wild germplasm collection, its agronomic evaluation, screening for diseases, drought and cold stress resistance, timber latex traits and utilization in crop improvement.

1. Introduction, conservation and documentation

1.1. Domesticated gene pool (Wickham collection) from secondary centers

This collection, generally referred to as the 'Wickham clones' as they have mainly descended from the original Wickham collection of 1876, are being conserved in a bud wood nursery (the clone museum) at RRII, Kottayam, and three arboreta (Germplasm Gardens) at CES, Chethackal. The clones in the bud wood nursery are being assessed for their tolerance levels to the primary leaf diseases. The arboreta serve the primary purpose of conservation and scientific data collection as and when necessary, and are a source of clonal flowers for breeding when required.

Among the five IRCA clones evaluated from Germplasm Garden 92, clone IRCA 130 and IRCA 111 recorded the highest girth (86.3 and 85.7 cm, respectively) as compared to the control clone RRII 105 (74.2 cm). IRCA

130 was superior to all other clones for yield (60.6 g t^{-1} t^{-1}). In an arboretum comprising 20 Wickham clones in Germplasm Garden 94 in the 18th year of tapping, RRII 23 was the highest yielder (95.0 g t^{-1} t^{-1}), followed by RRIC 100 (80.9 g t^{-1} t^{-1}) and RRIM 609 (71.1 g t^{-1} t^{-1}), compared to 49.0 g t^{-1} t^{-1} for the popular clone RRII 105. RRII 23 also continued to be the most vigorous clone and four other clones were more vigorous than RRII 105.

1.2. 1981 IRRDB wild germplasm

This gene pool was introduced during 1984-1990 into the country, and is the focus of the Division.

1.2.1. Conservation nurseries

The original nurseries established at the time of introduction, continue to serve as a source of flowers for hybridization programmes. These accessions were re-established in compact new conservation-cum-source bush nurseries (SBNs) from 2003 to 2008. The large number of potentially useful accessions identified during the characterization and preliminary evaluation in the juvenile stage for yield, yield contributing traits like latex vessels, disease and drought tolerance traits in these SBNs, are being put into Further Evaluation Trials. Simultaneously, these selections are also being established in separate bud wood nurseries (the Germplasm Working Collection) in order to ensure better care and accessibility. So far, 119 potential wild accessions have been established in the GWC, to which potentially useful accessions will be added as and when identified.

1.2.2. Heveatum

A separate *Hevea* arboretum (or *Heveatum*), comprising all the available genetic resources, is being established in phases at Teksragre farm, Tura, Meghalaya, with the primary intention of ensuring an insurance collection, as well as facilitating free cross pollination and genetic mixing between the different gene pools. So far, a total of 577 wild and Wickham accessions have been established here in five phases. Another arboretum comprising 120 accessions established earlier, is being maintained at Central Experiment Station, Chethackal.

1.3. Other *Hevea* species

Five species (*H. benthamiana, H. spruceana, H. nitida, H. camargoana*) other than *H. brasiliensis* and two accessions of *H. pauciflora*, are being conserved as an arboretum established in 2006 at CES. Five natural putative interspecific hybrids, two *H. brasiliensis* clones, and FX 516 (an interspecific cross between *H. brasiliensis* and *H. benthamiana*) have also been planted here. Among the other species, *H. pauciflora* from Sri Lanka, as well as Fx 516 continue to show relatively good yield.

2. Characterization and preliminary evaluation

The last three trials in the Preliminary Evaluation Trial format were planted at RRS, Padiyoor in 2000 (A&B) and 2002. Nine relatively high yielding selections from here *viz.* AC 3131, AC 552, RO 2136, RO 4363, RO 1313, AC 567, AC 1964, RO 341, MT 4351 and RO 210, and vigorous accessions for timber traits MT 4219, AC 4140, MT 387, AC 647 and RO 2883 are being conserved as male parents for future W x A hybridization programmes. Among this, the high yielding accession RO 341 was included in the Further Evaluation Trial–2019 at HBSS, Nettana. Wild accession RO 4363 of PET 200A was included in the abiotic stress tolerance studies of Plant Physiology Division.

3. Further evaluation and selection

Selections from preliminary evaluations with 50-80 per cent of the test tap yield of the controls, are evaluated in detail in clonal nurseries (CNs), and those with more than 80 per cent test tap yield of RRII 105, in field trials (FETs) at normal spacing.

3.1. Clonal nursery evaluation

Of the three wild accessions (AC 2199, MT 1056, AC 2027) with good growth and test tap yield higher than RRII 105 identified from a clonal nursery planted in 2010 at Central Experiment Station, accession AC 2027 was field planted in FET-2019 at HBSS, Nettana.

3.2. Further evaluation trials

All accessions with more than 80 per cent of the control yield on preliminary evaluation, as well as those with potential secondary traits, are subjected to detailed evaluation in FETs in statistically laid out trials at normal spacing. There are currently six FETs comprising 117 accessions. Two more FETs comprising 23 and 10 selections were planted at CES and Nettana, respectively this year.

Twenty-two wild accessions and three control clones are being evaluated for growth and yield traits in the FET 2003. Accession RO 2629, AC 4149, and AC 716 continuously recorded the highest yield, while RO 2629 recorded the highest girth followed by MT 2233 and AC 626 compared to the check clone RRII 105. Wild accession RO 4146 was included in the abiotic stress tolerance studies of Plant Physiology Division. Among the 22 wild accessions in FET 2005, MT 4788 and MT 43 had the highest yields in the 5th year of tapping, on par with check clones RRII 105, and PB 260. MT 4788 however is susceptible to ALF disease. In FET 2008, RO 2846 (72.1 cm), AC 176 (69.6 cm) and MT 200 (68.4 cm), recorded the highest girth in the twelfth year of growth as compared to the check clones RRII 105 (59.5 cm). Initiated yield monitoring in this trial and wild accession AC 176 was included in the abiotic stress tolerance studies of Plant Physiology Division. Among the 13 accessions evaluated in FET 2010 at CES, Chethackal, there were seven accessions with girth higher than clone RRII 105 and none of the accessions were superior to check clones RRII 430 and RRII 414. A set of 22 selected wild accessions along with three control clones, in the sixth year of growth were under observation in another FET 2013 at CES. The wild accession AC 167 recorded the highest girth followed by AC 5280 and RO 2784, compared to the check clone RRII 105 (28.4 cm).

3.3. On-farm trials

Selections from FETs are subjected to multi location evaluation in On-Farm Trials for confirmation of yield potential. The first OFT was established in 2010 at five locations *viz*. B.C. Cheruvally estate in Erumely, Malankara estate in Thodupuzha, Mooply estate in Thrissur, Calicut estate in Kozhikode and Bethany estate in Kanyakumari for evaluating the performance of the three selected IRCA clones (IRCA 130, IRCA 111, IRCA 109) and one wild accession (AC 166).

At Mooply estate, Thrissur, among the four test clones, wild accession AC 166 recorded the highest girth (57.4 cm) followed by IRCA 130 & IRCA 111 (52.6 cm). Among the check clones, RRII 414 (65.6 cm) was superior to RRII 430 and RRII 105. Yield recording this year in the trial was affected by rain and flood.

At Malankara estate, Thodupuzha among the four test clones, wild accession AC 166 recorded the highest girth (51.2 cm)

followed by IRCA 130. Among the check clones, RRII 414 (62.0 cm) was superior to RRII 430 and RRII 105. Among the test clones, highest mature yield was recorded by IRCA 111 (53.9 g t^{-1} t^{-1}) and the yield of wild accession AC 166 was 26.7 g t^{-1} t^{-1}. Among the check clones, RRII 430 recorded the highest yield (59.6 g t^{-1} t^{-1}). AC 166 and IRCA 130 recorded the highest girth as compared to the check clone RRII 105 in BC Cheruvally estate and Calicut estate and the trees were opened for regular tapping.

4. Screening for stress tolerance

4.1. Screening for biotic stress tolerance

In a 'hotspot' trial at Ulickal nursery, Iritty (Kannoor), 41 short listed wild *Hevea* accessions along with two control clones were under evaluation for confirmation of field tolerance to *Corynespora* disease.

4.2. Abiotic stress resistance

4.2.1. Drought tolerance

Twenty half-sib progenies selected from 40 potential half-sibs of nine clones in a Clonal Nursery evaluation at RRS, Dapchari were multiplied and a polybag nursery was raised for a bud wood nursery of these selections for further multiplication of these selections advancing to a large scale trial at RRS, Dapchari for developing location specific clones. But due to Covid-19 pandemic, could not visit the station and do any further field operations. In the clonal nursery at RRS, Padiyoor with 31 potential half-sibs of eight clones, six half-sibs from three pre-potent clones were selected on the basis of test tap yield and growth under drought stress. These selections will be advanced to LST.

In the further field evaluation of selected *Hevea* clones at RRS, Dapchari in collaboration with Botany Division, the growth during the summer and peak periods of growth in the 34 selected *Hevea* clones planted in 2007 comprising 23 wild accessions, five HP clones and six check clones *viz*. RRII 430, RRII 414, RRII 105, RRIM 600, RRII 208 and Tjir 1 was assessed. Among the wild accessions, highest mature yield was recorded by MT 4788 (88.4 g t^{-1} t^{-1}) followed by RO 2153 (38.1 g t^{-1} t^{-1}). Four wild accessions also were found to be promising. Among the hybrid clones, 93/105 recorded highest mature yield of 38.4 g t^{-1} t^{-1} and the check clone RRII 430 recorded highest yield among all (72.3 g t^{-1} t^{-1}) proving its drought tolerance. Highest girth was recorded by accession MT 1619 (58.3 cm) followed by MT 4788 (551.7 cm). Out of five hybrid clones evaluated, hybrid 93/105 recorded highest girth (51.0 cm). Among the check clones, RRII 430 recorded the highest girth of 55.1 cm. The growth and yield performance of these seedlings will be studied for selecting potential recombinants of wild and Wickham clones.

4.2.2. Cold tolerance

Two trials comprising of sixty four wild *Hevea* accessions along with check clones are under evaluation for cold tolerance at the Regional Experiment Station, Nagrakata, West Bengal. Highest girth was recorded in the accession RO 2902, MT 923 and MT 5105 as compared to the check clones SCATC 93/114 and RRIM 600 in Trial 1, while accession RO 2727, MT 915, and RO 3197 recorded the highest girth compared to that of the controls Haiken 1 and RRIM 600 in Trial 2. Among the wild accessions studied, AC 4653, AC 3514 and MT 915 recorded the highest yield. Selected wild accessions were included in the abiotic stress tolerance studies of Plant Physiology Division.

5. Screening for timber characteristics

5.1. Field screening

Out of 25 genotypes evaluated for growth at RRS, Padiyoor, MT 941, MT 1032 and AC 650 recorded the highest annual girth as compared to the control clone RRII 118. These accessions also indicated high timber potentiality.

6. Utilisation of *Hevea* germplasm

6.1. Hand pollination programmes

A budwood nursery of HP 2009 hand pollination programme was maintained at CES, Chethackal, involving three wild accessions and six cultivated Wickham clones, HP progeny and OP seedlings. Six promising hybrids and an OP seedling were in the process of further evaluation. Ten hybrid progenies from two parental combinations of 2009 HP at RRS, Padiyoor and seven OP seedling progenies of RRII 105 evaluated at RRS, Padiyoor were field planted for conducting a Clonal Nursery evaluation at HBSS, Nettana. A bud wood nursery of these selections is maintained at RRII campus.

Selected hybrids showing potential juvenile yield in the nursery were multiplied and planted in a field trial for further evaluation at CES 20. These comprised 20 resulting from W x A hybridisations and 13 of an interspecific cross (*H. brasiliensis* x *H. benthamiana*).

In the 2016 HP, of the 75 surviving W x A hybrids from three W x A cross combinations, progenies of the cross with the *Oidium* tolerant parent RO 2871 showed the highest vigour and survival percentage. The first round of test tapping identified two potential high yielders which will be taken up for further evaluation after the second round of tapping next year.

In the 2019 HP, 48 hybrids obtained were planted in the seedling nursery for evaluation. In 2020, 1100 crosses between eight selected wild accessions and three Wickham clones were made, with an initial fruit set of 58 (5.3%).

6.2. Open pollinated progeny evaluation

Growth of the surviving 282 OP seedlings collected from the further evaluation trials FETs 2003 and 2005, which comprised preliminary selections from the wild germplasm, interspersed with high yielding Wickham control clones was monitored and will be test tapped next year.

6.3. Phenotyping of mapping population for QTL identification

The interspecific mapping population was planted in a field trial in a statistically laid out design with four replications for phenotyping for yield and other traits.

7. Other studies

7.1. Studies on alternative sources of natural rubber yielding plants

Ceara rubber (*Manihot glaziovii*) - Seven germplasm accessions from Palakkad region and four plants multiplied through stem cutting collected from Vaikom region are being conserved at RRII.

ADVANCED CENTRE FOR MOLECULAR BIOLOGY AND BIOTECHNOLOGY (ACMBB)

The Advanced Centre for Molecular Biology and Biotechnology (ACMBB) set up during the XI[th] Plan period is a functional grouping of scientists working in the areas of Molecular Biology, Biotechnology, Genome Analysis, Molecular Physiology and Molecular Pathology. This was mainly done to functionally merge different labs working in similar areas for better efficiency and saving of resources. ACMBB together constitutes about 15 per cent of RRII research. The ACMBB conducts research on various projects which includes studies on the molecular basis of genetic improvement of natural rubber trees and biotechnological interventions for developing Genetically Modified (GM) rubber. Studies at ACMBB would help to speed up crop improvement, aiding in developing new high yielding, climate resilient and disease tolerant clones faster.

I. BIOTECHNOLOGY DIVISION

Crop improvement through biotechnological interventions is the prime objective of research in the Biotechnology Division. Genetic transformation in rubber was fine tuned for developing *Hevea* transgenics integrated with agronomically important genes. Experiments were done for incorporation of genes with desirable traits for imparting enhanced biotic and abiotic stress tolerance, improving latex yield and growth. Perfecting the system for development of antibiotic marker free transgenics was also attempted. Research programmes aimed to complement conventional breeding were also carried out. Other than these, development and perfection of protocols for the propagation of elite *Hevea* clones from different explants, development of ploidy variants, *in vitro* approaches for disease tolerance and cloning and characterization of genes are also being envisaged.

1. Development of Transgenic Plants

1.1. Genetic transformation of *Hevea brasiliensis* for stress tolerance

1.1.1. Multiple gene integration by repeated transformation in Hevea brasiliensis

Transgenic cell lines integrated with both *hmgr1* and *MnSOD* transgene were multiplied and made embryogenic. Proembryogenic masses were proliferated and cultured for somatic embryo induction. Low frequency embryogenesis was observed. New media formulations were tried for improving the frequency of embryogenesis.

1.2. Genetic modification with *hmgr1* gene for improved latex yield

Genetic transformation using the anther callus of clone RRII 105 produced three transgenic cell lines. Two cell lines were multiplied and presence of the transgene was

monitored by PCR analysis. Embryogenesis was achieved in one transgenic cell line at a low frequency. Fresh *Agrobacterium* infections were performed using the callus derived from immature anthers of *Hevea* (RRII 430) to develop transgenic plants as *hmgr1* transgene has proved to improve latex yield in *Hevea brasiliensis* from earlier experiments. Infected calli were maintained in selection medium. Transgenic plants developed earlier showing better yield than the control based on test tap data were multiplied by bud grafting.

1.3. Genetic transformation of *Hevea brasiliensis* with osmotin gene

Immature anther were isolated from flowers of the clone RRII 105 and cultured in callus induction medium as per the standard protocol. The calli induced were repeatedly cultured in proliferation media followed by embryo induction media. Embryogenic calli were induced after eight months of repeated subculture. Embryogenic calli were proliferated and used for transformation.

Proliferated embryogenic calli were used for *Agrobacterium* infection following standard protocol. The use of liquid coculture medium instead of solid co culture was followed and this could reduce the bacterial overgrowth considerably. After 50 days, new calli line emerged and were kept for proliferation.

After molecular reconfirmation of tobacco osmotin gene integration, native osmotin gene was amplified from *Hevea* and sequenced and compared with the inserted gene sequence. The native gene sequences were deposited in the gene bank.

1.4. Development of *Hevea* transgenics with IPT gene for TPD tolerance

Genetic transformation experiments for regenerating transgenic *Hevea* plants incorporated with iso-pentenyltransferase (ipt) gene for enhanced vegetative growth as well as TPD tolerance were carried out. *Agrobacterium tumefaciens* harboring the gene construct was infected with embryogenic callus derived from leaf tissues initiated during the reporting year for generating more transgenic lines. Several transgenic lines incorporated with *ipt* gene obtained could be proliferated and also tested to be GUS positive. Embryogenic callus initiation and further embryo induction was obtained in earlier standardized medium for leaf explants. All experiments for transgenic callus proliferation and embryo induction were carried out in the presence of Kanamycin (200 mg L^{-1}). PCR amplification (700 bp) of the isopentenyl transferase gene was obtained in transgenic callus with gene specific primers.

Embryo induction was observed in MS medium supplemented with 50 g L^{-1} sucrose and addition of amino acids. Ammonium nitrate and potassium hydrogen phosphate at reduced concentration and addition of calcium nitrate favored embryo induction. Addition of stress inducing compounds such as polyethylene glycol (8 g L^{-1}), and phytagel (0.4%) enhanced the embryo induction frequency. MS medium containing sucrose (30 g L^{-1}), B_5 vitamins and phytohormones *viz.*, GA (0.8mg L^{-1}) and IBA (0.2mg L^{-1}) gave highest embryo maturation and germination. The *ipt* transformants showed several developmental abnormalities. Several embryos germinated and some of the shoots were bushy. Shoots of such embroys did not develop further. The constitutive expression of *ipt* gene by its native promoter might have enhanced cytokinin production leading to phenotypic abnormalities in the transformants. Twelve plants that developed *in vitro* were subjected to hardening. The plants were transferred to sterile soilrite and optimum humidity was maintained. Three plants that

survived the initial phase of hardening were transferred to big polybags which survived only for one month. Attempts for hardening of the plants are being continued.

1.5. Development of biotic/abiotic stress tolerant plants with Hsp31 gene

Agrobacterium mediated genetic transformation experiments were carried out to incorporate Hsp31 gene into *Hevea* for abiotic/biotic stress tolerance. Embryogenic callus of clone RRII 105 and RRII 414 were used as target tissues for new genetic transformation experiments. Callus was desiccated by slow drying in the laminar flow hood before *Agrobacterium* infection. Putatively transgenic lines emerged from the infected tissues with a very high frequency. All the proliferating transgenic lines obtained were maintained by regular subculture since the construct does not have a qualitative marker.

Embryo induction and plant regeneration was also attempted from earlier developed Hsp31 gene incorporated embryogenic callus. Embryo induction with necessary modifications were tried for enhancing efficiency. Somatic embryogenesis and *in vitro* plant regeneration was obtained. Five transgenic plants regenerated *in vitro* were transferred to soilrite of which two could survive only the initial phase of hardening.

1.6. Genetic transformation of *Hevea* for enhanced biotic and abiotic stresses by the manipulation of epicuticular wax through Shine (SHN1) integration

As a preliminary step, epicuticular wax was quantified from different developmental stages of leaves from *Hevea benthamiana* and RRII 105 in two seasons (winter & rainy) from two different sources (field grown trees and budded plants) and no significant variation in wax content among *H.benthamiana* and RRII 105 was noticed.

1.7. Genetic transformation with S-6-PDH for abiotic stress tolerance

To initiate transformation experiments, target tissues were generated with immature anther for clones RRII 105 and RRII 430. Callus was induced and proliferated and embryogenic callus also raised. Using standard protocol, transformation experiments were carried out using two gene construct of S-6-PDH specific to cytoplasm and leaf with RRII 430 callus.

1.8. Development of marker free transgenics in *Hevea brasiliensis*

1.8.1. Development of marker free gene construct

Attempts for developing the gene constructs with marker free system could not give any positive results. Hence attempts to verify the sequence fidelity of the plasmids were made. Plasmids brought from Arkansas University was extracted and used for *E. coli* transformation. Positive colonies were identified by colony PCR and glycerol stocks were prepared. Plasmids were isolated from this culture using standard protocol and send for sequencing.

1.9. Gene identification for development of climate resilient transgenic plants

The genomic and cDNA sequence information of the translationally controlled tumor protein (TCTP) gene from *Hevea* clone RRIM 600 was collected. Sequences were deposited in genbank under the MN075137 and MK990704.

A project on "Development of *Hevea* transgenic plants integrated with the translationally controlled tumor protein (TCTP) gene towards improved vegetative growth and tolerance to tapping panel dryness (TPD) syndrome" was approved by

Science and Engineering Research Board (SERB), DST for external funding and attempts are being made to make the project functional.

2. Propagation of Elite *Hevea* Clones

2.1. Somatic embryogenesis and plant regeneration from immature anther, clone RRII 414

Since somatic embryogenesis in *Hevea* is strictly dependent on genotypes, experiments on somatic embryogenesis for RRII 400 series clones was carried out. Earlier developed protocol of RRII 414 was used for callus induction from immature anther of clones RRII 105 as well as RRII 414, RRII 417 and RRII 430. Callus was induced in medium containing 2.0 mg L^{-1} 2,4-D + 2.0 mg L^{-1} BA and proliferated in the same medium by sub-culture. Embryogenic callus was obtained for clone RRII 105 and 430 and embryogenesis attempted.

