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ADVANCES IN CROP IMPROVEMENT IN *HEVEA* IN THE TRADITIONAL RUBBER GROWING TRACT OF INDIA

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The para rubber tree, *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg., is the major source of natural rubber, and provides 99 per cent of the global requirement. Rubber plantation industry in India has registered commendable growth in production and productivity and at present occupies the third position in terms of production. More significantly, the country has attained the first position in productivity with 1576 kg per hectare per year. The contributions made by research, in particular the genetic improvement programmes, played the key role in achieving this. During the initial stages of plantation industry unselected seedling materials with an annual yield of 200-300 kg per hectare was in use. Now there are clones having a production potential of around 4000 kg per hectare per year. Such a spectacular advancement in productivity was achieved through diligent planning, systematic breeding, judicious selection and timely release of promising planting materials.

Crop improvement programmes were initiated in India just before the inception of the Rubber Research Institute of India. The objectives of *Hevea* breeding are to develop promising clones with higher production potential combined with desirable secondary characters like high initial vigour, smooth and thick bark with high number of latex vessels, tolerance to environmental stresses like cold, drought, wind etc. Development of high yielding clones is a priority area of research to reduce cost of production.

For crop improvement in *Hevea*, mainly three methods are being adopted viz., introduction, ortet selection and hybridization. The most promising method of developing clones of desirable genetic constitution is controlled hybridization between selected parent clones, evaluation of the hybrids and clonal selection of promising recombinants for further evaluation. The outstanding contribution of RRII is the development and release of the most promising high yielding hybrid clone RRII 105 and the latex timber clones like RRII 203 and RRII 5 in the early years of breeding.

Five hybrid clones developed from the cross RRII 105 x RRIC 100 *viz*., RRII 414, RRII 417, RRII 422, RRII 429 and RRII 430 have been included in Category III of the planting recommendations of the Rubber Board, since 2001. These clones have shown significant improvement in yield over the clone RRII 105 to the tune of 23-46% during the first 8 years of tapping in the small-scale evaluation trial. The vigour of these clones is also higher than that of RRII 105. The number of latex vessel rows in the virgin and renewed bark is more than that of RRII 105.

Another set of 30 hybrid clones was also found to be superior to RRII 105 in the small-scale evaluation trials. With a view to incorporate wild genes in the breeding pool, hybridization programme was undertaken incorporating 24 selected wild accessions as male parents and promising Wickham clones such as RRII 105, PB 260 and RRIM 600 as female parents. The progenies are under evaluation. Ortet selections from the large estates have also identified 12 promising clones having better yield than RRII 105. These are being evaluated in subsequent evaluation trials. Investigations on Genotype x Environment interaction, breeding and selection of latex timber clones, polycross breeding, studies for reducing the breeding cycle and molecular approaches as additional tools for breeding programmes are also being undertaken. The mandate of the two *Hevea* breeding sub-stations located at Paraliar in Kanyakumari District of Tamil Nadu and Nettana in Dakshina Kannada District of Karnataka are to identify clones suited to those locations along with evaluation of the clones under experimentation at RRII. Polyclonal seed gardens are being planted at Kanyakumari District incorporating the improved hybrid clones. One polyclonal garden was planted at New Ambadi estate in Kanyakumari incorporating nine promising hybrid clones.

In order to avoid the possible danger of monoclone planting, multiclone concept was introduced in 1991. Accordingly, only 50% area was advised to be planted with any one of the clones included in Category I and the remaining 50% with other promising recommended clones. Investigations on various techniques to reduce the immaturity period as well as cost of production in rubber are also in progress. Studies on stock scion interaction, comparative field evaluation of different propagation methods, bench grafting and establishment of root trainer nursery are some of the studies in this line. Research for identifying clones tolerant to drought and disease are also under way. Studies on bark and wood anatomy, cytology and palynology are also being undertaken.

INTRODUCTION

During the last decade (1991-2000) the natural rubber plantation industry has shown an increase of 72% in area, 40% in productivity, and 42% in price (Rubber Board, 2002). The drop in rubber prices during the latter part of the last decade has compelled to reorient the research and development programmes of the Rubber Board. Accordingly, the genetic improvement programmes were also prioritised. During the first phase, emphasis was primarily on yield; later, priority was given to combine yield and other desirable secondary characters like vigour, tolerance to diseases, drought and wind. Towards the end of the millennium emphasis was shifted to reduce the cost of production and to improve the quality of marketed forms of rubber. Development of high yielding clones with high timber volume is yet another area of research interest since it leads to higher returns. So in a globalised economy, research priorities will be towards global competitiveness in quality, cost and environmental aspects.