2.1.1. *Influence of calcium on induction of callus and embryogenesis*

To identify the suitable form of calcium at optimum level and to address whether the calcium in callus induction medium affects embryo induction and further plant regeneration, experiment was repeated with selected concentrations. Callus induction medium was supplemented with both $CaCl_2$ and $CaNO_3$ at three concentrations (3mM, 6mM, 9mM). Immature anthers (60 nos.) were dissected out and inoculated in each combination and experiment was repeated two times. Cultures were kept under darkness for two months. After 50 days, cultures were evaluated for callogenesis and results revealed that both forms of calcium responded more or less equally. By increasing calcium to 6mM, friability was increased and very friable callus obtained at 9mM. For optimizing the exact concentration, friable callus induced from each combination were sub-cultured to embryo induction medium and kept for embryogenic calli formation / embryogenesis.

2.1.2. *Influence of coconut water on callus induction*

A preliminary attempt was made to test the effect of coconut water(CW) at three levels (0, 5, 10%) for callus induction from immature anther of clone RRII 105. After 50 days of culture, observations were made and it was shown that CW yielded good response for callogenesis. Based on the observations, experiment was repeated twice with 60 anthers/combination.

2.1.3. *Enhancement of somatic embryo induction: A comparison of solid with liquid medium*

To improve the quality and quantity of somatic embryos, a liquid culture phase was experimented. Embryogenic callus was transferred to liquid medium for one to seven days with half strength of embryo induction medium. After each day, the callus was cultured to solid embryo induction medium lacking hormones along with solid embryo induction medium containing hormones as control kept for embryogenesis.

2.1.4. *Encapsulation of somatic embryos and synthetic seed production*

Synthetic seeds are, encapsulated somatic embryos covered with a protective coating formed by Na alginate and $CaCl_2$ solution. In earlier attempts few embryos were obtained, but the quality was not good. To find out the ideal hydrogel and its exact combination, experiments were initiated with 16 combinations of Na alginate (1-4%) and CaCl2 (50-200mM) at four different concentrations. Preliminary experiments were carried out with nodal explants to identify the exact combination and experiments are being repeated.

2.2. Somatic embryogenesis from leaf explants

Callus induction in culture leaves of clone RRII 105, RRII 414 and RRII 422 was carried out. Rate and time of callus induction was found to vary with the clone. As reported earlier, callus proliferation with change in texture was achieved through repeated subculture in medium with gradual increase in cyotkinin\auxin ratio and sucrose concentration. The effect of different concentration of adenine hemisulfate (0-300 mg L^{-1}) in the callus induction, proliferation and embryo induction medium was also studied. Towards the end of the subculture period for callus proliferation and texture improvement effect of stress inducing compounds such as poly ethylene glycol and phytagel at different concentrations were also supplemented in the medium for induction of embryogenic callus. Embryogenic callus induction and somatic embryogenesis was obtained in the earlier standardized medium in RRII 105 and RRII 414. Stress inducing compounds in the proliferation and embryo induction medium triggered formation of embryogenic callus. Presence of adenine hemisufate at a concentration of 50 mg L^{-1} in the callus induction medium, 100 mg L^{-1} in the callus proliferation medium and 185 mg L^{-1} in the embryo induction medium favored embryogenesis. The amino acids, asparagine and L-glutamine at different concentrations was supplemented in the embryo induction medium. Frequency of embryo induction could be enhanced by the presence of asparagine (150 mg L^{-1}) and glutamine (800 mg L^{-1}) in the embryo induction medium. Somatic embryos after one week culture in maturation medium were subjected to slow desiccation. Presence of folic acid at different concentration also influenced germination of somatic embryos of which 0.5 mg L^{-1} was found to be the optimum. Germination of the desiccated embryos was carried out in WPM medium supplemented with phytohormones, BA, GA and IBA. *In vitro* plant regeneration was obtained in MS medium containing BA and GA. Acclimatization of the plants was attempted in soilrite under humidity controlled conditions where the plants could survive the initial hardening phase.

2.2.1. *Effect of salicylic acid on somatic embryo induction*

The explants were pretreated with different concentration of salicylic acid (0-5 mg L^{-1}) along with phytohormones BA, NAA and 2,4-D for five minutes before culture initiation to study its effect on embryo induction. It was observed that callus induction with improved texture was obtained in 20 per cent of the cultures and good swelling with proembryo like protrubances observed in 10 per cent of the cultures. To study the effect of salicylic acid on embryogenic callus induction it was supplemented in callus induction medium at different concentration (0-5mg L^{-1}) along with the phytohormones BA, 2,4-D and NAA. Addition of 2.0 mg L^{-1} salicylic acid in the callus induction medium and 1.0 mg L^{-1} in the callus proliferation medium had a synergistic effect on embryogenic callus initiation from the proliferated callus. Experiments are being repeated.

2.3. *Ex vitro* adventitious rooting for production of self-rooted clones

Somatic plants of clone RRII 105 were established in nursery as stock plants and green bud grafted plants were generated. These bud grafted plants maintained in polybags in the glass house were experimented for *ex vitro* rooting. *Ex vitro* rooting of seedling shoots were also tried simultaneously. Experiments were continued

to identify suitable conditions and potting medium. Hormone pulse with different combinations of phytohormones such as BA,TDZ, IBA AND NAA at different concentration were tried for different time intervals. The shoots were transferred to sterile soilrite as well as mixture of sand and soil (1:1) for *ex vitro* rooting under humidity control. Adventitious root induction was observed in seedling shoots and few clonal shoots in a hormone combination of BA, IBA and NAA as well as, TDZ, IBA and NAA. Experiments are being repeated.

3. Induction of ploidy variation in *Hevea brasiliensis* through *in vitro* techniques

3.1. Development of homozygous diploids in *Hevea*

3.1.1. Embryo sac culture for the development of gynogenic haploids

The clones identified for initiating new haploid cultures during the reporting period were RRII 105, RRII 414, RRII 429 and PB 330. Embryo sacs were isolated from mature, unopened female flowers of these clones using the standardized technique and cultured for callus induction. It was observed that callus could be obtained in all the clones, though with different frequencies of callus induction, within four months of culture. The time span taken for callus initiation varied among the different clones, PB 330 being the fastest responding clone which took hardly one month for haploid callus induction. After proliferation the calli were sub-cultured for embryogenesis. Emergence of embryogenic callus was observed in all the clones except RRII 429. Somatic embryos have been induced in the clone PB 330. Some of the germinating embryos of this clone are in the plant regeneration stage.

From the haploid cultures of previous year, plantlets could be regenerated from both RRII 105 and RRII 414. Regenerated plantlets with matured leaves were subjected to hardening. Success rate during hardening was more in the clone RRII 414, compared to that of RRII 105. Plantlets from both the clones survived the initial phase of hardening. However, up on transfer to polybags filled with top soil for the second stage of hardening, only those plants from RRII 414 could survive. Subsequent field establishment also could be achieved for this clone. Repeated cytological analysis of leaf samples from different whorls during the course of plant growth from the filed established its haploid nature with a chromosome count of n=18. This is the first report of field establishment of haploid plants with confirmed ploidy in *Hevea brasiliensis* through embryo sac culture.

The callus obtained from the embryo sac cells of *Hevea* clone RRII 422 was confirmed as haploid through flow cytometer studies. Somatic embryogenesis was achieved from the embryogenic masses developing from callus cultures. Embryo induction efficiency was 32 per cent. Maturation of the embryos was achieved in half strength MS medium containing BA (1.0 mg L^{-1}) and NAA (0.3 mg L^{-1}). Matured embryos with bipolar differentiation were observed in half strength MS medium supplemented with Kinetin (1.5 mg L^{-1}) along with GA_3 (1.0 mg L^{-1}).

3.2. Development of polyploids

Embryogenic callus belonging to clones RRII 105, RRII 414 and PB 330 were subjected to colchicine treatment by culturing the calli over callus proliferation medium enriched with different levels of colchicine for different time intervals. Emergence of new callus could be obtained from all the clones within three months after the colchicine treatment. These calli have

been proliferated and transferred to embryo induction medium for further development.

4. *In vitro* approaches to complement conventional breeding programmes

4.1. Induction of Polyembryony

4.1.1. Development of uniform seedlings

In order to develop a pathway for developing uniform seedlings of known parentage, *in vitro* pollination experiments were conducted. Inflorescence were collected from field grown trees and the cut end was dipped in distilled water. Stigmatic pollination was carried out with freshly opened flowers. After 48 h, flowers were sterilized and fertilized ovules were isolated using standard protocol and inoculated in the media.

Simultaneously, in *vitro* ovular pollinations were also carried out using isolated ovules. Embryogenic calli emerged from one fertilized ovule resulted from stigmatic pollination. Simultaneously fruits were collected from the field one to two weeks after pollination and ovules were isolated after surface sterilization and cultured. Results awaited.

Yield recording in the polyembryony derived plants was continued. The first year yield data recording was completed in the field planted polyembryony derived seedlings. Poly plants had lowest CV among all treatments indicating their better uniformity.

5. *In*-vitro screening of rubber clones for disease tolerance

5.1. In vitro approaches to impart Corynespora Leaf Fall Disease (CLFD) tolerance in Hevea brasiliensis

5.1.1. In vitro selection of Corynespora tolerant lines of clones RRII 105 and RRII 414 through toxin challenge

During the previous year, experiments were initiated with RRII 105 which is the most popular, high yielding clone which at the same time is susceptible to CLFD. Embryogenic calli were cultured over medium fortified with different levels of cassiicolin toxin. After six weeks in culture, the surviving tolerant calli were proliferated in toxin free medium and again exposed to the toxin for another six weeks after which they were transferred to toxin free media for further development including embryo induction, subsequent embryo germination and plant regeneration. Regenerated plants were subjected to acclimatisation by transferring to earthenware pots filled with potting mixture consisting of top soil, sand and *Soilrite* in equal proportion. Plants which survived the initial stage of hardening were then transferred to big poly bags containing top soil and kept under partial shade. Later the plants with at least two whorls of mature leaves were field planted and maintained with regular watering and manuring for further foliage development. Attempts have also been initiated for multiplication of the field established plants through bud grafting.

Simultaneously, during the reporting period, the same experiments were carried out with another elite clone RRII 414 by exposing embryogenic calli to different levels of cassiicolin toxin. Plant regeneration from the toxin challenged calli has already been achieved for this clone and further experiments are in progress.

5.2. Laboratory level confirmation of tolerance of the regenerated plants towards Corynispora leaf fall disease (CLFD) - Leaf wilt bioassay

In order to confirm whether the plantlets regenerated from the toxin habituated cultures have acquired the desired tolerance towards cassiicolin, a

laboratory level experiment was performed using detatched leaves of the field established plants.

Leaf wilt bioassay was employed for testing the disease tolerance of the field established somatic plants raised from toxin challenged callus compared to the unchallenged control plants of RRII 105. In this assay, healthy young leaflets of light green stage were excised from both the experimental and normal plants and placed in McCartney bottles containing the toxin in such a way that the cut end of the petiole was immersed in the toxin solution. Simultaneously leaflets of the same stage from both experimental and normal groups were placed in bottles containing sterile distilled water which served as the control. The leaflets were incubated at room temperature and wilting intensity was assessed after 24 hours. Leaves of the normal plants exhibited browning and curling up of leaf tips followed by necrosis after 24 hours of toxin treatment whereas the leaves of the experimental plants remained intact without any signs of wilting even after 24 hours of toxin treatment. In other words, leaves of the control plants differed from leaves of experimental plants derived from selected calli by greater degree of aggressiveness in wilting intensity. Leaves from plants belonging to both the groups subjected to the control treatment of immersing in sterile distilled water showed no signs of wilting. These results reveal that the plants regenerated from toxin habituated plants have acquired certain level of tolerance towards CLFD.

II. GENOME ANALYSIS LABORATORY

Ongoing research projects in the Genome Analysis Laboratory are grouped under four major areas of research *viz*. (1) development, optimization and validation of molecular tools for the assessment of genetic diversity and evolutionary relationships in rubber and genetic linkage mapping (2) development of genetic markers for biotic and abiotic stress tolerance and understanding the stress adaptation processes through transcriptome analysis (3) cloning and characterization of agronomically important genes and (4) rubber genome sequencing and *de-novo* assembly. Besides the above research programs a collaborative project has been initiated with CSIR-NEERI on conversion of tropical forests to rubber plantations in Kerala and its impact on the soil environment and different eco-restoration strategies.

1. Development, optimization and validation of molecular tools for the assessment of genetic diversity in rubber, clonal identification and genome mapping

1.1. Single nucleotide polymorphisms (SNPs) in *Hevea*

1.1.1. SNP identification and haplotype structuring in the latex biosynthesis genes of Hevea brasiliensis

Phosphomevalonate kinase (*PMVK*) is a key enzyme in the rubber biosynthesis pathway which catalyzes the conversion of

mevalonate 5-phosphate and ATP to mevalonate 5-diphosphate and ADP leading to the synthesis of IPP, the monomeric subunit of natural rubber. Identification of variants and alleles of the gene encoding this enzyme is important in understanding the evolution of rubber biosynthesis genes in *Hevea* and for utilizing them in crop improvement programs for developing high yielding clones. A highly distorted *PMVK* gene indel locus associated with a short viral gene sequences was identified in *Hevea*. The presence of this indel allele was screened in popular clones, wild accessions, two hybrid progeny populations and five *Hevea* species. Frequency of the deletion allele was very high in natural population (wild accessions and species) whereas in popular clones, insertion allele frequency was higher. The progeny populations also showed distorted allele segregation with high frequency of insertion allele. Probably, selective breeding and shared ancestry of the popular clones may be responsible for this trend. On the contrary meiotic drive characteristics of the deletion allele which is almost free of viral sequences may be responsible for its high frequency in naturally occurring populations.

1.1.2. Development of a rapid clone identification system based on SNP markers

Fifteen popular clones were selected for genotyping using gene specific SNP primers. Genotyping was performed using three SNP markers and data was compiled. In order to identify novel unique SNPs, selected region from genes like *HMGR*, *HMGS* and *REF* were amplified from the genomic DNA of 15 clones. Sequencing and bioinformatics analysis revealed the presence of one new SNP from *HMGR* gene. Sequence analysis of *REF* and *HMGS* gene is in progress.

2. Characterization of stress-tolerant clones of *Hevea* using molecular markers and understanding gene regulation under abiotic stresses

2.1. Characterisation of NAC promoter sequence and development of a microsatellite marker

Genetic variations in gene promoters play key roles in the determination of gene expression and phenotypes, and transactivation regulation of nearby genes due to polymorphic short tandem repeats (STRs) in promoter sequences has already been reported. Therefore, allelic polymorphisms observed between RRIM 600 and RRII 105 in *NAC-tf* promoter sequence reported last year may have a regulatory role on differential expression of *NAC-tf*. Although evidence to support STRs as functional elements continues to accumulate, little information is known about how they operate. A microsatellite primers was designed to perform allelic profiling of the above short tandem repeat (STR) at the upstream of the promoter sequence of the NAC-tf gene from *Hevea* with the intention of developing it as a marker for abiotic stress tolerance. Microsatellite PCR reactions were set for 36 popular clones to assess the allele status of their NAC-tf microsatellite locus. The experiment to screen the alleles is in progress.

2.2. Methylation dynamics of *Hevea brasiliensis* genome

2.2.1. Identification of epigenetic markers for abiotic stress in Hevea

Bisulfite converted promoter region sequences of *REF* and *HMGS* from 24 DNA samples derived from the clone RRII 105, RRIM 600 and RRIC 100 before imparting the stress, after two weeks of giving stress and one month post stress were analysed using bioinformatics tools to identify DNA

methylation changes associated with abiotic stress. Consistent CG and CHG methylation changes before and after stress were observed in the promoter region of HMGS gene. Only CG methylation patterns changes were detected in REF promoter region analysed and consistent clone specific patterns could not be located. Sequencing of more colonies required as the Sinic bisulfite conversion quality of REF promoter region was not satisfactory for some samples; sequencing of additional colonies has to be carried out.

2.3. Functional genomic studies in *Hevea*

2.3.1 *Identification and validation of fungal transcripts obtained from Hevea root transcriptome data*

The presence of two Arbuscular Mycorrhizal Fungal (AMF) transcripts in the root tissue of *Hevea* was confirmed by root trancriptome analysis. Tissue specificity of the transcripts was estimated by RT PCR using root, bark and leaf RNA. Gene specific amplification and sequencing revealed that transcript-1 have 82 per cent homology to a hypothetical protein of *Rhizophagus irregularis* and transcript-2 have 64 per cent homology to a hypothetical protein of *Diversispora epigaea* (both are AM fungi under *Glomeraceae* family). Preliminary results obtained clearly indicate the presence of beneficial AM fungi within the root tissues of rubber. In order to verify their association with plant age, attempts were made to detect their presence in root of rubber plants of different age (5 months to 5 years). The experiment is in progress.

3. Cloning and characterization of agronomically important genes

3.1. Cloning and characterization of *WIN1/SHN1* gene from *Hevea*

INDUCER1/SHINE1 (WIN1/SHN1) is a transcription factor of the ethylene response factor (ERF) family. This transcription factor is known to trigger epicuticular wax production thereby enhancing drought tolerance in several plants. Attempts were made to amplify two isoforms of *WIN* genes (*WIN1* and *WIN1X*) from the genomic DNA of clone RRII 105 and *H. benthamiana*. As predicted from whole genome sequence data, a 750 bp amplicon was obtained for *WIN1* gene. Similarly a 870 bp fragment was obtained from both the genotypes for *WIN1X* isoform. Sequence analysis of *WIN* gene isoforms revealed that both the isoforms had significant sequence variations in the two genotypes. Both the genes had one intron near the 5′ end. Intron size was different in both the genotypes for *WIN1X* gene whereas *WIN1* intron was of the same size. Sequence analysis of *WIN1* gene from RRII 105, RRII 414, RRII 430 and *H benthamiana* revealed the presence of 11 SNPs. Sequencing also establish the presence of an SNP induced premature stop codon in one allele of *WIN1* gene in RRII 105 which might have translated to a truncated protein. Further analysis to characterize them is in progress.

3.2. Cloning and characterization of Osmotin gene from *Hevea*

Osmotin is a stress responsive multifunctional basic protein belonging to PR-5 protein family providing osmotolerance to plants. Genomic region of *Hevea osmotin* gene was amplified and sequenced from the clone RRII 105. Sequence analysis revealed that the gene is intron less in nature. Two different alleles were obtained from RRII 105 with five single nucleotide changes. Out of the five, three single nucleotide variations were non-synonymous. Both the sequences were submitted to genbank (Acc. No. MN683520 and MN683521).

4. Metagenomics and microbe identification in rubber ecosystems (Collaborative project with CSIR-NEERI)

The fungal ITS region was successfully amplified from all the 130 samples using fungal ITS region specific primers. Libraries were created using the amplicons derived for Next Generation Sequence (NGS) analysis. Good quality raw sequence data was derived from 113 samples and bioinformatics analysis is in progress to derive useful information from the data.

5. Development of genetically modified rubber plants with agronomically desirable traits

5.1. Molecular characterisation of transgenic lines developed

5.1.1. *Estimating the site of genomic integration of MnSOD gene in the transgenic MnSOD plants developed by RRII*

Detailed molecular characteristics of flanking sequences of insertions play an important role in the safety assessment of genetically modified crops. It is also essential to understand whether native genes are disrupted during the process and to predict and assess its impact on the plant development and function.

In order to identify the flanking sequences of one line of the MnSOD transgenic rubber plant developed by RRII, a PCR based restriction digestion library method was followed. Genomic DNA from the transgenic plant was isolated and three different restriction endonuclease digestion libraries was created. Respective adaptors were ligated to their ends and nested PCR amplification was performed using adaptor based primers and gene/construct specific primers from 5′ as well as 3′ ends. Secondary amplification, purification of amplicons and cloning is in progress.

6. Genome sequencing and de-novo assembly of rubber (*Hevea brasiliensis*) genome

6.1. Transcriptome sequencing

6.1.1. *Differential Gene Expression (DGE) Screening*

A total of 829 differentially expressed genes was identified between YA (Latex from high yielding germplasm accession) and YC (Latex from low yielding clone) samples with stringent homology search criteria against *Ricinus communis* protein data set.

Transcript quantification by RNA-Seq using Expectation Maximization method and differential expression analysis using Empirical Analysis of Digital Gene Expression Data in R yielded a total of 435 transcripts between N (Bark sample from healthy plant) and T (Bark sample from TPD plant - 20, 50 and 80 per cent TPD samples pooled together) samples. These transcripts will be further annotated and screened using homology search.

PLANT PATHOLOGY DIVISION

Plant Pathology Division research focuses on monitoring the pests and diseases of rubber and their management through chemical and biological methods, evaluation of new clones for disease resistance, identification of genes involved in disease tolerance, identification of quantitative trait loci for disease tolerance, understanding the biotic etiology of tapping panel dryness,beneficial microorganisms for plant growth and disease management *etc.* In addition to the focus areas of research, the Division takes up testing of spraying equipment, plant protection chemicals and analysis of water samples for bacterial population. Training on disease management, maintenance of spray equipment and apiculture are the other activities undertaken by the Division.

Advisory on disease management through direct field visits, telephonic advisory, Whats App and Online Rubber Clinic were also undertaken by the Division. During the reporting year 1220 cases were attended through What Sapp and telephonic advisory. 387 water samples were analysed for microbial contamination during the reporting year.

1. Leaf diseases

1.1. Abnormal leaf fall disease

Survey on abnormal leaf fall disease was carried out during 2019 disease season in Kerala and South Karnataka and it was observed that leaf fall incidence was low irrespective of clones and regions. No difference was observed between the clone RRII 105, RRII 414 and RRII 430.

Impact of abnormal leaf fall disease (ALF) on growth and yield was different among the clones RRII 414, RRII 422, RRII 429 and PB 260 giving varying results. The severity of ALF disease in general was low during 2019. Among the clones, 70-90 per cent leaf fall was recorded in unprotected blocks of RRII 414, RRII 422, RRII 429 and PB 260. The girth and yield of the trees in the sprayed blocks continued to be significantly higher in clones RRII 429, RRII 414 and PB 260.

Yield variation was recorded among the clones due to ALF at CES Chethackal. ALF was more in the clone RRII 429 (25.3%). The crown budded trees in CES, Chethackal recorded higher yield than control clone (PB 260). The yield loss data is presented in Table Path. 1.

Table Path.1. **Yield loss due to abnormal leaf fall disease**

Clone	Yield loss (%)
RRII 414	13.67
RRII 429	24.38
RRII 422	20.20
PB 260	20.07
Crown bud	31.13

1.2. Corynespora disease

1.2.1. Disease management

Nursery evaluation of bioagents (endophytic bacteria) and integrated control against Corynespora leaf fall disease on the clone RRII 105 was carried out at Ulickal nursery. The endophytic bacteria (8LK) were applied as broth ($1x1^8 mL^{-1}$) and talc formulation with carbendazim (500 mg) and Thiophonate methyl. The integrated treatment (carbendazim 0.025% + Antagonistic endophytic bacteria in broth ($1x10^8 mL^{-1}$) was on par with recommended chemicals (Table Path. 2). The disease intensity was recorded at 0-5 scale.

Table Path. 2. **Effect of integrated treatment on Coynespora leaf fall disease**

Treatments	Disease Intensity
Endophytic bacteria + Carbendazim 0.025%	0. 7
Carbendazim (0.05%)	1.2
Control	3.3
Thiophonate methyl (0.04%) + Endophytic bacteria	0.2
Thiophonate methyl (0.07%)	0.4
Endophytic bacteria alone	0.6
CD (P=0.05)	0.3

Evaluation of new generation fungicides, Propineb, Thiophonate methyl along with recommended fungicides and integrated treatment with endophytic bacteria (8LK) were carried out at Karnataka State in two locations during 2019-20 disease seasons. The endophytic bacteria were applied in broth ($1x10^8 mL^{-1}$) and talc formulation. Among the treatments, integrated treatment was found significantly superior to all other treatments in controlling the disease in 2020 disease season. The new fungicide Propineb was found effective in two locations. The results from location 2 (Kaniyoor) are given in Table Path. 3.

Table Path.3. **Effect of teatments on the control of *Corynespora* disease**

Treatments	Disease Intensity
Endophytic bacteria +Thiophonate methyl (0.035%)	0.3
Propineb(1gL^{-1})	0.4
Endophytic bacteria + Carbendazim (0.025%)	0.3
Carbendazim (0.05%)	1.1
Thiophonate methyl (0.07%)	0.3
Endophytic bacteria	1.0
Control	4
CD (P=0.05)	0.3

1.2.2. Whole genome sequence of virulent Corynespora isolate

Identified the virulent genes from the whole genome data of a virulent *Corynespora* isolate. The predicted proteins were searched against Database of Fungal Virulence Factors (DFVF), a comprehensive online database of known fungal virulence factors using blast p, which collected 2058 pathogenic genes produced by 228 fungal strains from 85 genera. 1026 proteins (approximately 10%) of the organism matched against the database with e value <0.0001. 229 (approximately 22%) proteins were classified as leaf spot associated virulence factors of the mapped genes which is predominant in rubber.

1.3. Powdery mildew disease

Powdery mildew disease incidence was observed to be low in the 2019-20 disease season. A bio-dust developed with endophytic bacteria along with recommended fungicide, carbendazim (0.025%/kg) dusted prophylactically on RRII 105 trees at CES, Chethackal. Treatments were imposed at eight days interval. No disease incidence in the experimental area (Disease escape).

1.4. Colletotrichum Circular Leaf Spot

The circular leaf spot symptom and leaf fall was reported during May to November 2019 in the traditional rubber growing areas. The pathogen is identified as *Colletotrichum* spp. Heavy leaf fall was observed in the infected plantations of mature and immature area. The symptom is pin spot with yellow/brown halo initially which turns white discolored round spot on the mature leaf and later leading to leaf fall (Fig. Path. 1). The symptom size varies between 1-8 mm diameter. During the reporting year, the

Fig. Path. 1. Symptoms of Colletotrichum circular leaf spot disease.

disease incidence observed in the plantations of Thrissur, Idukki, Kottayam, Ernakulam, Pathanamthitta districts and Punalur region. Disease appeared after the summer rains and the season was from May to November.

Infection was on mature leaves. Infected leaves were with discoloured white spots (1-3 cm in diameter). Leaf yellowing and dark round infection starts in early monsoon. Certain infected spotted leaves remained on the tree for the whole year. Intermittent rain and dry spells increase the disease incidence. All recommended clones were susceptible to this disease. Disease spread was from lower leaves to upper whirls.and the leaf fall observed from lower mature leaves and spreads to upper whirls. Around 3000 samples were observed, and in all the samples *Colletotrichum* spores were present. Disease incidence reduced in the sprayed areas in the observation trials. Spraying of water based fungicides at seven days interval was found effective in in controlling the disease.

1.5. Thread blight disease

A survey on the incidence and severity of thread blight disease was undertaken in the Pala, Thodupuzha and Kothamanalam regions in 2019-20. The incidence and severity varied from 10-60 per cent and the highest incidence was observed at Kaliyar region.

2. Tapping panel dryness (TPD)

Experiment was conducted at RRII and Central Experimental Station Chethackal. Trees were selected for daily tapping and graded them into TPD/healthy by visual observation. The trees were monitored continuously for TPD incidence and grouped to TPD affected, partially affected and healthy. The affected trees were treated with 1000 ppm Tetracyclin in the tapping panel daily. Bark tissue from the affected region and healthy region were processed and observed under microscope and confocal scanning microscope. The tissues were

stained with nuclear fluorescent stain Bis–benzamide (Fluorescent nuclear stain–minor groove). The tetracyclin (1000 ppm) treated TPD trees showed fresh latex production in the panel. The microscopic examination of the phloem region stained with Congo red revealed that the affected phloem region was blocked with callose deposits. Healthy region was totally free from callose deposit. The sections from the TPD plants showed nucleated organisms in the sieve tube. At the same time, these organisms were totally absent in healthy sieve tubes.

3. QTL marker development for disease tolerance

3.1. Leaf diseases

3.1.1. Abnormal leaf fall disease

Global analysis of rubber transcriptome in response to *Phytophthora* infection, using resistant (FX 516) and susceptible (RRIM 600) clones, in both control and pathogen-challenged conditions was undertaken. NGS study provided understanding about the differentially regulated genes and illustrated critical pathways involved at different stages of disease development at varying time points. Transcription factor group were up-regulated, which could be associated with enhanced immunity against the pathogen. Up-regulation of disease resistant protein ascertained about clonal response to pathogen. Increase in carbohydrate metabolism showed induction of defence-related gene expression and repression of photosynthesis. Up-regulation of chitinase, beta-glucanase, and genes involved with proteolysis proved ability of resistant host to degrade pathogen cell wall components. Pathogenesis-related proteins were confirmed to be synthesised and accumulated with time to prevent invasion and establishment of pathogen. PR 2 (^{2}-1,3-glucanase), PR 3 (chitinase) and PR 7 (endoprotease) were found to be released to plant intercellular space. Catalyse degradation of structural components in the cell walls of pathogen was established. Transcriptional regulation established its role in defending infection from progressing in the resistant clone. Validation through qRT-PCR assays as well as using more number of tolerant clones is in progress to confirm differential regulation of transcripts upon infection with pathogen.

One hundred Wickham clones were tested for their tolerance to *Phytophthora* by detached leaf disc assay using zoospore suspension. The clones wee categorized into 5 groups based on their response to the pathogens. Ten clones were found to be highly tolerant, 20 were tolerant, 26 were moderately tolerant, 34 were susceptible and 10 were highly susceptible. One more round of screening is in progress for confirmation.

3.1.2. Corynespora leaf disease

One hundred and sixty four Wickham clones were tested for their tolerance to *Corynespora* through leaf wilt bioassay using toxin isolated from *Corynespora cassiicola*. Twelve clones were identified to be highly tolerant, 45 tolerant, 50 moderate, 43 susceptible and 14 highly susceptible. Twenty six clones recently imported from five different countries through the IRRDB clone exchange programme (eight from Vietnam, five from Thailand, five from China, five from Cambodia and three from Indonesia) were tested for their level of tolerance. Among the eight clones from Vietnam, four were found to be tolerant to *Corynespora*. All five clones from Thailand showed moderate to high levels of tolerance. All five clones both from China and Cambodia were found to be highly tolerant

whereas the three Indonesian clones were moderately susceptible/ tolerant to *Coyrnespora*.

3.1.3. Colletotrichum leaf disease

One hundred and sixty four Wickham clones were tested for their tolerance to *Colletotrichum* through leaf wilt bioassay using toxin isolated from *Colletotrichum acutatum*. Of the 164 clones tested, 10 were highly tolerant, 32 were tolerant, 52 were moderate, 54 were susceptible and 14 were highly susceptible to *Colletotrichum*. A total of 26 international clones recently imported from five different countries through the IRRDB clone exchange programme (eight from Vietnam, five from Thailand, five from China, five from Cambodia and three from Indonesia) were tested for their level of tolerance to *Colletotrichum*. Among the eight clones from Vietnam, two were susceptible to *Colletotrichum*. All five clones each from Thailand, China and Cambodia were susceptible to *Colletotrichum*. The three Indonesian clones were moderately susceptible/ tolerant to *Colletotrichum*.

4. Construction of genetic linkage map, mapping of quantitative trait loci and development of high throughput markers for early detection of leaf diseases of rubber

Disease response of parents and progeny population derived from an interspecific cross between *Hevea brasiliensis* (clone RRII 105) as the maternal parent and *H. benthamiana* (clone F4542) as the paternal parent to three major pathogens: *Phytophthora meadii*, *Corynespora cassiicola* and *Colletotrichum acutatum* were carried out in controlled laboratory conditions. Tolerance to *Colletotrichum* and *Corynespora* was evaluated through leaf wilt bioassay using toxin isolated from the respective pathogen. Tolerance to *Phytophthora* was estimated by detached leaf disc assay using zoospore suspension. They were categorized into five groups namely highly tolerant (HT), tolerant (T), moderately tolerant/ susceptible (M), susceptible (S) and highly susceptible (HS) based on their response to each pathogen. As genotypic data generated using next generation sequencing platforms may contain errors which can significantly impact the analysis of data, additional data filtering methods were employed to effectively remove these errors before performing analyses with varying phenotypes using the same population. Linkage map was constructed with the filtered genotypic data which grouped into 18 linkage groups, consistent with the chromosome number of *Hevea* (n=18). QTL markers were identified for all three diseases. Genotypes at two markers in LG 1 and four markers in LG 8 distinguished highly resistant progeny. Two progenies possessed all three resistance genes and could be useful in pyramiding the resistance. Genetic analysis identified pathogenesis-related protein coding sequences in QTL regions. Candidate gene sequences identified could be useful in designing primers for resequencing of these genes and could be useful in pathogenesis related gene isolation.

PLANT PHYSIOLOGY DIVISION

The major areas of research in the Plant Physiology Division are studies on physiology of growth and yield, environment and stress physiology, gene expression analysis in relation to rubber biosynthesis, latex flow, ethylene biosynthesis and signalling and studies on ecological impact on rubber cultivation.

Clonal responses were studied in Hevea under high and low temperature stresses in terms of excess light management and other stress adaptive mechanisms. Many wild germplasm accessions and ortets selected from different agro-climatic conditions were evaluated for tolerance to extreme climatic conditions. Observations indicated that Agartala selections were superior to other ortets for growth vigour and test tap yield. Field application of a plant growth regulator, known as paclobutrazole (PBZ) and evaluation of growth and development of immature rubber plants indicated that better trunk girth in a treatment with PBZ@0.25gcm-1 diameter. Gene expression analyses were carried out to understand ethylene mediated signal transduction and ethylene biosynthesis in different rubber clones with varying rate of metabolism. Overall life time emission potential of various rubber farming activities in the traditional plantation region was accounted to be around 27 MT CO_2 ha^{-1}.

1. Environmental and Stress Physiology

1.1. Studies on adaptive mechanisms in Hevea for drought and cold stresses

An experiment was conducted with an objective to study the adaptive mechanisms of rubber plants for drought and cold stresses. Polybag plants of different clones with contrasting responses to drought and cold stresses were raised at RRII experimental farm and were subjected to stress conditions. As a measure of excess light management in plants under stress xanthophyll cycle pigment analysis was carried out in six different Hevea clones of varying cold tolerance. Marked variations in carotenoid pigments content among the rubber clones were observed in response to low temperature stress. The proportions of xanthophyll pigments (neoxanthin, zeaxanthin, violaxanthin, lutein and ^{2}-carotene) were largely altered by cold stress. A marked and similar level of increase in zeaxanthin and antheraxanthin contents was observed in clones RRIM 600 and RRII 422. Stressed leaves showed an increased total carotenoids to total chlorophyll ratio (X+C / Chl a+b) which was correlated with a higher xanthophyll pool to total chlorophyll ratio (V+A+Z / Chloro a+b) and a higher lutein to total chlorophyll ratio. This inferred an enhanced level of photo protection under stress condition as both xanthophyll pigment pool and lutein protect the photosynthetic apparatus from photo-oxidative destruction. Upon allowing cold stress recovery, clones like RRII 208, RRII 430 and RRII 422 showed better regrowth whereas RRII 105 did not show any recovery from two week period of cold stress. In the case of drought recovery all the clones showed regrowth and clones RRII 429, RRII 430 and RRII 422 had new branch development. Further analysis of data is being carried out to classify the clones for relative drought and cold tolerance potentials.

1.2. Studies on drought effects on Hevea in relation to oxidative stress and antioxidant responses

Germplasm accessions namely, MT 5100 and MT 4788 and a few elite clones namely, RRII 105, RRII 208 and RRIM 600 were raised at RRII farm. Drought stress was imposed by withdrawing irrigation. Analysis of xanthophyll cycle pigments under control and drought conditions revealed significant variations among the pigment components of xanthophylls. However, there was not much variation in ^{2}-carotene content in control and drought imposed plants. The ratio of zeaxanthin to ^{2}-carotene was found increased under drought condition in all the clones studied. Excised leaf water loss level was almost same in MT 5100 and MT 4788. Among the elite clones RRII 208 showed relatively a small loss of water content from mesophyll tissue than other clones.

1.3. Physiological adaptation of selected ortets under varying agro-climatic conditions in India

A multi-location trial with sixteen ortets selected from five different agroclimatic regions of India along with seven check clones were planted at three different locations in 2012 is continued in which CES, Chethackal being one of the locations. The young plants were allowed to grow in a closed planting design till four years after that alternative plants were removed to allow normal spacing for the plant growth. Mean girth recorded for ortets during March 2020 ranged from 28.1cm for ortet NGK 69 to 46.9 cm for RRSA 98 (Agartala selection) which was on par with that of check clone RRII 430 (46 cm). Three years consecutive test tap yield indicated that ortets RRSA 98 followed by RRSA 585 recorded higher yield and NGK 69 and DAP 34 recorded the lowest yield. General observations indicated that Agartala selections were superior to other ortets for growth vigour and test tap yield.

2. Production Physiology (Growth and Yield)

2.1. Productivity enhancement of NR through HDP and growth regulation by application of PBZ

This project was continuing at RRII experimental farm with an objective of finding out the response of rubber plants to the exogenous application of paclobutrozole (PBZ), canopy and root system modulations and enhancement of NR productivity through high density planting (HDP). The treatments were control, PBZ @ 0.25g cm^{-1} diameter and PBZ @ 0.5g cm^{-1} diameter in different spacing and planting material (polybag and root trainer plants of clone RRII 430). The growth data indicated better trunk girth in plants raised from polybag plants as planting material with 5mx5m spacing and PBZ @ 0.25gcm^{-1} diameter than other treatments. The effect of plant growth regulator and planting density on girthing showed variation between 0.25g and 0.5g PBZ applications.

2.2. Intercropping with tree crops in rubber

This project was continuing at CES, Chethackal with a major objective of finding out the impact of tree intercrops and competition for light on the growth and yield of rubber plants. The mean trunk girth was 71.5 cm, 71.2 cm and 71.3 cm for pure stand of rubber, three rows of mahogany and rubber with one row of mahogany trees along with one row of pathimugam trees, respectively. The growth data indicated that tree intercrops did not affect the girth of rubber plants. The trees were tapped for seven years under 5/2 d3 system of tapping

and from April 2017 onwards the tapping system was changed to S/2 d7 and monthly stimulation was provided at 2.5 per cent ethephon. When the rubber yield in pure stand of rubber compared with intercropped plots there was significant reduction in tree intercropped treatments with 100.2 g, 80.0 g and 78.0 g per tree per tap for control, with three rows of mahogany and one row of mahogany+pathimugom trees, respectively. The result showed that tree intercrops obstructed rubber yield markedly. Among the intercrops, the pathimugom stand was very poor due to shading by the mature rubber trees, whereas mahogany trees (62 cm) were growing better as an inter-crop with rubber because the mahogany canopy height was as equal to rubber canopy in a grown-up plantation.

2.3. Effect of stimulation on latex regeneration mechanism in Hevea brasiliensis

To understand the molecular mechanism associated with latex regeneration after ethephon stimulation in different clones, the relative expression levels of four genes encoding key regulatory enzymes involved in latex regeneration mechanism (sucrose transporters SUT 1&2, ATPase and Glutamine synthatase (GS) were analysed in latex samples of clones RRII 105, a clone with high metabolic rate and good response to stimulation, PB 260, a high metabolic clone with very low sucrose levels and low response to stimulation and RRII 33 and RRII 38, low metabolic and low stimulation response clones. The clones were selected based on latex yield and biochemical components related to latex metabolism observed in stimulated and unstimulated trees for previous three years. The trees were tapped under d3 system with three stimulations per year (May, September and November). The qPCR data indicated that the expression of these genes was differentially regulated in different clones after stimulation (Table Phy. 1). SUTs, ATPase and GS were significantly up regulated in clone RRII 105 than PB 260 after simulation compared to their control trees. The pattern of expression of SUTs and GS were similar in stimulated trees of low yielding clones compared to unstimulated control. Yield increase was also high in clone RRII 105.

Table Phy. 1. **Relative quantification (fold change) of genes related to latex regeneration in different clones with varying metabolism and response to stimulation**

Treatment/clones	SUT1	SUT2	ATPase	GS
Unstimulated controls	1	1	1	1
RRII 105	3.96	3.8	3.11	3.27
PB 260	3.88	2.44	2.05	2.72
RRII 33	0.92	1.32	0.85	1.33
RRII 38	0.5	0.52	1.15	1.54
CD (clone x treatment)	0.18	0.51	0.39	0.49

2.4. Molecular and biochemical basis of ethylene induced latex production in *Hevea brasiliensis* Ethylene receptors and signal transduction mechanism

To study the molecular mechanism of ethylene induced latex production, expression level of genes involved in ethylene biosynthesis *viz*. S-adenosyl methionine synthase (SAM), ACC Synthase (ACS), ACC oxidase (ACO); ethylene perception and signal transduction (ETR1, ETR2, ERF) and cyanide metabolism (β-Cyanoalanine synthase (β- CAS) was carried out in different clones with varying response to stimulation. Ethylene receptors ETR1, ETR 2, β- CAS and ethylene response factor (ERF) were highly up regulated after ethephon stimulation in clone RRII 105 which was reflected in yield

Table Phy. 2. **Relative quantification (fold change) of genes related to ethylene biosynthesis and signal transduction in bark samples of different clones with varying metabolism and response to stimulation**

Treatment/Clone	Genes						
	SAM	ACS	ACO	(β- CAS)	ETR1	ETR 2	ERF
Unstimulated controls*	1	1	1	1	1	1	1
RRII 105	2.32	2.63	1.70	3.66	2.90	1.45	3.97
PB 260	4.42	4.25	2.45	1.59	0.98	1.36	1.46
RRII 33	1.25	1.21	1.26	0.75	0.64	0.52	0.75
RRII 38	0.94	0.84	1.45	0.49	0.54	0.55	0.87
CD (clone x treatment)	0.50	0.36	0.38	0.34	0.46	0.38	0.24

*Control trees of respective clones as calibrator

increase also. Ethylene biosynthetic genes were significantly up regulated in stimulated trees of clone PB 260 (under d3 tapping with three stimulations per year). The receptors and signalling genes were not further up-regulated after stimulation in this high metabolic clone compared to control trees. The pattern of expression of all the ethylene biosynthetic genes were similar in control and stimulated trees of low yielding clones RRII 33 and RRII 38. The receptors ETR1 and ETR2 were down regulated in these clones (Table Phy. 2). During the period of experiment more number of trees of clone PB 260 succumbed to TPD syndrome. Experiments on gene expression analysis in bark tissue of these TPD affected trees are progressing.

2.5. Relationship of ATP status of latex with rubber yield

Further to confirm our earlier studies on latex [ATP] as a physiological marker for rubber yield, a field experiment was initiated at RRII farm with five polyclonal selections screened based on latex ATP and three control clones (RRII 105, RRII 417 and RRII 430). Test tapping was initiated in these clones during peak yielding season 2019 to evaluate the yield potential of these clones.

3. Secondary metabolites

3.1. Water relation of latex with reference to the content of inositols and sugars in the latex during drought

This study was continuing with an objective to know the relationship of latex osmolytes and water relations in terms of drought tolerance mechanism in *Hevea clones*. Growth of the plants was observed by recording the trunk girth. Three years growth data showed only a slight difference in mean girth among the clonal materials (4 clones) used in the experiment. In an experiment with studies on water relations in ethephon stimulated trees peak yielding season latex samples from the control and stimulated trees of five different clones were collected from a trial at CES, Chethackal. Observations on osmotic potential of latex serum indicated higher osmotic concentration in RRIM 600 a relatively drought tolerant clone than other clones.