Crop improvement programmes were initiated in India during 1954 just before the inception of the Rubber Research Institute of India (RRII). The breeding objectives of the institute have been tailored in tune with the interest of the growers and the plantation industry as a whole. So far 127 clones were introduced to India from other rubber growing countries. During the last decade bilateral clone exchange programme was effected with Cote'd Ivore, Malaysia, Indonesia and Sri Lanka. A total of 13 clones were introduced from these countries in exchange for nine Indian clones (Table 1). The introduced clones are being evaluated in field experiments to assess their performance under different agro-climatic conditions in India.

HYBRIDIZATION AND CLONAL SELECTION

The objectives of *Hevea* breeding are to develop ideal clones with higher production potential combined with desirable secondary characters like high vigour, smooth and thick bark with high number of latex vessel rows,

Table 1. **Clones exchanged under bilateral exchange programme**

Country	Year of exchange	Clones	
		Provided	Received
Cote d'Ivoire	1991	RRII 5, RRII 105, RRII 118, RRII 208, RRII 300	IRCA 18, IRCA 109, IRCA 111, IRCA 130, IRCA 230
Malaysia	1993	RRII 109, RRII 176, RRII 208, RRII 308	RRIM 712, RRIM 722, RRIM 728
Indonesia	1995	RRII 105, RRII 176, RRII 208	BPM 24, PR 255, PR 261
Sri Lanka	1995	RRII 176, RRII 208	RRIC 110, RRIC 130

good bark renewal, high growth rate, tolerance to diseases and environmental stresses like cold, drought, wind etc. Priority is also being given to evolve clones having low occurrence of tapping panel dryness (brown bast) and good response to stimulation coupled with low intensity tapping. In small holding sector, clones having high girth and high yield are preferred.

The major constraints in *Hevea* breeding are long gestation period, seasonal nature of flowering, lack of any reliable early selection parameters, very long period of field experimentation and pronounced interaction of genotype and environment. The major advantages are monoecious nature of the tree, which make hybridization easy and the amenability to vegetative method of propagation.

The most important method of developing clones of desirable genetic constitution is the controlled hybridization between selected parent clones, evaluation of F_1 hybrids and selection of promising recombinants for further evaluation. During the initial years, primary clones were used as parents for hybridization, which resulted in RRII 100, 200 and 300 series of clones. Among clones of RRII 100 series, RRII 105 is the outstanding high yielder (Nair *et al.*, 1975; George *et al.*, 1980), which enjoys maximum popularity in the planting sector. The best selections from RRII 200 series are RRII 203, RRII 208 (Saraswathyamma *et al.*, 1990) and that from RRII 300 series

Table 2. Performance of RRII 400 series selections in the small scale trial

Clone	Yield at 4½ years age (g/t/t)	Girth at regular opening (cm)	Girth during 9th year of tapping (cm)	Mean yield over 8 years of tapping (g/t/t)	Improvement over RRII 105 (%)	No. of latex vessel rows: At opening	At 10th year after planting (Virgin bark)	Renewed bark 8th year after opening
RRII 403	13.83	54.54	75.27	61.87	13.58	11.50	18.25	32.79
RRII 407	15.89	56.34	88.11	60.68	11.40	7.28	15.39	25.17
RRII 410	14.82	53.52	74.53	64.07	17.60	8.75	19.58	27.57
RRII 414	18.08	57.49	81.00	77.86	42.94	11.77	21.76	34.65
RRII 417	13.55	54.73	72.84	70.39	29.23	13.00	20.49	31.55
RRII 421	11.64	50.64	61.39	67.68	24.25	13.45	20.44	30.31
RRII 422	17.62	52.40	65.04	70.63	29.66	14.62	21.66	25.56
RRII 429	19.90	62.77	82.54	79.29	45.56	12.95	22.00	33.09
RRII 430	13.86	53.42	68.20	67.17	23.31	11.73	18.32	27.49
RRII 105	9.85	49.04	62.68	54.47	-	10.58	15.21	30.13
CD($P \leq 0.05$)	4.44	6.50	5.08	10.46	-	3.36	4.27	NS

are RRII 300 and RRII 308 (Premakumari *et al.*, 1984). Many potential high yielding clones showing better performance than RRII 105 are under evaluation.