4. Ecological impact of rubber cultivation

A provisional report on life cycle emission potential of various field activities in a rubber plantation was submitted. The data analysis indicated that farm activities related to land conversion, planting

operation and tillage are not considered to be the major sources of GHG emission but the emissions are largely associated with fertilizer and fossil fuel use in the plantation activities and transport. Potential emission from the use of chemical fertilizers alone was likely to be around 12.7 MT CO_2 ha^{-1} life $cycle^{-1}$. Emissions from the use of pesticides and weedicides accounted to be around 5 MT CO_2 ha^{-1}. Overall emission from rubber farm after accounting the major plantation activities in traditional region is around 27 MT CO_2 ha^{-1} $cycle^{-1}$.

LATEX HARVEST TECHNOLOGY DIVISION

The Division continued focused research on crop harvesting aspects of rubber. The ongoing trials on low frequency tapping, low frequency controlled upward tapping and programme on popularizing weekly tapping among small and medium holdings were continued and progressed well during the period under report. Other activities of the division included testing and evaluation of various products, advisory and training on all aspects of crop harvesting of rubber.

1. Low Frequency Tapping

1.1. Programme on popularizing weekly tapping

The growers who have participated in the programme continued weekly tapping with satisfactory results. Tapping days realized shows considerable variation due to climatic constraints and practices followed (Tables LHT. 1-3).

1.2. Low frequency (d10) tapping system in clone RRII 105

1.2.1. Large scale trial on d10 frequency of tapping in clone RRII 105

The large scale onfarm commercial evaluation trial in 1987 field on d10 frequency tapping initiated during 2015 at Kanthimathy Estate , Kulasekharam, Tamil Nadu in 10 tapping blocks (425-450 trees $block^{-1}$) was continued. Mean dry rubber yield of 1813 kg ha^{-1} with 30 tapping days under renewed basal panel tapping could be obtained under d10 frequency of tapping during 2019-20. Per tap yield ranged from 33 kg to 84 kg and g t^{-1} t^{-1} ranged from 70 to 196 g. Controlled Upward Tapping (LFCUT) under d10 frequency with periodic panel change was also introduced in four tapping

Table LHT 1. **Yield performance of clone RRII 105 under weekly tapping**

Location/Region	Yield (g t^{-1} t^{-1})	Tapping days	Number of plots
Thodupuzha1	82.2	42	6
2	113.2	41	2
3	78.2	42	6
Muvattupuzha			
1	69.8	40	3
2	90.4	41	6
3	107.6	42	10
Kanjirappally			
1	105.3	28	3
2	96.9	43	5
Thrissur			
1	95.3	52	2
Thalaserry			
1	122.8	32	1
Mean	96.2	40	-
Total	-	-	44

Table LHT 2. **Yield performance of clone RRII 414 under weekly tapping**

Location/Region	Yield ($g\ t^{-1}\ t^{-1}$)	Tapping days	Number of plots
Kottayam			
1	78.5	46	2
Muvattupuzha			
1	57.4	37	1
2	72.6	41	3
Thodupuzha			
1	106.9	41	5
Kanjirappally			
1	83.1	43	6
2	73.1	35	15
Thalaserry			
1	131.1	52	1
2	68.1	38	1
Mean	83.9	42	-
Total	-	-	39

Table LHT 3. **Yield performance of clone RRII 430 and mixed clone under weekly tapping**

Location/Region	Yield ($g\ t^{-1}\ t^{-1}$)	Tapping days	Number of plots
Muvattupuzha			
1	66.1	41	2
2	84.1	40	3
3	118.8	40	2
4*	80.3	40	4
5*	107.3	41	2
6*	120.5	44	1
Kottarakkara	75.1	33	1
Thalaserry			
1	99.3	30	1
Palakkad			
1	77.3	41	1
Puthur (Karnataka)			
1	61.4	50	5
Mean	89.0	40	-
Total	-	-	22

* Mixed clone

blocks. Initial results are promising. With the introduction of Controlled Upward Tapping further yield increase could be obtained ranging d from 74 to 240 $g\ t^{-1}\ t^{-1}$.

1.2.2. *Exploratory trial on d10 frequency of tapping in clone RRII 105*

This exploratory trial on d10 frequency of tapping was initiated from April 2004 at CES, Chetackal in field 1987 in clone RRII 105 and d10 frequency of tapping with once in 20 day's stimulation continued to give good yield during 2019-2020. CUT (S/3 d10) was practiced for six months and rest of the months trees were tapped in the basal panel tapping (S/2 d10). Yield of 1715 kg 400 $trees^{-1}$ was obtained during 2019-2020. It was 4.3 kg $tree^{-1}$ $year^{-1}$ and 52.1 kg tap^{-1}

1.2.3. *Large scale experiment on Low Frequency Tapping (d10) in clone RRII 105 (Panel BO-1)*

The large scale experiment on d10 frequency of tapping in comparison with weekly tapping to study the yield performance of clone RRII 105 in 2009 field laid out during 2018 at Kanthimathy Estate, Kulasekharam, Tamil Nadu was continued. There were five treatments comprising of weekly and d10 frequencies of tapping and different levels of stimulation. Significant yield variation among the treatments was observed. Higher dry rubber yield was observed under weekly tapping. However per tree yield of 4.7 kg could be realized under d10 frequency of tapping with 5 per cent ethephon (18/y) application (Table LHT. 4).

Table LHT. 4. **Yield performance of clone RRII 105 to d10 frequency of tapping**

Treatment	$g\ t^{-1}\ t^{-1}$	kg $tree^{-1}$
T1- S/2 d6 ET 2.5% Pa 12/y	156 b	7.3 b
T2- S/2 d6 ET 5% Pa 12/y	173 a	7.8 a
T3- S/2 d10 ET 2.5% Pa 18/y	152 bc	4.5 c
T4- S/2 d10 ET 5% Pa 18/y	147 c	4.7 c
T5- S/2 d10 ET 2.5%, 5 % Pa 18/y	150 bc	4.5 c

Values followed by same letter/s are significantly different

1.2.4. Large scale experiment on Low Frequency Tapping (d10) in clone RRII 105 (panel BO-2)

An RBD experiment was laid out in six blocks of clone RRII 105 (Field 2002) and imposed yield stimulation as per the schedule under LFT systems. There were six treatments and four replications (80 trees $plot^{-1}$) comprising d7 (with monthly stimulation as control) and d10 frequencies of tapping with different frequencies of stimulation. Yield under weekly tapping with monthly stimulation (ET.2.5%) was comparable to that of d10 frequency of tapping with once in 10 days and once in 20 days stimulation (ET5%). Yield of 1451 kg 400 $trees^{-1}$ was obtained under d7 frequency of tapping with monthly stimulation (ET 2.5%) in the BO-2 (3) panel (Table LHT. 5). Mean drc under d10 frequency with monthly stimulation (2.5%) was significantly higher than weekly tapping (Table LHT. 5).

Table LHT.5. **Yield response to Low Frequency Tapping (S/2 d10) in clone RRII 105**

Treatment	Yield (Kg 400 $trees^{-1}$)	DRC (%)
T1- S/2 d7 ET 2.5% 12/y	1451 a	40.7 cd
T2- S/2 d10 ET 2.5% 36/y	1371 ab	41.0 bcd
T3- S/2 d10 ET 2.5% 18/y	1212 ab	42.1 b
T4- S/2 d10 ET 5% 18/y	1307 b	40.4 d
T5- S/2 d10 ET 2.5% 12/y	1222 b	43.9 a
T6 – S/2 d10 ET 5% 12/y	1215 b	41.6 cd

Values followed by a common alphabet are not significantly different by DMRT

2. Controlled Upward Tapping (CUT)

Controlled Upward Tapping (CUT) is a powerful technology and a tool to get sustainable yield from old and senile rubber trees to improve productivity in plantations. Proper implementation of Controlled Upward Tapping (CUT) with appropriate stimulation can address decline in productivity to a great extent with profitable returns.

2.1. Large scale on farm trial on Low Frequency Controlled Upward tapping (LFCUT) under weekly tapping

The large scale on farm trial on Low frequency controlled Upward tapping (LFCUT) under weekly tapping with periodic panel change initiated during 2017 at Kanthimathy estate, Kulasekharam, Tamil Nadu in 12 tapping blocks (8 blocks of 1978 mixed clone and 4 blocks of 1962 seedling population) was continued with promising results (Table LHT. 6).

3. Other Experiments

3.1. Response of RRII 400 series clones to yield stimulation

At CES, Chethackal, in field 2004, RRII 400 series clones (RRII 414, RRII 422 and RRII 429) were identified for the experiment. The statistical design was completely randomized single tree single plot consisting of more than 100 trees of each clone. Tapping system adopted in this trial S/2 d3 6d/7. Three rounds of stimulation (ET 2.5% pa) was given during 2019-2020 in comparison with the unstimulated control trees (50% trees for stimulation and 50% trees unstimulated, for each clone).

In clone RRII 422, stimulated trees (S) showed significantly higher yield than unstimulated trees (US). No significant yield increase was noticed in stimulated trees of clones RRII 414 and RRII 429 (Fig. LHT. 1). Good yield was observed both stimulated and unstimulated trees of clone RRII 422 than other two clones of RRII 414 and RRII 429 in BO-2 (4) panel.

Table LHT. 6. **Yield performance of LFCUT under weekly tapping**

Month	Mixed clone		Seedling population	
	kg block^{-1}	g t^{-1} t^{-1}	kg block^{-1}	g t^{-1} t^{-1}
Apr'19	100	62	111	73
May	107	50	167	78
June	59	37	76	66
July	126	75	177	83
Aug	125	77	158	98
Sep	123	87	108	98
Oct	160	109	160	107
Nov	164	99	164	96
Dec	174	106	180	109
Jan'20	190	105	291	152
Feb	94	74	135	85
Mar	94	73	93	87
Total	1503	-	1820	-
Mean	141	80	152	94

3.2. Response of clone RRII 430 to yield stimulation under LFT

In another experiment at HML, Palapilly Estate, performance of clone RRII 430 to yield stimulation under Low Frequencies of Tapping (d3, d4 and d7) was studied from June 2016 in field 2000 (Panel BO-1). The statistical design was RBD with four treatments and five replications. Each replication consists of more than 300 trees. There were four treatments comprising of d3 (without stimulation as control), d3 (2/y), d4 (4/y) and d7 (12/y) frequencies of tapping.

Agro climatic constraints had affected the crop performance during the year under report. Higher dry rubber yield was observed under weekly tapping (70 g t^{-1} t^{-1}) followed by d4 frequency of tapping (56 g t^{-1} t^{-1}) and d3 frequency of tapping (46 g t^{-1} t^{-1}). Annual mean drc values of trees tapped under d7 frequency of tapping with twelve rounds of stimulation was higher (42%).

4. Testing and evaluation of products, training and advisory

Eight rainguard adhesive samples, 36 LDPE samples and four Ethephon samples were tested during the year under report. One

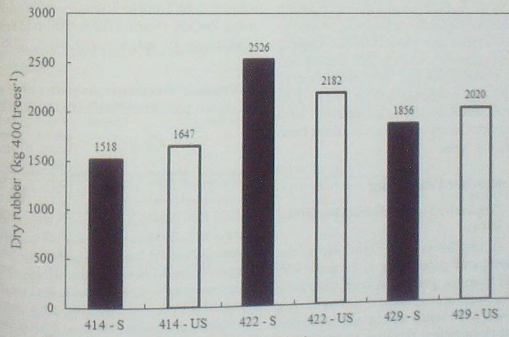


Fig. LHT.1. Cumulative yield performance of RRII 400 series

ADVANCED CENTRE FOR RUBBER TECHNOLOGY (ACRT)

Advanced Centre for Rubber Technology (ACRT) established during the 10th plan period by integrating different units in rubber technology/processing disciplines under Rubber Board started functioning in the present form from 2006 onwards and a new building commissioned in February 2009. Now ACRT comprises of two Divisions namely, Rubber Technology Division (RT) and Technical Consultancy Division (TC). The Centre mainly focuses research on the downstream activities of rubber sector like primary processing, rubber technology research, quality control of rubber products, product development *etc.* The Centre also conducts research work on long-term projects which has industrial importance. The Centre is also engaged in the preparation of project reports, defect analysis and trouble shootings of rubber products/factory processes. Being a recognized research centre of Universities, ACRT has registered scholars for Ph.D programmes.

RUBBER TECHNOLOGY DIVISION

In the current year activities of the Division were focused mainly on evolving improved techniques in rubber processing latex technology (preparation of DPNR directly from filed latex without creaming or centrifuging and new leaching process to reduce extractable protein in NR surgical gloves), rubber technology (NR latex carbon black master-batch and silica reinforcement of NR) and rubber recycling (stable free radical assisted devulcanization and cytotoxicity analysis of crumb rubber from end of life tyres).

1. Rubber Processing

1.1. Preparation of sheets from preserved latex

It has been a demand from the growers and processors to prepare RSS sheets from the preserved latex. We have conducted many experiments using different techniques and finally we found that if we pre-treat the latex we can retain the quality within the limits. In order to find out whether the pre-treatment affects the technological properties of the rubber prepared from the preserved latex, the rubber thus obtained was compounded using ZnO-5, stearic acid-2, antioxidant-1, HAF black-40, naphthenic oil-4, CBS-1,

Table Chem. 1. Vulcanizate properties of sheets prepared from treated preserved latex

Properties	Control	Pre-treated LATZ latex	Pre-treated HA latex
Tensile strength (MPa)	27.01	26.42	26.44
Tear strength (N/mm)	98.24	97.17	97.11
Modulus 100% (MPa)	2.81	2.59	2.10
Modulus 200% (MPa)	5.84	5.83	4.80
Modulus 300% (MPa)	10.48	10.46	9.86
Elongation at break (%)	608	573	580
Compression set (%)	19	20	20
Heat buildup (ΔºC)	18	14	17
Abrasion loss (mm^3)	113	83	88
Hardness, Shore A	58	58	57

Table Chem. 2. **The raw rubber properties of solid DPNR prepared by RRII process**

DPNR	Nitrogen (%)	Dirt content	Volatile matter	Ash content	P0	PRI	MV
DPNR-1	0.09	0.03	0.49	0.23	31.0	79	61.3
DPNR-2	0.11	0.03	0.45	0.34	32.5	78	64.3

sulphur-3 per hundred part of rubber. The technological properties were studied. The results are shown in Table Chem.1.

The results show that the heat buildup and abrasion loss were lower for the treated sample compared to control. Other properties were comparable to control. This showed that the pretreatment does not adversely affect the technological properties of dry rubber prepared from it.

2. Latex Technology

2.1. Production of solid deproteinised natural rubber (DPNR-S)

The DPNR solid samples were prepared by processes developed at RRII. The evaluation of raw rubber properties of solid DPNR by standard protocols is given in Table Chem.2.

2.2. Preparation and evaluation of DPNR latex

The preparation of DPNR latex by treatment of field latex with a deprotenizing mixture, followed by creaming was attempted. The stability of the deproteinised latex after 24 h and creamed latex were observed and those having stability were evaluated. The total solid in creamed latex varied from 50-59 per cent. The creamed DPNR latex and controls were compounded using 2 phr sulphur, 1.5 phr ZDEC , 0.5 phr ZnO, and 1phr antioxidant (SP). The vulcanisation of casted film samples after 24 h of casting were done at 100°C for 45 minutes. The measurement of extractable protein (EP) in the film samples before and after leaching was done as per ASTM D 5712. The creamed DPNR films showed significantly lower EP (500 $\mu g/dm^2$) than the control NR latex without deproteinization treatment (2500 $\mu g/dm^2$) before leaching. The creamed DPNR film was further subjected to leaching under different conditions and its EP values measured. The EP value of control film was 570 $\mu g/dm^2$. The EP value for the creamed DPNR films varied from 494 to 63$\mu g/dm^2$ depending on the leaching conditions (Table Chem. 3).

Table Chem. 3. **Extractable proteins of DPNR films by ASTM D5712**

Type of leaching	Extractable protein level ($\mu g/dm^2$)	Percentage decrease from control
Control DPNR film before leaching	570	-
Leaching in hot water at 80p C, 10 min	493	13.4
Leaching by in house method-1	288	49.4
Leaching by in house method-2	301	47.2
Leaching by in house method -3	240	57.8
Leaching for 30 min in PBS	195	65.6
Leaching for 72 hrs in PBS buffer	66	88.3
Leaching for 72 hrs in stilled water	63	88.9

3. Rubber Technology - Reinforcement of rubber

3.1. NR Latex carbon black master-batch

Latex-carbon black master-batches were prepared in presence of 10 parts nano filler. The vulcanizate properties were studied and compared with a control (Dry mix). The results are shown in Table Chem. 4.

Table Chem. 4. **Vulcanizate properties of master-batch with nano filler**

Properties	Control	Master Batch
Tensile strength (MPa)	25.74	25.00
Tear strength (N/mm)	135.53	132.88
Compression set (%)	16.38	16.30
Heat buildup (°C)	29	27
Abrasion loss (mm^3)	94	73
Modulus 100% (MPa)	3.14	5.45
Modulus 200% (MPa)	7.90	11.34
Modulus 300% (MPa)	13.97	17.78
Elongation at Break (%)	507	430
Hardness, Shore A	62	66
Flex Resistance (cycles)	152131	381786

The results show that the tensile strength, tear strength and Compression set of master-batch is comparable to that of control. Heat buildup was also slightly lower for the master-batch compared to control. The abrasion loss for the master-batch was 73 mm^3 while that for the control was 94 mm^3 which shows that abrasion loss was considerably lower for master-batch compared to control. The modulus, hardness and flex resistance of the master-batches were considerably higher compared to control.

Latex carbon black master-batches were prepared by replacing ISAF with HAF. The samples were compounded and the vulcanizate properties were studied. The results are shown in Table Chem.5.

Table Chem. 5. **Vulcanizate properties of master-batch with HAF**

Tests	Control (Dry mix)	Master-batch
Tensile strength (MPa)	18.16	15.81
Tear strength (N/mm)	75.6	74.88
Elongation at break (%)	366.58	333.71
Modulus, (100%)	3.39	3.50
Modulus, (300%)	13.82	14.08
Hardness, Shore A	66	66
Abrasion loss (cm^3)	94	107
DeMattia Flexing, Complete failure	38243	147524
Compression Set	26.56	35.7
Heat buildup (ΔºC)	18	18

Latex carbon black master-batches were prepared and the crosslink density of the master-batch was adjusted with that of the dry mix by adjusting the accelerator and the samples were analyzed. The results are shown in Table Chem. 6. The results showed that the properties are not improved by increasing the crosslink density.

Table Chem. 6. **Vulcanizate properties of master-batch with equal crosslink density**

Properties	Control (Dry mix)	Master batch
Flexing (Complete failure)	38243	147524
Compression Set (%)	26.56	35.7
Heat buildup (DºC)	18	18
Tensile strength (MPa)	18.16	15.81
Tear strength (N/mm)	75.6	74.88
Elongation at break (%)	366.58	333.71
Modulus 100% (MPa)	3.39	3.50
Modulus 300% (MPa)	13.82	14.08
Hardness (Shore A)	66	66
Abrasion loss (mm^3)	94	107

3.2. Silica Reinforcement of NR

Silica has equal reinforcing potential as carbon black in rubber. To achieve the same, silica has to be treated with a silane coupling agent and it works very well with synthetic

rubber which is the basis of modern passenger car tyre technology. In comparison with carbon black reinforcement, silica reinforcement provides high wet grip (*safety*), low rolling resistance (*energy saving*) and equal abrasion resistance (*durability*) among which safety is the most important aspect for car tyres.

NR is the key raw material for truck/bus/ earth movers/ air craft tyre manufacturing and abrasion resistance is the most critical property requirement. Due to reasons so far not fully established, silanised silica reinforced NR could not achieve the same level of abrasion resistance that could be achieved by carbon black reinforcement. This is the prime reason for the non-use of silica as reinforcing filler in truck and other tyres. It is assumed that low abrasion resistance originate from insufficient number of covalent bond formation between silanised silica and NR main chain during vulcanisation.

The standard cure system used in silica reinforced rubbers is CBS or TBBS/ DPG/Sulphur combination which works very well in developing sufficient amount of covalent bonds between silanised silica and synthetic rubbers. This bond formation is essential for developing abrasion resistance equivalent to carbon black filled vulcanisates. It was found that this standard cure system was used in NR/silica/silane system resulted in poor abrasion resistance compared to the NR/carbon black system. Table Chem. 9 shows the significance of the cure system on the reinforcement of NR with silica. In these experiments, silanised silica (sSilica) was used to avoid the complications of *in situ* silanisation of silica during mixing. The results in the Table Chem.7 clearly show that abrasion resistance comparable with NR/HAF system can be achieved with NR/ Silica system by using appropriate cure system.

4. Rubber recycling

4.1. Recycling of rubber: Storage behavior of devulcanized rubber

NR based original sample to be devulcanized was prepared and properties determined. The test samples and tensile sheet for devulcanization were moulded at 150°C at optimum cure time. The samples were devulcanized by shearing in a two roll mill in presence of 4-hydroxy TEMPO (4phr) (DV- HT samples) and without using TEMPO (DV sample). The devulcanized samples were kept in a closed plastic bag at room temperature for storage studies after determining the residual crosslink density, crosslink density distribution and revulcanizate properties immediately after devulcanization. The stored samples were characterised after 20 days and compared

Table Chem. 7. **Comparison of cure system in NR/s Silica reinforcement**

Property	CBS/DPG/S	Cure system 1	Cure system 2	Cure system 3	NR/HAFSemi-EV
Tensile strength, (MPa)	25	25.5	20.3	24	25
M100, (MPa)	2.5	2.6	3.2	3.4	2.5
M200, (MPa)	5.7	6.7	8.3	8.4	6.2
M300, (MPa)	9.9	12.4	15.1	14.5	10.9
Elongation at break, (%)	565	503	373	450	508
Tear, (N/mm)	115	116	80.1	82	107
Din abrasion loss, (mm^3)	157	99.6	97.9	107	96.3
Hardness, Shore A	70	68	72	70	58

Table Chem. 8. **Crosslink density and crosslink distribution**

Sample	Crosslink density x 10^4 mole/cm^3	Polysulphidic cross links, %	Di + Mono sulphidic crosslinks, %
Original sample*	3.334	72.54	27.46
DV0	1.458 (43.7%)	65.31	34.7
DV20	1.538 (46.13%)	69.89	30.11
DVHT 0	1.2032 (36.1%)	36.09	66.2
DVHT20	1.398 (41.9%)	41.92	59.8

with the sample properties immediately after devulcanization.

A comparison of the crosslink density, crosslink distribution of the devulcanised samples with original sample is given in Table Chem.8. Irrespective of the methods, the crosslink density of devulcanised rubber increased with storage under ambient temperature. It is also interesting to note that, in both cases, the polysulphidic links increased with storage and the per cent increase is higher when the extend of devulcanisation is higher. The revulcanisate properties of the samples are given in Table Chem. 9. The storage of the devulcanised rubber for 20 days did not significantly affect the revulcaniste properties.

4.2. Cytotoxicity analysis of crumb rubber (CRP)from end of life tyres

The TGA analysis shows that the CRP composition has low molecular weight components of 4 per cent, polymer content of 55 per cent, carbon black filler of 32 per cent and silica filler of 8.8 per cent (w/w). The HPLC studies of CRP showed that the aqueous leachable components significantly increased with the reduction in particle size of CRP and increase with leaching time with aqueous extraction buffers used in the study. Higher leaching was observed in PBS extract than neat aqueous extracts, hence the PBS extracts were used for cytotoxicity studies

The cytotoxicity analysis of aqueous extracts of CRP in both phosphate buffered saline (PBS) and minimum essential medium (MEM) were done against L929 cell lines. The ISO 10993-5 method show Grade 0 cytotoxicity with intact cell morphology (Fig. Chem. 1) and the MTT assay at the different dilutions (50-6%) of the 72 h PBS extraction of CRP shows high cell viability (80-100%) as in the cell controls (Fig. Chem. 2). The aqueous phosphate buffer saline (PBS) extracts of the CRP shows absence of cytotoxicity.

The morphology loss of cells treated with 100 per cent MEM extract shows severe grade 4 cytotoxicity and treated with 50 and 25 per cent dilution of MEM extract shows grade 2 cytotoxicity as per ISO 10993-5 method (Fig. Chem. 3). The MEM extracts of the CRP shows significant cytotoxicity in MTT assay The different dilutions (100-12%) of the 72 h MEM extracts shows low cell viability (20-50%) like the positive control

Table Chem. 9. **Comparison of re-vulcanisate properties**

Properties	Original sample*	DV0	DV 20	DVHT0	DVHT20
Tensile strength, (MPa)	24.1	15.1	13.57	21.9	20.1
M100, (MPa)	3. 4	2.39	2.87	1.61	2.45
M200, (MPa)	8.0	6.33	7.22	5.1	5.9
M300, (MPa)	13.5	12.8	13.95	10.2	11
EB, (%)	461	332	300	444	405
Tear strength, (N/mm)	116.4	37.0	38.8	66.35	68.6

*NR-100, HAF-50, Aromatic oil-5, A.O. TDQ 1.5,ZnO-4, Stearic acid- 2, CBS-1.5, S-1.5.

Fig. Chem.1. The intact cell morphology of L929 cell line after the treatment with the PBS extract of CRP after 24 h (A), 72 h (B) and 7 days (C) of PBS extraction by ISO 10993-5 method

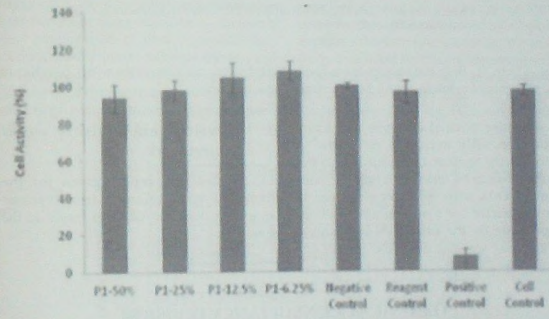


Fig. Chem. 2. The MTT assay of the PBS extracts (after 72 h incubation of CRP in PBS) with L929 cell line

Fig. Chem. 3. The MEM extract of CRP treated with L929 cell line at 100 (A), 50 (B) and 25 per cent (C) dilution as per ISO 10993-5 method

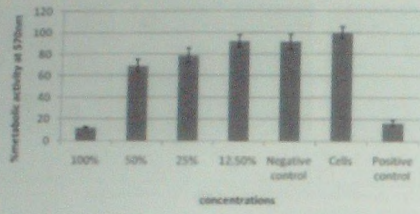


Fig. Chem. 4. The MTT assay of the MEM extract of CRP (after 72 h incubation of CRP in MEM) in L929 cell line

(Fig. Chem.1). Both the above assays show the presence of cytotoxicity for MEM extract of CRP.

Under normal aqueous extraction condition, CRP extract is not showing cytotoxicity against L929 cell lines. But caution has to be taken as it has leachable components with inherent potential to show toxicity for mammalian cell lines, depending on the extraction buffer used and the concentration of leachable components.

5. Development/advisory work/ project work

Tested and report given for the damaged tyres referred from various consumer disputes redressal forum in the country.

TECHNICAL CONSULTANCY DIVISION

Technical Constancy Division was constituted with the aim to appease the demands of the rubber based manufacturing industries in the country. The goals of the Division are intended in such a way that the rubber based units of the country numbering to over 3845 will be able to take advantage of the applied research and developmental activities being conducted in RRII. Technical Consultancy Division is an NABL approved laboratory and has the facility to test enormous parameters of rubber products. The latex products testing section of the Division has almost all facilities and probably it is the only one laboratory in the public sector. Since the laboratory is following ISO 17025: 2005 norms for its routine analysis its test certificates are universally valid and are valuable to the exporters of rubber products in the country. The Division also stack up knowledge on industrially important problems by conducting R&D programmes so that the problems in the manufacturing

sector can be overcome within the shortest possible time.

The services provided are R&D activities of rubber industry (both products and processes), development of new products, testing/certification of rubber products as per relevant national and international standards. The services offered by the division include (i) testing support to industries as per national and international standards *i.e.,* ISO, BIS, ASTM, EN, ASRTU *etc.* ii) Product development-demonstration/practical training for quality improvement (iii) evaluation of chemicals (iv) preparation of project profiles and technical bulletins (v) advisory services and (vi) conducting awareness meetings/ lectures to entrepreneurs regarding trouble shooting/cost reduction of factory processes.

The highlights of the projects are given below.

1. Research Projects

1.1 Shelf life study of gloves

Shelf life prediction of rubber medical products is unavoidable since clients' demand for reliable prediction of shelf life in the lab. Shelf life time of gloves was calculated using WLF equation, based on two parameters: tensile strength and crosslink density. 75 percent retention of properties has to be maintained by all gloves as per the relevant specifications. When the study conducted at different temperatures for 14 days the 75 percent retention was achieved for different properties at different temperatures. From Fig. TC.1, it is clear that

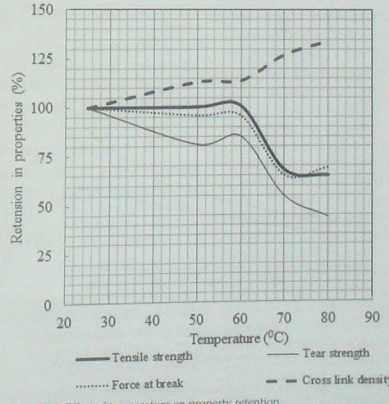


Fig. TC.1. Effect of temperature on property retention

on 14th day 75 percent retention for tensile strength was obtained at 68°C, tear strength obtained at 64°C and force at break at 66°C. Crosslink density values increased as the temperature increases from room temperature to 80°C.

Calculations using ARDL P & K method was done. Real time experimentation on shelf life of rubber surgical gloves of the first year was conducted. Evaluations of the data in cross link density, swell index, tensile and tear properties are in progress.

1.2. Morphological Studies on Latex Films of Prevulcanized Preserved Field Creamed Latex (PPFCL)

Latex casted products from prevulcanized preserved creamed field latex (PPFCL) and creamed latex (CL) (control) were utilized for studying the properties. Acetone extractables and ash determinations were done. Acetone extraction shall be considered solely as a quantitative expression of a property normally associated with degree of cure. Moreover, residual chemicals available also come in acetone extract, *i.e.* from the values it is clear that CL has 0.6 percent more acetone extractables than PPFCL. It was found that lower ash content values were observed in the case of PPFCL compared to CL. This may be the reason for the observation of better clarity films derived from PPFCL.

Protein content was compared after and before leaching of the films. Before leaching, the protein content of PPCFL film was 772µm g^{-1} and that of CL was 665µm g^{-1}. There was a slight difference in their values. During prevulcanization, hydrolysis of protein had taken place. This may be reason

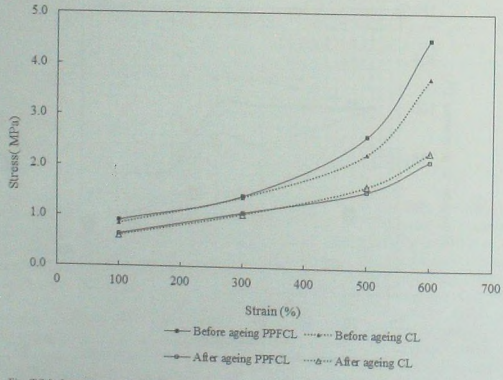


Fig. TC.2. Stress-Strain properties of prevulcanized preserved creamed latex and the control (Creamed latex compound)

for the change in values. During leaching water soluble protein were extracted and resulted in lower protein content of PPFCL film.

The effect of prevulcanization of preserved field latex and its creaming on stress–strain properties were studied; the observations were drawn in the Figure below. Before ageing, the modulus and tensile values were higher in PPFCL than in CL. But after ageing the modulus and tensile values are higher for CL.

The high modulus before ageing indicated that maximum crosslinking had taken place

Beyond certain period due to over-vulcanization and the consequent restricted coalescence of rubber particles, decrease in modulus and tensile was observed.

In water absorption studies it is found that leaching proceeded more rapidly in the case of prevulcanized film than that of control film. Leaching and water absorption proceeds more rapidly in prevulcanized film than in postvulcanized film. For prevulcanized, film rate of drying was faster compared to creamed film.

1.3. Rubber-based adhesives

The performance of a natural rubber (NR)-based solution adhesive for rubber to rubber bonding was examined. The effect of different grades of CB say ISAF (N220), HAF (N330) and GPF (N660) as a reinforcing filler in adhesive was evaluated. The loading used was different for the three grades of CB in order to achieve the required level of hardness for the adhesive. A blend of natural rubber and butadiene rubber was used as the adherent substrate. The vulcanization characteristics, mechanical properties, swelling measurements and adhesion strength of different CB filled NR-based solution adhesive were studied. The measured properties of all the three grades of CB filled NR-based solution adhesives were found to be comparable at the fixed hardness level. The effect of wood rosin (WD), coumarone-indene (CI), terpene-phenol (TP) and phenol-formaldehyde (PF) resin tackifiers on the vulcanization characteristics, mechanical properties and adhesion strength of carbon black (CB) filled NR-based solution adhesives was studied. Retardation of vulcanization properties was observed by the addition of tackifiers in NR-based solution adhesives. Reduction in mechanical properties of NR adhesive was also observed by the introduction of tackifiers. Solvent-based polychloroprene (CR) adhesive was formulated using four different types of tackifiers. Wood rosin (WD), coumarone-indene resin (CI), terpene-phenolic resin (TP) and para-tert-butyl phenol-formaldehyde (TBPF) resin were added into CR at amounts between 20 and 50 phr (parts per hundred parts of rubber). Effect of resin nature and amount on the adhesion peel strength was measured on both leather to leather and rubber to rubber joints, and the resin that provides the optimum adhesion performance was identified. Results indicated that the nature of resin greatly influenced the performance of the CR adhesive. The peel strength of CR/TBPF adhesive was higher than that of CR/TP, CR/CI and CR/WD adhesives. The role of four different types of nanofillers (layered silicates) on the properties of CR-based adhesives was examined. The compatibility of various nanofillers with polychloroprene (CR) in CR-based adhesives was studied using differential scanning calorimetry (DSC). Role of nanofillers on the thermal decomposition resistance of CR-based adhesives was also studied.

1.4. Effect of reclaim rubber on NR/BR blend system for tire tread

The whole area of the work was focused on developing high quality and low cost tire tread materials. For this purpose, various studies were conducted on NR/BR blends. Studies of interest include the incorporation whole tire reclaim rubber and latex waste reclaim rubber on NR/BR blend systems and incorporation of carbon black filler in the latex stages of the elastomers. The effects of both the reclaim rubbers were studied in detail. For this purpose, a total mix of 18 numbers was taken to optimize the amount of reclaim rubber on NR/BR blend for tire tread application. Samples for studying tensile strength, abrasion resistance, heat build-up and compression set were moulded and tested according to ASTM standards. Study on the effect of reclaim rubber on thermal degradation characteristics was carried out. Activation energy of NR/BR/reclaim rubber was studied using TGA analysis. Study on the effect of reclaim rubber on thermal degradation characteristics was carried out. Correlation of thermal behaviour with the rheometric curves were also carried out. Dispersion study of whole tire reclaim using carbon black dispergrader has also been performed. Scanning electron microscopy of NR/BR/WTR blends were performed and evaluated for dispersion quality. The result was correlated with carbon black dispergrader analysis. An abrasion resistance index of 160 is acceptable for PCTR according to ASRTU. This parameter is well satisfied by the incorporation of reclaim rubber (Fig. TC. 3).

Literature survey on filler master batch technique was performed to develop tread material with superior quality. An attempt to disperse carbon black (N220) was performed. A trial and error method was used to develop a stable dispersion of N220. 25 per cent dispersions of N220 and N330

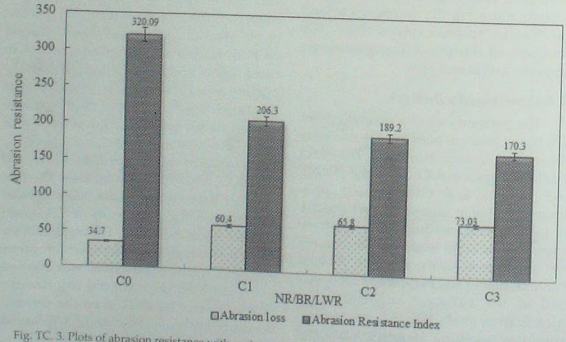


Fig. TC. 3. Plots of abrasion resistance with various combination of NR/BR/LWR

were prepared. 4 mixes of NR/BR/CB were taken in an internal mixer to study the effect of filler incorporation at the latex stage itself. Mechanical properties were studied.

1.5. Radiation vulcanization / Prevulcanized natural rubber latex

Nano and micro composites of radiation vulcanized natural rubber latex (RVNRL) were prepared by incorporating aqueous dispersion of fumed silica and conventional china clay. The crosslink density was computed and was found that RVNRL nano silica composite have higher crosslink density compared to RVNRL-clay composites. RVNRL-nano silica composite have offered a significant improvement in the mechanical properties. The tensile strength increased with silica loading up to three phr and then decreased. In the case of RVNRL-clay composites, tensile strength was decreased continuously. Tear strength of nanosilica composites was increased continuously. FT-IR spectra of nano silica and china clay composites were analyzed. Transparency increased upon nano silica loading upto 1 phr and then slightly decreased. In the case of china clay composites, transparency decreased even at low concentration. It was evident that loading of silica significantly improved the mechanical properties.

The addition of fillers to polymer matrices is a powerful tool to confer their interesting properties to the polymer materials. Among the different polymer composites, transparent composites are of particular interest due to their significance in a wide range of applications. To obtain a high level of transparency in the polymer composites, it is necessary to minimize the aggregation of the particles that induce significant light scattering and thus obstruct the application for transparent materials. The effect of three types prevulcanized latex film (sulphur, peroxide and radiation prevulcanized natural rubber latex) and their composites on light transmittance was studied. The transmittance values at a wavelength of 600 nm and thickness of 0.2-0.3 mm at which maximum light transmittance was obtained and is optimized. The transparency of the composites is temperature dependant. It is found that after leaching and ageing, transparency of the composites was improved. Among three different prevulcanized latex film, radiation vulcanized natural rubber latex has maximum transparency. The addition of nano meter order particle is effective to obtain high transparency.

2. Testing and certification

2.1. NABL accredited testing services

The NABL Desktop Surveillance audit of the TC laboratory has been carried out successfully on October 10th 2019. Three officers had participated in the training on "Laboratory Quality Management System and Internal Audit as per ISO/IEC 17025: 2017" conducted at STIC, Kochi on 19th to 22nd June 2019. Works like inter laboratory comparison, calibration of equipment, internal audit were performed. All officers attended the concerned works related to Desktop Surveillance Audit of NABL. Division undergone Desktop Surveillance auditing of NABL, completed the procedures and the validity of the period is up to 22/11/2020. A new quality manual as per ISO/IEC 17027:2017 for upgrading the system from ISO/IEC 17027:2005 was prepared. Final modification is going on.

The laboratory follows the ISO/ISE 17025 documentation and national/ international testing procedures for its routine services. Products belonging to

natural rubber, synthetic rubber, latex, thermoplastics are tested as per the relevant national and international standards (export market). *Various kinds* of rubber products tested in the Division are bridge bearings, rubber diaphragms, pre-cured/conventional treads, bonding gum, black vulcanizing cement, tyre flaps, inner tubes, rubber channels/beadings, floor mats, Hawaii soles, sponge rubber, O-rings, bushes, engine mounts, automobile components *etc.* The *major* classes of *latex* based *goods* tested include examination and surgical gloves, latex adhesives, latex thread, balloons, Folly catheters, condoms *etc.* Purity of rubber chemicals and the quality certification of reclaimed rubber are also tested consistently by the Division. A clear picture of the rubber products tested for the last year is given below in Table TC. 1.

Table TC. 1. **Number of samples tested and the revenue collected (2019-20)**

No. of clients	359
No. of samples tested	649
No. of parameters analysed	2205
Consultancy letters/e-mail	1296
Hands-on training imparted	5
No. of test reports issued	649
Component analysis	64
Total revenue collected, Rs	18,74, 884

3. Product development

The division offers facilities to industrialist as well as existing rubber based entrepreneurs in the development of rubber products based on both synthetic and natural rubber. In this area, the numbers of services given are categorized as follows (Table TC. 2).

Some of the prime clients who are availing the services of the division are VSSC, BPCL Kochi *etc.*

Table TC. 2. **Number of know-how transferred to industries**

Name of products developed	Numbers
Adhesives	3
Automobile components	10
Expanded rubber sheets and soles	3
Fire resistant mats	1
Latex based dipped and foamed goods	5
Pre-cured tread, bonding gum and tube valve	15
Rubber based agro machinery components	2
Rubber based engineering components for railway, defence, BSF *etc.*	2
Rubber molds	1

4. Externally funded major projects

4.1. Consultancy to M/s Karnataka Forest Development Corporation Ltd, Sullia, Karnataka

The consultancy work for M/s. Karnataka Forest Development Corporation Ltd, (KFDC) Sullia, for the improvement in quality and consistency of processing units (centrifuging latex/ and crump rubber was completed.

4.2. Design of environment management system for technically specified rubber unit

Preliminary design of the Effluent treatment system for M/s. Southern TSR LLP, Guwahatti, Assam was prepared. As per the feedback, it was redesigned to make it cost effective with environment friendly effluent treatment system.

4.3. Diversification of Industrial unit-COIRFED at Alleppey

After the visit to the Kerala State Co-operative Coir Marketing Federation Ltd. (Coir fed), Alleppey, preliminary evaluation and data collection for use of coir pith in the development of a suitable product were investigated. A draft proposal for getting funds for the project from Coirfed was prepared. Possibilities for making coir /

rubber products like weed control blanket and agricultural products are being investigated.

4.4. Other projects

- Revised proposal for funding of Incubation Centre at RRII under MSME was presented for approval of KSIDC.
- Proposal for REACH laboratories have been submitted as requested by Association of Mat Manufactures Kerala.
- Developed House Hold Gloves using Prevulcanized latex, Room Temperature cure latex and Ordinary compound.
- Re-designed the automatic dipping plant and also provided the technology for the manufacture of household gloves for NEBEL India Pvt, Bodhjung Nagar, Tripura
- Plant lay-out was offered to M/s. Maximus Rubber Industries, a tread rubber manufacturing unit at Tripura.
- Visited M/s. DNNG And Company, Mumbai and has given directions for the construction of the dipping plant for the manufacture of latex based "snake bite resistant shoes" (patented product) for protecting laborers involved in agricultural activities against snake bite.
- Given consultancy to M/s. Kerala Minerals & Metals Ltd, Chavara, Kollam for the study on premature failure of Rubber lining materials.
- Prepared Project report for fully automatic Surgical Gloves manufacturing unit of M/s. Ravenbuck Latex & Surgicals, Rubber Park
- As per the request received from an entrepreneur to develop a project profile for starting rubber band unit with semi-automatic dipping machinery, was completed.
- *Common Facility Service Centre (CFSC), Manjeri. Development of project report for Intermix unit.* Technical details to proceed with the project report and commercial details are to be finalised after the reply from the organisation.
- Consultancy services were given and technical report was prepared for M/s. NHMP Multy Production Industries, Tripura on 29/10/19 in the production of fluorescent rubber band from field latex.
- Prepared and submitted report on cost benefit study of Kanyakumari Rubber Park
- Technical report and hands-on training was given on orthodontic rubber band which complies with the FDA regulations.
- Technical consultancy services and hands-on training given on Exercise Band to M/s. J K Polymers, Punjab
- RRII registered as a host institute for Incubation Centre under MSME, Govt. of India

5. Project profiles/Technical bulletins

As per the request of the entrepreneurs, five project profiles and technical bulletins were issued on payment basis.

6. Advisory services

Matters relating to various aspects like selection of raw materials, dosage of ingredients, redesign of formulation, processing conditions, recent regulation *etc.* were always a subject of concern among the clients. Division had given appropriate guidance in all these aspects.

7. Miscellaneous work

7.1. Specialized hands on training with technical reports was given to various clients such as M/s. NHMP Multy Production Industries, Tripura in the production of fluorescent rubber band from field latex, M/s. Oswal Polymers, Kottayam in the manufacture of carpet backing and M/s. Periyar Rubber Band on orthodontic rubber band preparation, which complies with the FDA regulations etc.

7.2. Revised 20 nos. of BIS standards related to natural rubber latex and raw rubber.

ECONOMICS DIVISION

The broad research areas of the Division comprises of farm management, primary processing and marketing, rubber products manufacturing industry and foreign trade and intercrops and by-products. In these areas inter-divisional collaborate projects are also undertaken for comprehensive understanding of the sector.

1. Collectivism to circumvent the structural bottlenecks in the rubber smallholdings sector of Kerala for ameliorating tappers scarcity and ensuring sustainability

The study suggested collectivism to circumvent structural bottlenecks in the rubber smallholding sector of Kerala for resolving tappers scarcity and ensuring sustainability. The smallholding sector of Kerala, which is still the prime contributor to the national rubber production, is under severe crisis due to shortage of rubber tappers and declining profitability. The sector has become incapable to attract new entrants for tapping as wage income of tappers is much lower than their counterparts in the rural labour market (Table Eco. 1) through wage rate of tappers has been increasing in the sector till the recent past (Fig. Eco.1).

In the present scenario, the sector is incapacitated to augment wage income of the tappers for the existence of structural bottlenecks such as smaller size of holdings, less number of trees available for tapping, piece rate wage payment system and prevalence of single grower dependence. The average annual wage income of tappers in the sector was found to be much lower than wage income of agriculture labourers and helpers in the rural construction sector. To attract more tappers into the sector wage income of tappers has to be increased. This would be possible only through collectivism as through collective approaches only the structural bottlenecks identified could be circumvented. Collectivism will not only help the tappers to get regular employment, sufficient tapping task and remunerative wage income, it would also have the added advantage of bringing down the cost of production and increasing profitability of natural rubber cultivation as it would facilitate large scale adoption of cost saving technologies like low frequency tapping.

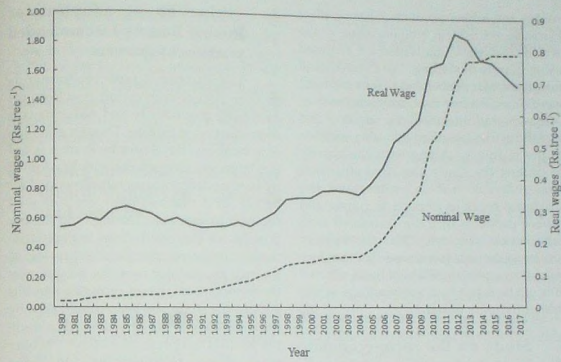


Fig. Eco. 1. Trend in wage rate of tappers (1980-2017)

2. Tariff policies and external trade performance of India's rubber and rubber products under the RTAs

The study was initiated in the backdrop of higher growth in imports of rubber and rubber products from the member countries of the Regional Trade Agreements (RTA) of India. Product subheading-wise trade data of rubber and rubber products provided by UNCOMTRADE in the World Integrated Trade Solution (WITS) of the World Bank was used for the study. Trade data of 38 countries spanning 30 years for rubber and rubber products (at the six digit level of HS) were collected. The study analysed product-wise impact of tariff liberalisation under the RTAs on the import of rubber and rubber products of India. All the product subheadings covered under the chapter on

Table Eco.1. **Comparison of average annual wage income of rubber tappers and labourers in rural Kerala**

Category of labour	Wage payment system	Estimated annual average working days	Average wage rate (Rs./day)	Estimated average annual wage income (Rs.)
Tappers	Piece rate system	151*	Rs. 1.75/tree x 286 trees per tapping day*	75,575
Agricultural labourers	Daily wages	180	750@	1,35,000
Helpers in construction sector	Daily wages	230	800@	1,84,000

Note: * Data from tappers census; @ Personal enquiry made in Central Kerala, 2018.

rubber and rubber products (Chapter 40) of Harmonised System Nomenclature of the World Customs Organisation are analysed using gravity modelling. For the analytical purpose major rubber and rubber products were classified into four categories such as raw material, intermediate, non-tyre and tyre industries based on the value addition of the industry. Along with the gravity modelling the study also used structural change/break test to understand the structural break in imports of rubber and rubber products of India associated with other events/factors. The preliminary results of the analysis shows that the duty reduction under the RTAs of India affected only sixteen product subheadings of the rubber industry of India.

3. Study on the socio-economic impact of rubber cultivation under the Block Planting Units in Tripura

This study is an attempt to understand the decadal changes in the socio-economic characteristics of tribal rubber growers in Tripura. The first comprehensive study on the socio economic impact of NR cultivation under the block planting scheme of Tripura was completed and reported during the year 2009-10. In order to capture the decadal changes in the socio-economic characteristics of the tribal society due to rubber cultivation, a survey in the same region wass conducted during the year 2019-20. Field survey in Tripura, among 421 rubber farmers under nine block planting units and two group process centres, *viz.*, (i) Rambabu Para (ii) Khamber Bari (iii) Rani (iv) Dariabagma (v) Kariayamura II (vi) Lakshmandepha (vii) RS Para (viii) PS Para (ix) Kamalasagar (x) Rajarshiand (xi) Janmabhumi were completed.

4. Evaluation of adoption of Rubber Board's recommended practices by growers

The Rubber Board recommends various rubber cultivation practices for increasing productivity and reducing cost of production of rubber. Though adoption of technologies developed by Rubber Board like improved clones were widely adopted by farmers, technologies recommended for better farm management are not well received by farmers. Through the Rubber Board made concerted efforts to popularise these rubber production technologies through its extension network, adoption by the farmers were not encouraging. In this backdrop a study has been undertaken by the Division with the objectives (i) to study the level of adoption of different rubber production technologies by the smallholders, (ii) to study farmers' perception on importance of rubber production technologies for enhancing profitability and to study the factors influencing adoption of rubber production technologies.

A well-structured questionnaire was prepared for data collection. Data will be collected from 1000 randomly selected farmers from South, Central, North-central and North Kerala using trained personnel. Descriptive statistical, Adoption Index, Adoption Quotient and Likert Scale will be used for interpreting the data.

5. Trends in Rubber Consumption in the Non-Tyre sector: An exploratory analysis

A study on the trends in rubber consumption in non-tyre sector was undertaken in the Division during the reporting period. The major objectives of the study are: to analyse the trends in the

composition of consumption of rubber in the selected non-tyre products and to identify the techno-economic factors contributing to the changes in the composition of NR consumption in the non-tyre sector. A well-structured questionnaire was prepared for data collection and was sent to manufacturers of non-tyre products.

6. Policy advisories to the Rubber Board/Ministry of Commerce and Industry

Based on the results of studies undertaken in the Division, policy advisories were given to Rubber Board and to the Ministry on various matters.

- A detailed note on ASEAN-India FTA with latest trends in trade was prepared, and communicated to the Joint Director (Eco), Planning division for communicating to the Parliamentary committee
- Provided the details on the import of rubber products of India from ASEAN to the Planning division in response to the query in Parliament, on import growth of rubber products from ASEAN member countries

7. Consultancy /Advisory work

- Estimated the upset value of more than 50000 rubber trees of M/s State Farming Corporation of Kerala Limited, Punalur in January 2020 and communicated.
- Estimated the timber volume and upset value of rubber trees in RRS Dapchari and intimated.

CENTRAL EXPERIMENT STATION, CHETHACKAL

The Central Experiment Station, Chethackal established in 1966 is situated at a distance of about 56 km from Kottayam. The Station has a total land area of 254.8 ha of which 36.4 ha is under immature rubber, 151.8 ha under mature rubber and 27.59 ha area is under budwood nursery and close planting. The Station meets the field trial needs of various disciplines like crop improvement, crop management, crop protection, crop physiology, latex harvest technology and meteorological observation. The Station works under A and B Divisions of almost equal area. The priority areas of experimentation at present are breeding for high yield and other beneficial secondary characters with special emphasis on disease and drought tolerance, evaluation of clones developed conventionally, nutrition studies, intercropping systems, reduction in cost of cultivation, planting system, low frequency tapping systems, Germplasm evaluation *etc*.

Total number of research trials under various Divisions are 91. A three part tree crown budded area with canopy from FX 516 is laid to study disease resistance mechanisms. The Eddy covariance tower installed in the Station gives micro environmental data. The Station also functions as a centre for training growers in various aspects in farming operations of rubber plantation industry.

During the reporting period, the total crop realized was 111 MT. The total number of tapping days realised was 295 and 56 tappers were engaged for tapping. The total

man-days engaged in this station were 35039 days. The Station having 155 permanent workers is managed by Officer-in-charge with 24 staff for office administration, farm management, dispensary, security and canteen. The dispensary attached to the Station caters to the medical needs of the workers. The total patients attended to during the period under report were 3233. The total IEBR raised during the reporting period was Rs. 1.45 crores.

REGIONAL RESEARCH STATION, GUWAHATI, ASSAM

1. Crop Improvement

1.1 On-farm evaluation of selected ortets of *Hevea*

In an attempt to evaluate performance of selected promising ortets under the agroclimate of Asssm, five genotypes (3 primary ortet selections *viz*. RRSG 9, RRSG 3 and RRSG 1 and two clones *viz*. RRIM 600 and RRII 429) were planted in large scale in Morigaon district. Girth of ortets after four years of planting was at par with RRIM 600. However, mean girth of RRII 429 was high compared to that of RRIM 600 or other ortets.

Table Ghy. 1. **Girth at 4th year of planting**

Name of clones/ortets	Mean girth at 4th years of planting (cm)	Range of girth (cm)
RRIM 600	25.8	17.0 - 38.8
RRSG 1	26.1	18.9 - 35.5
RRSG 3	26.2	19.0 - 34.5
RRSG 9	24.9	16.0 - 35.1
RRII 429	29.2	17.8 - 42.1
CD (P=0.05)	NS	

1.2. On-farm evaluation of potential clones in Assam

For final evaluation of potential clones of NE under the agroclimate of Assam, budding of SCATC 88/13, RRII 429, RRII 417, RRIM 600 and RRII 208 was completed and polybag plants were raised. Planting will be done in next season. Area was cleared and field preparation is under progress.

2. Crop Management

2.1. Soil fertility mapping in Assam, Arunachal Pradesh, West Bengal, Manipur, Mizoram and Nagaland

A survey of rubber growing soils of North-East India was conducted for developing soil fertility assessment based online fertilizer recommendation system and during the reporting year a total of 484 soil samples were collected from Assam. Location coordinates of all the soil samples were recorded using GPS device along with data related to cultural practices of each location. Soil sample collection from West Bengal, Arunachal Pradesh and Manipur was already completed during last year.

REGIONAL RESEARCH STATION, AGARTALA, TRIPURA

The major areas of research of this Station are evaluation of clones, crop management, latex harvesting and ecosystem study. Site specific nutrient management recommendations to rubber growers and estimation of dry rubber content of latex samples are being continued.

1. Crop Improvement

The crop improvement programmes were undertaken for development and evaluation of clones for this region. One hundred and thirty one selected clones *viz.* 20 hybrids, 21 OP progenies and 90 half-sib progenies were under evaluation in six clonal and seedling nurseries.

In clonal nursery evaluation of OP progenies (2013), the test tap data showed that mean yield was highest for AGOP 08A/31(101.7g t^{-1} $10t^{-1}$) and lowest for AGOP 08A/32 (38.0 g t^{-1} $10t^{-1}$). In another OP progenies nursery (2014), test tap yield was highest for AGOP 08B/15 (78.4 g t^{-1} $10t^{-1}$) and lowest for AGOP 09/153 (27.7 g t^{-1} $10t^{-1}$).

In clonal nursery evaluation of selected half-sibs (2014), test tap yield was highest for AGHS 09/207 (99.5 g t^{-1} $10t^{-1}$) and lowest for AGHS 09/04 (29.4 g t^{-1} $10t^{-1}$). In another half-sibs nursery (2015), test tap yield data indicated that highest yielder, AGHS 10/428 recorded the highest yield of 59.6 g t^{-1} $10t^{-1}$ followed by 48.4 g t^{-1} $10t^{-1}$ by AGHS 10/447 and 46.40 g t^{-1} $10t^{-1}$ by AGHS 10/447 and the check clone RRII 208 recorded an yield of 48.6 g t^{-1} $10t^{-1}$.

In clonal nursery evaluation of selected hybrids (2013), among 13 different clones the mean test tap yield was highest for AGHY 07/09 (124.3 g t^{-1} $10t^{-1}$) and lowest for AGHY 07/68 (39.6 g t^{-1} $10t^{-1}$). In another hybrid nursery (2015), AGHY 09/076 recorded highest average test-tap yield of 89.8 g t^{-1} $10t^{-1}$ followed by check clones, RRII 429 (86.2 g t^{-1} $10t^{-1}$) and RRIM 600 (84.3 g t^{-1} $10t^{-1}$).

Evaluation of clones was undertaken in two Large Scale Trials: one immature and another one mature. In first large scale trial, DD/6/5 showed highest girth (40.3cm) during fifth year compared to control RRIM 600 (31.3 cm). In another LST (G x E) trial, yield was highest in clone RRII 176 (65.5 g t^{-1} t^{-1}) followed by RRII 430 (63.0 g t^{-1} t^{-1}) and control clone RRIM 600 (58.9 g t^{-1} t^{-1}).

A new experiment on Genotype x Environment interaction was initiated during the reporting period. Field planting of this trial with 20 clones and 37 pipeline genotypes has been completed.

Standardization of distinctness, uniformity and stability (DUS) testing norms in 57 clones is being maintained. A germplasm garden having 213 wild *Hevea* accessions, source bush nurseries and a breeding orchard are being maintained in the Station.

2. Crop Management

2.1. Soil fertility mapping

Composite soil samples were collected from rubber growing soils under North East India to prepare a soil fertility map. Work is carried out to develop an on-line fertilizer recommendation for rubber growers in these locations. The details of the sampling location like clone, age of plantation, planting history, cultivation practice and location co-ordinates were recorded using GPS. Total 1394 composite soil samples were collected from the state of Tripura. Analysis of soil samples were taken up to record their fertility status. Majority of the soil samples (90%) from Tripura recorded extreme

acidity with pH ranging from 4 to 4.5. About 84.5 per cent of the rubber growing soils of Tripura are deficient in available Zn and 71.4 per cent soils are deficient in available B.

The influence of silt pits on growth and yield of rubber being grown in the hillocks (slope of 5-7%) of Tripura was studied. No significant improvement in trunk girth of plants was recorded due to imposition of treatments. However, a positive and significant increase in mean yield in the tune of 9.8 - 11.7 per cent was observed due to adoption of conservation pits. It was observed that about 3.98 - 5.42 mt soil ha^{-1} $year^{-1}$ could be conserved in the pits. A considerable amount of available N, P, K ranging from 21.6 to 31.5, 3.1 to 4.5 and 30.6 to 35.5 kg ha^{-1} yr^{-1}, respectively was conserved from the soils that were deposited in the pits. In addition to this, 29.14 kg OC and 216.2 kg clay per ha could be rescued per annum from these lands.

2.2. Development of cropping system and management practices

A new trial on evaluation of multi-faceted land use system under rubber based homestead farming in North-East India has been initiated. Three models have been developed to assess the sustainability of crop diversification under rubber homestead system. Field planting of clone RRII 208 has been completed in three different models having different planting geometry. First model is the paired row system of planting where plant to plant distance is 2.4 m and the space allotted within the paired row is 4 m and between the two paired rows it is 14 m. The second model is a quartet cluster approach where plants in each cluster are equidistant at 2.5 m and a space of 20m is given within two cluster rows. The third model is a rectangular system of planting where a spacing of 3.0 x 6.7 m is maintained. The different perennial intercrops introduced in different models are presented in Table Agar. 1.

Table Agar. 1. **Different perennial intercrops in three different models**

Model I	Model II	Model III
Lemon	Lemon	Lemon
Carambola	Mango	Pineapple
Valancia	Litchi	
Mosambi		
Dragon fruit		
Guava		

In the experiment on evaluation of cropping system model, the girth of rubber in the intercropping plots (61.2 cm for Model I and 61.9 cm for Model II) and in monocropped plots (62.7 cm for Model I and 62.9 cm for Model II) is on par after 11 years of planting. The yield of rubber obtained from intercrop and monocrop in both the models were also on par *i.e.* 1634 kg ha^{-1} and 1684 kg ha^{-1} for intercrop and monocrop in model I and 1640 kg ha^{-1} and 1706 kg ha^{-1} in model II, respectively. Intercropping was carried out for entire immaturity period in model I (Paired row system) and only for five years in model II (usual rectangular planting).

In the skipping fertilizer experiment, the yield performance has been recorded subsequently and the result shows that the mean girth of rubber in 'no fertilizer plot' and conventional fertilized plots is statistically on par *i.e.* 54.2 cm and 54.9 cm, respectively. The mean yield in 'no fertilizer plot' and 'conventional fertilized plots' was 1374 kg ha^{-1} and 1327 kg ha^{-1}, respectively.

The zero tillage experiment at block planting units, the girth data indicated that pits of larger dimensions have no advantage on growth of plants after fifth year of planting. The mean girth was 38.5 cm and 39.2 cm respectively for normal pit and reduced size pit.

3. Latex harvesting study

Effect of frequency of stimulation with ethephon (2-CEPA) on yield performance of different RRII 400 series clones *viz*. RRII 417, RRII 422, RRII 429, RRII 430 and control clone RRIM 600 were evaluated under S/2 d3 6d/7 system with stimulation and (S/2 d2 6d/7 system) without stimulation with two month tapping rest. The five year study showed that increase in dry rubber yield due to application of three to four stimulations per year in d3 system of tapping in all the clones. Highest yield was observed in clone RRII 429. Tapping panel dryness was non-significant. Four round of stimulation in a year gave higher yield of 1866 kg 400 trees^{-1} in clone RRII 429 under d3 system which was comparable with d2 system.

In low frequency tapping in clone PB 235, d3 system of tapping continued to show higher yield compared to d4 and d7 system. The experiment on effect of planting density on d3 tapping systems is being continued with clone RRII 429. Higher yield was observed in high density planting compared to lower density. In block trial experiment, d3 system showed higher yield compared to d7 system of tapping in clone RRIM 600.

4. Ecosystem study

In studies on invasive potential of various plant species using ecological niche modelling, it was observed that distribution of *Hevea* in two distinct region (Western Ghats as traditional region and NE region as non-traditional region) can be classified as two different climate population. Therefore, it was envisaged to evaluate the need to construct separate species distribution model for two distinct populations instead of a common approach. Two global climate models (GCM) (BCC-CSM and HadGEM2) were used to construct the ecological niche distribution of *Hevea* species in NE region using three representative climate pathways (RCP) of 2.6, 4.5 and 8.5. In an initial attempt, there was no significant difference between the GCMs and RCPs in terms of distribution pattern except few minor pockets in Assam under present climate scenarios. It was observed that minimum temperature in winter season in NE is predicted to increase from 14.8p C in 2000 scenarios to 17.3p C in 2050. Annual average temperature is also going to be higher in NE (26.1p C in 2000 to 28.2p C in 2050).

In an observational trial on non-recruitment of rubber seedlings under the canopy of rubber plantations of different age groups and other vegetation, it was observed that seedling population during second year is maintained in old plantation and jungle rubber conditions where human activity is less. The plantation, where tapping activity is more, the number of seedlings m^{-2} land is also less. During the rainy season (July-September), the seedling population was maintained in all experimental plots except in one where anthropogenic activity (tapping) is more. Maintenance of seedling population during rainy season could be due to higher availability of soil moisture. The average number of seedlings m^{-2} plot in jungle rubber and other areas, where human interference is less, is 21 whereas the number of seedlings m^{-2} plot is less than 10 under mature rubber plantations.

In the ecology study, a soil health index under five land use system *viz*. Pure Rubber (PR), Rubber with Tea (PT), Jungle Rubber (JR), Natural Forest (NF) and Adjacent Fallow land (FL) was developed

based on minimum data set. The order of health index was: NF (0.8) > JR (0.7) > PR (0.59) >RT (0.56) > FL (0.46). A reduction in OC (%), pH and OC content under rubber soils was observed which significantly influence the soil health.

5. Advisory work

Total 306 soil samples from small holdings were analyzed and offered site specific fertilizer recommendation. Total 126 latex samples were tested for dry rubber content.

REGIONAL RESEARCH STATION, TURA, MEGHALAYA

The Regional Research Station, Tura continued its research activities on evaluation of clones, polyclonal population, crop physiology/ latex harvest technology and crop management.

1. Crop Improvement

1.1. Poly-cross progeny evaluations

In the 2008 poly-cross progeny evaluation trial, a new set of Clonal Nursery Evaluation Trial 2014 has been started at the Rubber Board campus, Dakopgre, Tura in two designs in RBD. Plants are maintained in the field. In another set of 2011 populations, a total of 34 top yielders were selected on the basis of growth performance and juvenile yield and maintained in the field for further evaluation.

1.2. Half-sib progeny evaluation trial 2008 and 2009

Populations selected on the basis of growth performance and juvenile yield for both the years are maintained in the field for further evaluation.

1.3. On-farm evaluation of selected clones

Three on-farm trials were started during 2009 and 2010. Trial I included blocks of six clones, *viz.* RRII 417, RRII 422, RRII 429, PB 235, RRII 203 and RRIM 600 in Mendipathar (North Garo Hills) and Trial II included four clones *viz.* RRII 417, RRII 422, RRII 429 and RRIM 600 in Bolchugre, West Garo Hills. In the North Garo Hills, three years mean yield data were recorded in both the trials and preliminary data on yield found highest mean annual yield in RRII 429 (39.5 g t^{-1} t^{-1}) closely followed by RRIM 600 (38.4 g t^{-1} t^{-1}), RRII 422 (35.2 g t^{-1} t^{-1}), PB 235 (34.4 g t^{-1} t^{-1}) and RRII 417 (30.8 g t^{-1} t^{-1}) and minimum yield was recorded in RRII 203 (25.4 g t^{-1} t^{-1}) (Table Tura 1).

Table Tura 1. **Mean annual yield (g t^{-1} t^{-1}) of different clones in the on-farm trial at Mendipathar, North Garo hills of Meghalaya during initial three years**

Clones	Mean annual yield (g t^{-1} t^{-1})
PB 235	34.4
RRII 417	30.8
RRII 429	39.5
RRII 422	35.2
RRII 203	25.4
RRIM 600	38.4
Mean	34
SD	5.2
CV (%)	15.3

1.4. Evaluation of poly-cross progenies from four stations of NE region

The promising seedlings were screened on the basis of test tap yield among

polyclonal seeds which were collected from four locations in the NE region *viz*. RES Nagrakata, RRS Agartala, RRS Guwahati and RRS Tura and the selected bud woods are maintained in the nursery for further study.

1.5. Nursery evaluation of poly-clonal seedlings trial 2013 and 2014

The poly clonal seeds collected from Poly Clonal Seed Garden, Mizoram were planted in the field in the year, 2013 at two locations of the RRS, Ganolgre farm and one location at R.B. campus, Dakopgre, Tura. On the basis of test tap yield, top 25 best performing progenies have been selected and maintained as bud-woods at Rubber Board campus, Tura and five progenies have been selected at RRS, Ganolgre farm for further evaluation.

1.6. Germplasm arboretum at Teksragre Farm

In order to maintain the 1st, 2nd, 3rd, 4th and 5th set of Germplasm Arboretum under the agro-climatic condition of Garo Hills of Meghalaya at Teksragre farm near Anogre. 395 poly bag plants (belonging to 131 Accessions including 26 Wickham) for 5th set of Germplasm were planted in the field during August, 2019 and maintained the plants. Field preparation work for 6th set of Germplasm planting is in progress. All the plants were affected by the hailstorm during May, 2019.

2. Crop physiology/ Latex Harvesting Technology

2.1. Effect of low winter temperature on yield of rubber at high altitude

Severe low winter temperature is one of the main factors for depression of yield and per cent dry rubber content (drc) in *Hevea* under the agro-climatic condition of Garo Hills. The annual mean yield (29.7 g t^{-1} t^{-1}) and DRC (33.9 %) for reporting year was recorded. Low temperature adversely affected the yield and DRC. Early defoliation and refoliation was observe and during winter DRC ranges was from 28.5 to 29.2 per cent. Lowest soil moisture content was also recorded in the months of February and March.

2.2. Shallow tapping – an option to stress alleviation in *Hevea* plantations during winter in NE

There was no significant difference between treatments. Maximum annual mean yield was recorded in normal tapping system (30.5 g t^{-1} t^{-1}) followed by normal continuous tapping (29.4 g t^{-1} t^{-1}) and LFT + normal tapping (28.3 g t^{-1} t^{-1}) and lowest was in shallow + normal tapping system (26.0 g t^{-1} t^{-1}). Annual mean DRC was low (33.8 %) in normal continuous tapping and high (34.4 %) in shallow + normal tapping system. Normal continuous tapping system showed higher TPD (7.2 %) followed by the shallow + normal tapping system (6.8 %) and LFT + normal tapping (6.0 %) and minimum was in normal tapping system (5.5 %).

2.3. Location specific stimulant application

Ethylene induced stress response in the tapping panel of the *Hevea* trees was initiated to reduce the stress in tissues in the tapping panel. In RRIM 600 six treatments were adopted with bark applications of 5 per cent ethaphon. Results showed that maximum annual mean yield (45.2 g t^{-1} t^{-1}) and low DRC (33.4 %) was recorded in T3 (Bark application) of 5 per cent ethaphon at 150 cm above bud union and near bud union and minimum yield (30.6 g t^{-1} t^{-1}) and high DRC (34.1 %) was recorded in T6 (unstimulant trees). There was no significant difference in DRC between treatments.

3. Crop Management

3.1. Soil moisture retention characteristics under the rubber growing soils of Meghalaya

Soil samples were collected each month at the depth of 0-15 cm, 15-30 cm and 30-60 cm for soil moisture study. Soil moisture content increased with increase in the depth. Maximum soil moisture content was observed in August/September and minimum in Jan/Feb. Annual mean was 24.4, 25.3 and 26.1 per cent, respectively.

3.2. Analytical/advisory work for fertilizer recommendation

During the year, twenty four (24) soil samples were collected from the rubber growing areas indicated that the OC content was at the medium range (0.84 to 1.38 %) in the surface soil (0-30 cm), available P was at low range (3.1 to 7.5 mg kg^{-1}) and available K was at medium range (72 to 93.5 mg kg^{-1}). The soil is acidic in nature with pH ranging from 4.5- 5.4 and fertilizer recommendations were given accordingly.

3.3. Evaluation of soil fertility status and mapping of soil fertility of Meghalaya

Collected 162 composite soil samples (0-30 cm depth) from the rubber growing areas of Garo hills of Meghalaya (West, East, North, South and South-west Garo Hills districts) using GPS system. Samples were dried and packed and transported to RRII for analysis.

REGIONAL EXPERIMENT STATION NAGRAKATA, WEST BENGAL

1. Crop Improvement

1.1. Evaluation of clone

Twenty six promising clones were evaluated under the agro-climatic conditions of sub-Himalayan West Bengal. After 27th year of planting, significantly higher girth were exhibited by clones PR 107, SCATC 93/114, RRIM 703, RRIM 605, RRII 118 and RRIM 612 than check clone RRIM 600. Two clones PB 310 and PB 280 recorded significantly higher rubber yield than check clone RRIM 600.

1.2. Evaluation of Germplasm

Germplasm evaluation trials comprising of 21 accessions were continued and were under evaluation under the Nagrakata conditions. Highest growth was observed in RO 2629, MT 44, RO 3430, RO 2635, MT 196, MT 2229, AC 619, RO 5557 and RO 2890. As compared to check clone RRII 105 significantly higher dry rubber yield was recorded in AC 763.

1.3. Performance of polycross progeny raised from seeds of locally adapted mature rubber plantation

Performance of native climatic traits may have influence on development of *Hevea* seeds which may be reflected on to the next generation(s). Aiming this, the study on polyclonal seedling trees raised from seeds of NE as well as traditional region was initiated. It showed that seedling trees raised from seeds of NE performed better than that from Kanyakumari. The climatic condition of Kanyakumari and NE

region is widely different especially in terms of temperature throughout the year. The seeds developed in NE climate may have appreciably adapted to the native environment which is reflected in the performance of seedling trees under cold stress condition in terms of growth and yield. Evaluation of the performance of both the seedlings found that seedlings raised from seeds collected from Assam showed superior performance followed by that of Tura; performance of trees from Nagrakata seeds also showed better adaptive potential. Five superior selections were screened along with 16 primary selections that would be further screened for streamlining potential mother trees for better planting material for the region.

1.4. Multi trait screening of half sib progenies for cold tolerance and yield attributes

Half-sib progenies were raised from seven different clones in 2014. During non-winter period the juvenile yield was the highest progenies raised from seeds of SCATC 88/13 followed by RO 5363. During winter, the average juvenile yield of SCATC 88/13 progenies was higher than that of RRIM 600, followed by RRII 417 and RRII 429. Number of seedling plants showing above average juvenile yield was also higher in SCATC 88/13. The potential of half-sib progenies of SCATC 88/13 was shown to be prominent from this study.

1.5. Performance of new generation clones under the agro-climate of sub-Himalayan West Bengal

Evaluation of five promising new generation clones under the cold agro-climate of sub-Himalayan West Bengal showed that girth and yield of all the clones were on par with RRIM 600. However, yield of RRII 422 was found high followed by RRII 429 and RRII 417 during the year. Comparatively RRII 414 recorded lower yield than other clones in this region.

2. Crop Physiology

2.1. Performance of polycross progenies raised from seeds of locally adapted mature rubber plantation

Mean rubber yield of the population was 34.6 g t^{-1} t^{-1} and average yield of seedlings raised from seeds collected from four different places were similar ranging from 2.5 to 117.6 g t^{-1} t^{-1}. Twenty promising ortet mother plants recorded yield potential of around 60 g t^{-1} t^{-1} during 2nd year of tapping.

2.2. Physiological evaluation of rubber clones in abandoned tea growing areas of Dooars belt of North Bengal

A total of five clones were under evaluation in high pH soil. Growth of all five clones was at par with that of RRIM 600 in high pH soil except RRII 422 which showed significantly lower growth. In normal soil, growth of all the five clones was at par with RRIM 600 indicating the sensitiveness of clone RRII 422 to high pH.

2.3. Evaluation of Ortets for abiotic stress tolerance in different agro-climatic regions

Juvenile yield of the check clone RRIM 600 was high in both non-winter and winter periods followed by RRST 24, RRSG 1 and RRST 37.

REGIONAL REESEARCH STATION, DAPCHARI, MAHARSHTRA

The mandates of this Station are to develop suitable clones and location specific agro technology for the prevailing drought condition. The experiments on crop improvement (screening of wild *Hevea* accessions, evaluation of clone, polyclone, pipeline clones, marker assisted clones, HP, OP clones, selected ortets and wild *Hevea* accessions for growth and yield performance under Dapchari condition) and environmental physiology (physiological evaluation of selected ortates from various agroclimates of India) are being carried out.

1. Environmental Physiology

1.1. Evaluation of environmental stress tolerance and physiological adaptations of cold and drought tolerant ortet selections under varying agro-climates

The trial started in 2011 to evaluate the physiological and biochemical adaptation potential and common mechanisms involved in cold and drought tolerant traits using molecular physiology/biochemical tools for ortet selections from cold and drought by interchanging the clones to different agro-climatic regions and to study the GxE interaction for growth and yield under varying agro-climates.

In general, ortet RRSA is superior in growth characters studied followed by RRST and Dap ortets were found poor in growth performence.

2. Crop Improvement

A total of nine experiments are being conducted to evaluate the growth and yield performance of clone, pipeline clones, HO/OP clones, ortets, wild *Hevea* accessions, half sib progeny, polycross seedlings, different root stock plants to identify drought tolerant clones for their adaptability and stability to the agro climatic condition of Maharashtra.

2.1. Large scale trials

2.1.1. Evaluation of selected Ortets

Trial started during 2008 to evaluate the growth and yield performance of ortets selected from polycross seedling planted at this Station with control clones. Among the ortets OS 135, OS 36 showed higher plant height and girth compared to other ortets.

2.1.2. LST with 20 hybrids evolved for drought tolerance under drought (2018)

The objective of the trials was to evaluate growth and yield potential of 20 hybrid clones. The experiment is in initial stage. A significant difference in height, no. of whorls and leaves were recorded among the HP and OP clones. The height ranges from 82.8 cm in P 207 to 138.7 cm in P 225. Among the HP/OP clones P 027 recorded highest height of 138.7 cm in November 2019 and all clones are at par with P 207 except P 205 (87cm), P 207 (82.7 cm) and RRII 430 (86.0 cm). The clone P 225 recorded a highest no of whorls (3.1) while lowest no of whorls was seen in clone P 207 (2.1).

Clone P 218 recorded the highest no of leaves (26.8) while lowest no of leaves was observed in clone P 083 and RRII 430 (14.1 cm). In general, among the check clones, RRIM 600 is superior in all growth characters studied.

2.2. Further field evaluation trial

A total of three experiments comprising of 25, 47, 11 selections are being evaluated since 2007, 2010, 2014 and is at initial stage.

2.2.1. Field evaluation of selected Hevea clones for drought tolerance (2007)

Trial was laid out using 23 potential drought tolerant wild *Hevea* accession for drought under Dapchari condition along with five HP clones and RRII 105, RRIM 600, Tjir 1, RRII 430, RRII 208 as check clones in Augmented RBD, to study the drought tolerance potential of the selected wild accessions. The accessions showed a wide variability for all characters studied and after experimenting 11 summer periods (2008 to 2019), 4 wild accessions recorded girth higher than proven drought tolerant clone RRIM 600. MT 40 recorded highest girth at 12th year under drought. The growth and yield performance of the seedling will be studied for selecting potential recombination of wild and Wickham clones.

2.2.2. Small scale further field evaluation trial of selected wild accession for drought tolerance (2010)

Experiment was initiated with 47 selection from wild *Hevea* accessions along with four check clones (RRII 105, RRII 208, RRII 430, RRIM 600) to confirm the drought tolerance potential of selected seven wild accessions from preliminary field screening

2.2.3. Field evaluation of selected wild accessions for drought tolerance (2014)

Trial based in rectangular lattice design was laid out with 11 wild *Hevea* accessions along with two check clone (RRII 105 and RRIM 600) in order to evaluate juvenile and mature performance under drought condition.

2.3. Clonal nursery evaluation

A total of five clonal nursery evaluation trials are in initial stage for evaluation of half sib progeny, polycross, half sib progeny of prepotent clones and pipeline clones.

2.3.1. Germplasm screening

A Screening for wild *Hevea* accession (135) for drought under Dapchari condition was laid out in 2003 with RRII 105, RRIM 600, Tjir 1 in Augumented block design. In general, Mato Grosso accessions were superior for all growth characters studied than those from Randonia and Acre provenances. The test tapping in peak season and in summer season for assessing the yield potential after 16 years under drought stress. The selections will be advanced to Large Scale Trial at drought prone regions.

2.3.2. Clonal nursery evaluation of promising Hevea clones (Half Sib Progeny of Prepotent Clones) in hot spot areas for drought tolerance

The objective was evaluate the clones in a clonal nursery and advance the potential ones showing drought tolerance along with rubber yield to LST and PCE to reduce the breeding cycle. In the clonal nursery of 40 potential half sibs of 9 clones and 26 half sib progenies from eight prepotent clones were selected on the basis test tap yield and growth under drought stress. These selections will be advanced to a large scale trial at RRS, Dapchari for developing drought tolerant clones.

2.3.3. Clonal nursery evaluation of pipeline clones (2011)

Trial laid out in rectangular lattice experiment with pipeline clones (50 number with 2 check clone RRII 105, RRIM 600) with objective to identify drought tolerant clones for their adaptability and stability to this agro climatic condition of Maharashtra. Clone responses for field establishment were assessed. The growth and yield of

pipeline clones were assessed under cold and drought condition 14 pipeline clones were found to be superior to clone RRII 430. Highest test tapping yield was recorded in P 20 along with RRII 430. While 11 clones performed better than clone RRII 105 and showing the local adoptive nature of pipeline clones under drought condition.

2.3.4. Evaluation of polyclones of Kanyakumari origin in clonal nursery (2019)

Three thousand five hundred seedlings was raised from seeds obtained from Kanyakumai region in 2019 monsoon and the survival percentages and early girth was recorded and trial is maintained.

2.3.5. Development of drought tolerant root stock for the non-traditional areas (2015)

The drought tolerance capacity of the selected progenies developed through hybridization between high yielding clones (RRII 105, female parent) were evaluated in a clonal nursery trial. Fourty clones and 9 control were planted in this trial. 16 clones in terms of growth and 25 clones in terms of test tap yield were found superior to the check clones RRII 422 and RRII 417. The selection 69 showed a superior growth and yield performance.

2.3.6. Clonal nursery evaluation of pipeline clones/ marker assisted selection for drought and cold tolerance

The trial was laid out in July 2019 to evaluate the drought tolerance potentiality under drought condition. The survival percentages recorded and vacancy filling was done.

REGIONAL RESEARCH STATION, DHENKANAL, ODISHA

The Station continued its research activities with the particular objective of identifying clones suited to the dry sub humid climate region.

1. Crop Improvement

Six clone evaluation trials are in progress. The trials were laid out to screen and evolve the most suitable high yielding clones under the dry sub humid climate.

2. Clone evaluation

In Trial 1 (1987), the elite clone RRIM 600 has recorded highest mean yield of 48.9 g t^{-1} t^{-1} and GT 1 recorded the lowest yield (41.2 g t^{-1} t^{-1}) but GT 1 (86.8 cm) has recorded significantly higher mean girth over RRII 105. In terms of growth the performance of all three clones was satisfactory in the region (Table OR.1).

Table OR. 1. **Growth and yield performance of elite clones**

Clone	Yield (g t^{-1} t^{-1})	Girth (cm)
RRII 105	44.6	78.4
RRIM 600	48.9	82.5
GT 1	41.2	86.8
CD (P=0.05)	5.5	4.97

In the clone trial (1990), RRIM 600 (64.6 g t^{-1} t^{-1}), SCATC 88-13 (70.7 g t^{-1} t^{-1}) and RRII 208 (57.5 g t^{-1} t^{-1}) were found most high yielding clones. Other popular clones also performed well in the region. SCATC 93-14 recorded comparatively lower yield

(37.2 g t^{-1} t^{-1}). However, SCATC 93-14 (99.3 cm) recorded comparatively best growth in terms of girth, followed by SCATC 88-13 and RRII 208 recorded highest girth. Haiken 1 recorded comparatively lower girth.

In the 1991 experiment, clones differ significantly in mean yield. RRII 208 (69.8 g t^{-1} t^{-1}), RRIM 600 (58.6 g t^{-1} t^{-1}) and RRIC 102 recorded highest yield among the clones. Polyclonal seedling population (42.7 g t^{-1} t^{-1}) yielded low though having highest girth (116.7 cm) and adaptability under the prevailed stress conditions (Table OR. 2).

Table OR. 2. **Performance of different clones in the region**

Clones	Yield (g t^{-1} t^{-1})	Girth (Cm)
GT 1	47.3	102.7
RRII 105	59.6	90.4
RRII 208	69.8	101.1
RRII 5	51.1	93.8
RRII 300	48.9	99.8
PR 261	52.2	91.3
PR 255	54.6	99.5
RRIC 102	61.5	93.8
RRIM 600	58.6	89.7
Polyclonal	42.7	116.7
CD(P= 0.05)	13.7	9026

In the other modern clones' trial (2000), the highest mean yield was observed in RRIM 600 (60.3 g t^{-1} t^{-1}) and IRCA 109 (57.2 g t^{-1} t^{-1}). The lowest mean yield was recorded in RRII 51 (33.1 g t^{-1} t^{-1}). Highest growth in terms of girth was observed in RRII 300 (70.7 cm).

A source bush nursery with clones namely RRII 105, RRII 208, RRII 414, RRII 417, RRII 422, RRII 429, RRII 430, RRIM 600 and SCATC 88-13 was established to generate planting material for on farm trial and others in coming seasons.

1.2. Polyclonal ortet evaluation

In polyclonal ortet evaluation ortet clones DNKL 3 and DNKL 4 recorded comparatively higher yield and almost at par with high yielding clones in the region. The ortets DNKL 8 (46.3 cm) followed by DNKL 8 (46.2 cm), and DNKL 4 showed comparatively good girth attainment.

REGIONAL RESEARCH STATION, PADIYOOR

Identification and evaluation of clones adaptable for commercial cultivation in the region, development of agromanagement techniques for improved production/ productivity with reduction in gestation period and clonal tolerance to drought/ disease are the major thrust areas of research in the station. The station has a well maintained agromet observatory and a source bush nursery of promising clones and ortet selections suited to the region.

1. Crop management

1.1. Response to applied fertilizers in high yielding clones

The trial with three clones (RRII 105, RRII 414 and RRII 429) and four fertilizer levels (recommended dose, twice the recommended dose, three times the recommended dose and a zero fertilizer control) did not show any significant differences in yield with respect to the

different fertilizer levels applied. Clonal variations were also non-significant. The trial has been concluded.

2. Crop Improvement

2.1. Large scale evaluation of clones

IRCA 130 and PB 255 were the best adaptable clones for the region both in respect of annual and summer yield. The effect of stimulation on yield of the clones was proposed to be undertaken before conclusion of the trial.

2.3. Clone evaluation under high altitude situation

Two ortets P 270 and Iritty 1 and two-hybrid clones RRII 203 and RRIC 100 were selected for high yield and growth adaptation under the agroclimatic conditions in Ambalavayal, Wayanad. Ortet P 213 recorded high mean yield, but the clone showed low tappability indicating high growth variability. PB 86 was a high yielder in the region with medium girth. The ortet P1 recorded the highest girth. The selected ortets were established in the budwood nursery at the farm of RRS Padiyoor. The field trial at KAU, Ambalavayal was concluded.

2.4. Participatory clone trial

An on farm trial was laid out under the Participatory Clone Evaluation Project in an area of 2.5 ha. In co-operating 19 pipeline clones and three check clones RRII 105, RRII 430 and RRII 417. The 24 tapping blocks in the farm was converted from the 1/2S d3 system of tapping to weekly tapping (1/2S d6 6d/7).

HEVEA BREEDING SUB-STATION KADABA, KARNATAKA

Hevea Breeding Sub-station (HBSS) with a research farm at Nettana was established in 1986. The major constraints in commercial cultivation in this region is drought in summer months and occurrence of *Phytophthora* and *Corynespora* leaf fall diseases during rainy seasons. The research programmes in the station are envisaged to identify clones tolerant to different biotic and abiotic stress factors and to identify locally adapted clones for South Konkan region. The farm has a source bush nursery of 106 clones for generating nucleus planting material and a well-established Class B Agro-meteorological Observatory. There are five ongoing trials and four new trials were initiated during 2019 in the Station.

1. Large scale clone evaluation trial (1990)

In LST 1990 trial HP 372 and HP 223 were found superior yielders with 94.8 and 90.4 g t^{-1} t^{-1}, respectively while RRII 105 yielded around 60 g t^{-1} t^{-1}. Least yield was observed in Tjir 1 (43.6 g t^{-1} t^{-1}) (Table Kad. 1).

2. Small scale clone evaluation trial (1991 A)

In 1991, three Small Scale Trials were planted *viz.*, 1991 A (36 clones), 1991 B (13 clones) and 1991 C (13 cones). In the trial 1991 A with 36 clones, PB 235 (90.4 g t^{-1} t^{-1}), RRII 203 (89.9 g t^{-1} t^{-1}) and PB 280 (89.0 g t^{-1} t^{-1})

Table Kad. 1. **Yield from large scale clone evaluation (1990)**

Clones	Yield (g t^{-1} t^{-1})
PB 260	64.2
HP 223	90.4
Mil 3/2	56.9
HP 204	45.7
HP 185	74.3
PB 217	66.9
RRII 105	59.8
HP 372	94.8
PB 311	65.3
Tjir 1	43.6
GI 1	45.3
Hil 28	53.5
GT 1	59.6
PB 235	77.0
HP 187	60.5
CD (P=0.05)	22.5

were found exceptionally high yielders while seven clones performed significantly better than RRII 105 in terms of yield. Clone RRIM 701 registered least yield (25.1 g t^{-1} t^{-1}).

3. Small scale clone evaluation trial (1991 B)

Among the 13 clones evaluated in the trial 1991 B, RRII 5 (90.8 g t^{-1} t^{-1}) and RRII 118 registered significantly higher yield (68.3 g t^{-1} t^{-1}) than RRII 105 (28.6 g t^{-1} t^{-1}).

4. Small scale clone evaluation trial (1991 C)

No significant difference could be observed with respect to yield among the clones. However, the clone PR 261 recorded better yield.

Table Kad. 2. **Yield from large scale trial 2000**

Clone	Mean yield over seven years (g t^{-1} t^{-1})
RRII 422	34.5
RRII 414	60.1
RRII 403	40.1
RRII 105	35.8
RRIC 100	56.1
RRII 429	48.1
RRII 407	34.7
RRII 430	86.6
SE.d	9.65
CD (P=0.05)	20.7

5. Large scale trial (2000)

In the large scale trial (2000) with hybrids RRII 403, RRII 407, RRII 414, RRII 422, RRII 429 and RRII 430 and their parents *viz.*, RRIC 100 and RRII 105, significant difference in yield was observed while highest mean yield was recorded in RRII 430 (86.6 g t^{-1} t^{-1}) compared to check clone RRII 105 (35.8 g t^{-1} t^{-1}) (Table Kad. 2).

HEVEA BREEDING SUB-STATION, THADIKARANKONAM, TAMIL NADU

1. Genetic improvement of *Hevea brasiliensis* for developing ideal clones

1.1. Conventional breeding

Different experimental trials under the four projects *viz.* clone evaluation, hybridization and clonal selection, new generation polyclonal seed garden and participatory clone evaluation were under progress at the Station during the year 2019-20. The highlights of the results in these trials are reported hereunder.

1.1.1. Clone Evaluation

The block trial was laid out during October 2018 at Maruthamparai Unit of Chithar Division of Arasu Rubber Corporation Ltd. (ARC Ltd.) with 11 clones *viz.*, PB 255, PB 314, IRCA 109, IRCA 111, RRII 203, RRII 414, RRII 417, RRII 422, RRII 429, RRII 430 and RRII 105.

During the period under report, vacancy enumeration was undertaken and a total of 24 causalities were replaced with the plants of the respective clones.

1.1.2. Hybridization and clonal selection

The research farm at Thadikarankonam constitutes of two breeding orchards comprising of 51 parental clones which were properly maintained. During the period under report, the flowering was very poor due to the higher day temperature followed by summer showers. Sufficient flowers were not realized in the individual parents and moreover, there was non-synchrony in the selected parents. Based on the test tapping data, four selections were pollarded from the previous years' hybrids for the next stage of evaluation (Table Tha. 1).

Table Tha.1. **Test tap yield of hybrid seedling selections**

Hybrid seedling selections	Test tap yield ($g\ t^{-1}\ t^{-1}$)*
RRII 105 x RRII 118	4.10
RRII 105 x RRII 118	3.91
RRII 105 x RRII 203	3.70
RRII 105 x RRII 203	2.90

*(No. of tappings : 30)

1.1.3. New generation polyclonal seed garden

The seed garden with nine constituent clones at New Ambady Estate was maintained well. Around 2000 polyclonal seedlings obtained from the seeds collected from the polyclonal seed garden have been raised for seedling nursery evaluation. Six selections were pollarded from the previous seasons' seedlings based on test tapping data (Table Tha. 2).

Table Tha. 2. **Testtap yield performance of polyclonal seedling selections over 30 tappings**

Polyclonal seedling selections	Test tap yield ($g\ t^{-1}\ t^{-1}$)*
2016/1	3.62
2016/2	2.82
2016/3	2.71
2016/4	2.60
2016/5	1.98
2016/6	1.83

*No. of tappings : 30

1.1.4. Participatory Clone Evaluation Experiments

A total of four trials in four phases have been laid out in the region for

evaluation of the performance of 57 pipeline clones.

1.1.4.1. Participatory evaluation of pipeline clones Phase I (2008)

In the trial laid out in Tharavayar estate, Thadikkarankonam the clones P 10 (58.6 cm) and P 21 (58.8 cm) were found more vigorous among the 11 trial clones based on the annual girth data after 11 years of growth. The mean girth of the check clones was 57.6 cm, 58.0 cm and 59.4 cm, respectively for RRII 105, RRII 414 and RRII 430. The mean girth for the covariance component for all the plots *i.e.*, RRII 105 was 55.0 cm.

The yield data during the period under report indicated that clones P 021 (78.5 g t^{-1} t^{-1}) and P 076 (71.1 g t^{-1} t^{-1}) were promising among the trial clones. Among the check clones, RRII 430 registered the highest yield (77.8 g t^{-1} t^{-1}) and the average yield of the covariance plots of RRII 105 was 67.2 g t^{-1} t^{-1}.

1.1.4.2. Participatory evaluation of pipeline clones Phase III (2012)

In the trail laid out in Bethany Estate, Mukkampala the annual girth of the 11 clones along with the checks RRII 105, RRII 417 and RRII 430 after 8 years of growth found that among the trial clones, maximum girth was recorded for clones P 102 (60.3 cm) and P 049 (57.5 cm). The mean girth of the check clones *viz.*, RRII 105, RRII 414 and RRII 430 was 52.3 cm, 60.2 cm and 59.9 cm respectively. The mean girth for the covariance component RRII 105 for all the plots was 55.0 cm.

The mean yield data for the period under report revealed that clones P 066 (54.2 g t^{-1} t^{-1}) and P 049 (47.5 g t^{-1} t^{-1}) were promising among the 11 trial clones. Clone RRII 417 registered the highest yield (50.3 g t^{-1} t^{-1}) among the check clones, while the average yield of the covariance plots of RRII 105 was 37.0 g t^{-1} t^{-1}.

1.1.4.3. Participatory evaluation of pipeline clones Phase V (2016)

In Phase V of the trial laid out in ARC Ltd., Chithar Division among the 16 trial clones planted, the clones P 202 (21.8 cm) and P 215 (20.6 cm) were found to be relatively more vigorous. Among the 3 control clones RRII 422 was relatively more vigorous (20.9 cm). The mean girth of the covariance plots of RRII 105 was 19.4 cm.

1.1.4.4. Participatory evaluation of pipeline clones Phase VI (2019)

The Phase VI of Participatory Clone Evaluation trial was laid out at Manalodai Division of Arasu Rubber Corporation Ltd. The trial was planted during August 2019 with 19 trial clones (P 073, P 243, P 248, P 249, P 264, MK 1, MK 2, MK 3, MK 4, MK 5, TG 1, TG 2, TG 3, TG 4, TG 5, TG 6, TG 7, TG 8 and TG 9) and three check clones *viz.* RRII 105, RRII 422 and RRII 430.

LIBRARY AND DOCUMENTATION

The Library and Documentation Centre attached to Rubber Research Institute of India is well maintained with a collection of 23030 books, 24754 bound volumes of periodicals, 6045 standards, 1563 reprints, 192 Theses/Dissertations and 1200 Microfiche/Microfilms Subject bibliographies and computer based bibliographic databases of all books, research articles, standards, theses and reprints are also accessible to the users.

Library continued the information and literature support to its in-house and outside institutional users by providing reference services, current awareness services and reprographic services. During the current year 434 bound journals, 32 books, and 37 standards were added to the stock. During the year Library received and registered 287 issues of journals as subscription/exchange.

Compiled information bulletins, *viz.*, *Documentation List* (1-4) 2019, *New Additions List* 2019, *Staff Publications list* 2019-2020 and bibliographic list of reprints/photocopies with 1382 items. Databases were updated with the details of 204 books, 167 research articles, 37 standards, 2 theses and 434 bound journals. Circulated 519 books, technically processed 425 books, filed 1170 press clippings of relevant articles and provided 6029 photocopies. Library membership issued to 3 members, reference service extended to 386 users and No dues certificate issued to 88 members.

As a part of sales promotion of RRII publications, library organized the sale and distribution of 604 copies of the journal *Rubber Science* and 158 other publications including RRII Annual Report and collected Rs.79,497.00 including the price of publications sold, charges for overdue on circulated books, and photocopying.

SCIENTIFIC ADVISORY COMMITTEE RECOMMENDATIONS 2019-20

- Recommended one-whorl or two-whorl direct-seeded polybag or root trainer rubber plants as suitable planting materials in the field.
- Recommended ornamental plants, Dracaena and Heliconia as suitable intercrops in rubber plantations. Heliconia can be cultivated during immature phase whereas Dracaena can be cultivated under partial shade (3 years after planting of rubber) and also during mature phase.
- Upgradaed three PB clones namely, PB 280, PB 255 and PB 314 from Category 2 to Category 1 of planting recommendations and releasing them for commercial cultivation in the traditional rubber growing regions with standard plant protection measures. Their region-wise recommendation as below is also approved.

  PB 280: for South Kerala, Karnataka and Central Kerala

  PB 255: for South Tamil Nadu, Central Kerala, North Kerala and South West Karnataka

  PB 314: for South Tamil Nadu, Central Kerala and North Kerala

- Upgraded clones IRCA 130 and IRCA 111 from the Category 3 to Category 2 of planting recommendation for the traditional region.
- Considering the advantage of lower bark consumption, ease of use and less bark injury, the Scientific Advisory Committee (SAC) recommended the non-motorized tapping knife developed by Shri. A.G. Somanathan for use by rubber growers.
- Recommended *Calopogonium caeruleum* as an alternate cover crop in rubber plantations. This leguminous cover crop can be established under partial shade also during later immaturity period of rubber.
- Approved the recommendation of a new water based combination fungicide with the formulation of 5% Pyraclostrobin + 55% metiram (trade name Mantram) at a concentration of 1g/L for the control of Corynespora leaf disease in rubber plantations in addition to already recommended fungicides.

ANNUAL EXPENDITURE

Expenditure at a glance (2019-20)

Head of Account	Expenditure (Rs. In lakhs)
Plan	
Rubber Research other than NE Region	2,323.73
Rubber Research - NE Region	557.99
Total	2,881.72

PUBLICATIONS

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SCIENTIFIC AND SENIOR SUPPORTING PERSONNEL

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C. Bindu Roy, M.Sc., Ph.D.	Senior Scientist
E. Edwin Prem, M.Sc. (Ag.)	Senior Scientist
E.P. Joy	Farm Officer

Crop Physiology Division

K. Annamalainathan, M.Sc., M.Phil, Ph.D.	Joint Director/ Principal Scientist
S. Sreelatha, M.Sc. (Ag.), Ph.D.	Principal Scientist
Jayasree Gopalakrishnan, M.Sc., M.Phil., Ph.D.	Senior Scientist
K.V. Sumesh, M.Sc., Ph.D.	Scientist
Sheela P. Simon, M.Sc., Ph.D.	Junior Scientific Officer (upto 6.1.20)
Rajan Mathew, B.Com	Farm Officer

Climate Change and Ecosystem Studies

Shammi Raj, M.Sc., Ph.D.	Principal Scientist
T. Sailajadevi, M.Sc.	Senior Scientist
B. Pradeep, M.Sc.	Junior Scientist
K.K. Jayasooryan, M.Sc.	Junior Scientist (upto October 2019)
K.G. Jayan	Assistant Farm Manager

Latex Harvest Technology Division

R. Rajagopal, M.Sc., M.Phil., Ph.D., Dip. Stat.	Senior Scientist
K. Karunaichamy, M.Sc., Ph.D.	Principal Scientist

Rubber Technology Division

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Benny George, M.Sc., Ph.D.	Senior Scientist
Joy Joseph, M.Sc.	Senior Scientist
Manoj Kurian Jacob, M.Sc., Ph.D	Scientist
M. Susamma Joseph, M.Sc.	Assistant Scientific Officer
M.L. Geethakumariamma, M.Sc., Ph.D.	Assistant Scientific Officer

Technical Consultancy Division

Siby Varghese, M.Sc., Ph.D.	Joint Director/ Principal Scientist
Shera Mathew, M.Sc., M.Tech., Ph.D.	Scientist
P.S. Sadeesh Babu, B.Tech., PGDBA	Senior Scientist
M.A. Fancy, M.Tech.	Assistant Rubber Technologist
K.K. Sasidharan, M.Tech., Ph.D.	Assistant Rubber Technologist (upto 31.5.19)
Mathew Joseph, B.Tech.	Assistant Rubber Technologist
Reethamma Joseph, MSc., Ph.D.	Assistant Rubber Technologist
K.I. Elizabeth, M.Sc., M.Tech., Ph.D.	Assistant Scientific Officer
Tessy K. George, M.Sc., M.Tech.	Junior Scientific Officer

Economics Division

Toms Joseph, M.A.	Joint Director (working arrangement at H.O. w.e.f.17.08.07)
Binni Chandy, M.A.	Senior Scientist
S. Veeraputhran, M.A., M. Phil.	Scientist
T. Siju, M.Sc. (Ag.), Ph.D.	Scientist
Joby Joseph, M.A.	Scientist

Library and Documentation Centre

N. Latha, M.Sc., M.L.I.Sc.	Documentation Officer
A.S. Ajitha, M.A., M.L.I.Sc	Senior Librarian
V.R. Sujatha, B.Sc., M.L.I.Sc.	Librarian

Statistics and Computer

B. Biju, M.Sc., M.C.A.	Assistant Director (Systems)
P. Aneesh, M.Sc., P.G.D.C.A.	Assistant Statistician
K.A. Santhosh, M.C.A.	Assistant Systems Officer

Instrumentation

M.R. Anilkumar, Dip. in Inst. Tech.	Instrumentation Officer
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Administration

T.M. Ushalakshmy	Assistant Secretary (Res.) (up to 31.5.19)
P.C. Lillikkutty	Assistant Secretary (Res.) (upto 29.8.19)
Sajiya Krishnakumar	Section Officer

Accounts

V. Ganeshan, M.Com.	Deputy Director (Finance) (upto 29.8.19)
R. Pushpakumari, M.Sc., I.C.W.A.	Accounts Officer (upto 29.8.19)

Security Wing

M.T. Varghese, M.A.	Assistant Security Officer

Central Experiment Station, Chethackal, Kerala

Thomas Eappen, M.Sc., B.Ed.	Senior Scientist
N.K. Suresh, MBBS	Medical Officer
T.V. Thomas, B.A.	Assistant Farm Manager
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Radha Lakshmanan, M.Sc. (Ag.), Ph.D.	Principal Scientist
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Regional Research Station, Guwahati, Assam

Gitali Das, M.Sc., Ph.D.	Deputy Director (RS)

Regional Research Station, Agartala, Tripura

Sushil Kumar Dey, M.Sc., Ph.D.	Joint Director/ Principal Scientist
Debasis Mandal, M.Sc. Ph.D.	Senior Scientist (upto 29.2.2020)
Debabrata Ray, M.Sc. (Ag.)	Scientist
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Regional Research Station, Tura, Meghalaya

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Regional Experiment Station, Nagrakatta, West Bengal

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Regional Research Station, Dapchari, Maharashtra

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Hevea Breeding Sub station, Kadaba, Karnataka

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Regional Soil Testing Laboratory, Palai, Kerala

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Research divisions and functions

The major research divisions are Agronomy/Soils, Biotechnology, Botany, Climate Change & Ecosystem Studies, Germplasm, Latex Harvest Technology, Plant Pathology, Plant Physiology, Rubber Technology, Technical Consultancy and Economics. Studies on Clone Evaluation, Genome Analysis and DRIS Fertilisation are dealt separately.

The thrust areas of research of Agronomy/Soils Division are investigations on the nutritional requirements of rubber, irrigation, intercropping, cover crop management, weed control and the study of the rubber growing soils. Development of tissue culture and another culture system for propagation and development of transgenic plants incorporating agronomically important genes for improvement of *Hevea* are the important areas in which the Biotechnology Division is engaged. The Advanced Centre for Molecular Biology and Biotechnology (ACMBB) is a functional grouping of scientists working in the areas of Molecular Biology, Biotechnology, Genome Analysis, Molecular Physiology and Molecular Pathology. The important fields of research of the Botany Division are breeding, evaluation and selection of new clones, propagation techniques, planting methods, anatomical studies and cytogenetic investigations. The Climate Change & Ecosystems Studies Division is pursuing studies on climate change process in traditional and non-traditional rubber growing regions of India and developing information system on rubber cultivation using remote sensing (RS) platform to identify area under rubber cultivation and suitable area where rubber plantations can be extended. The Germplasm Division is concentrating on the introduction, conservation and evaluation of *Hevea* germplasm. The Plant Pathology Division is engaged in investigations on the diseases and pests of rubber and associated cover crops and their control. The Plant Physiology Division conducts studies on both fundamental and applied aspects of *Hevea* tree physiology. The Latex Harvest Technology Division is concentrating on all applied aspects of crop harvesting in rubber. The Rubber Technology Division concentrates on improvement in primary processing of rubber, its chemical modification, rubber product manufacture and quality control of processed rubber. The Technical Consultancy Division provides consultancy services for the promotion of the rubber industry. The Rubber Technology Division and Technical consultancy Division together forms the Advanced Centre for Rubber Technology (ACRT). The Economics Division undertakes studies on economic aspects related to rubber plantations.

The research supporting sections includes Library and Documentation, Instrumentation, Statistics, Computer and Maintenance Wing. There is also a small experimental farm of 33 ha. at the headquarters of RRII.

Central Experiment Station

The 255 ha. Central Experiment Station at Chethackal (Ranni), 50 km away from Kottayam, was started in 1966. Field trials laid out by the research divisions cover almost the entire area.

Regional Research Stations

RRII has established a North-Eastern Research Complex with headquarters at Agartala having regional research stations at Agartala in Tripura, Guwahati in Assam and Tura in Meghalaya. The RRII has also set up regional research establishments at Dapchari (Maharashtra), Dhenkanal (Orissa), Nagrakata (West Bengal), Thadikarankonam (Tamil Nadu), Kadaba (Karnataka) and Padiyoor (Kerala).

Regional soil testing laboratories have been established at Kozhikode, Thrissur, Muvattupuzha, Pala, Kanjirappally, Adoor and Nedumangad. Mobile units for soil and leaf analysis are available at Kozhikode laboratory, apart from that at the headquarters.

National/International collaboration

RRII is a member of the International Rubber Research and Development Board (IRRDB), an association of national organizations devoted to research and development on natural rubber. Rubber Board is a member of the Association of Natural Rubber Producing Countries (ANRPC) and International Rubber Study Group (IRSG).

The RRII has research/academic linkages with the Banaras Hindu University (Varanasi), Kerala Agricultural University (Thrissur), Kerala University (Thiruvananthapuram), Mahatma Gandhi University (Kottayam), Cochin University of Science and Technology (Kochi), Indian Agricultural Research Institute (New Delhi), Indian Institute of Sciences (Bangalore), Indian Institute of Technology (Kharagpur), National Chemical Laboratory (Pune), Sree Chitra Tirunal Institute of Medical Sciences and Technology (Thiruvananthapuram), Tamil Nadu Agricultural University (Coimbatore), University of Agricultural Sciences (Bangalore) and University of Goa (Goa).

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