From the 1982 hand pollination programme, 23 hybrid clones resultant of the cross of RRII 105 x RRIC 100 were evaluated in a small scale trial planted during 1985. These clones have been designated as RRII 400 series clones. Based on early performance at four and a half years of growth nine hybrid clones were selected as having comparable/more yield than RRII 105. These clones were found to exhibit promising yield trend in the mature phase too as given in Table 2. (Licy *et al.*, 1992, 1997 and 2002). Out of these clones, five clones viz. RRII 414, RRII 417, RRII 422, RRII 429 and RRII 430 have been included in Category III of the planting recommendation of the Rubber Board, since 2001.

Incorporating these selections a large scale trial was laid out in 1993 at Central Experiment Station of RRII at Chethackal. These clones are showing more vigour than RRII 105 at the time of opening and the improvement in girth over RRII 105 ranged from 2 to 20%. Multilocational large scale trials were laid out at five locations. Kanyakumari District in Tamil Nadu, Padiyoor in Kerala, Bhubaneswar in Orissa, Agartala in Tripura and Nagrakatta in West Bengal, where, girth of clones RRII 417, RRII 429 and RRII 430 were observed to be better than that of RRII 105 (Meenattoor *et al.*, 2000). On farm trials were initiated at Cheruvally and Kaliyar estates incorporating the nine selected clones in 1998 and 1999 respectively. Small quantities of budwood of these clones are being supplied to both large and small growers as nucleus material for collaborative experiments. Evaluation trials are also in progress at Koothattukulam, Velimalai, Vaikundam and New Ambadi estates. If the yield trend observed in the small-scale trial is confirmed in further evaluation trials, these clones will be upgraded in the planting recommendation.

ORTET SELECTION

Ortet selection, which is otherwise known as mother tree selection or plus tree selection is the oldest selection method adopted in rubber. In ortet selection, elite seedlings of GG 1, GG 2 and PBIG series were selected by screening of seedlings resultant of natural recombination, cloned and evaluated. Many promising primary clones like Tjir 1, Gl 1, GT 1, PB 86, PB 28/59 were derived through this method. Currently more emphasis is being given to evaluate the clones of selected ortets.

Under the current ortet selection programme, seedling area of 1275 ha was screened and 270 promising seedlings were selected. These were multiplied and small scale trials were laid out. Details of the promising selections planted in Cheruvally and Koney Estates are given in Tables 3 and 4.

Table 3. **Performance of promising ortets at Cheruvally Estate**

Clone	Girth at opening (cm)	Mean yield over five years (g/t/t)
35	59.96	60.3
30	53.60	55.6
41	64.43	64.2
48	63.76	60.8
72	51.70	57.5
RRII 105	49.30	52.9

Table 4. **Performance of promising ortets at Koney Estate**

Clone	Girth at opening (cm)	Mean yield (g/t/t) over three years
6	57.47	43.83
10	53.11	48.09
16	56.79	45.35
26	54.63	47.04
25	52.10	59.66
27	57.73	61.42

ON FARM EVALUATION

Evaluation of clones in grower's plots is done in this stage. One block each of the promising clones is being evaluated along with the most popular clone for comparison. The results from trials at Chithelvetty, Koney, Shaliacary and Chemony estates are presented in Tables 5 to 8. At Chithelvetty PB 260 is the highest yielding clone followed by RRII 105 (Table 5).

Table 5. **Performance of clones in on-farm evaluation at Chithelvetty Estate**

Clone	Girth at opening (cm)	Mean yield (kg/ha/year) over eight years
RRII 1	45.69	1272
RRII 43	43.86	1007
RRII 44	47.49	696
RRII 105	46.46	1343
RRII 300	47.86	710
RRIC 52	51.79	727
PB 235	50.74	1089
PB 260	52.24	1409
PB 310	44.19	1093
PB 311	50.06	1297
PR 255	50.23	1120
PR 261	43.43	1017

At Koney estate PB 260 was the most vigorous clone with maximum girth at opening and 72.03% tappability at the time of opening. Mean yield over four years revealed clone PB 260 to be the best performer with a yield of I 2015 kg/ha/year followed by PB 314 (1852 kg/ha/year) and RRII 105 (1693 kg/ha/year) respectively Table 6.

Seven selected clones, SCATC 88-13, RRII 51, PB 255, RRII 176, PB 28/59, PR 255 and RRII 105 were planted with one block each at Shaliacary estate during 1993. Girth at opening was the highest for PB 255 followed by PB 28/59. The vigorous habit of PB 255 was evident from its uniform growth and 73% tappability at the time of opening. RRII 105 recorded the highest yield (1498 kg/ha/year) followed by PR 255 (1473 kg/ha/year) and RRII 176 (1217 kg/ha/year) Table 7. Performance of clones in ten large estates revealed that PB 260 is the highest yielder followed by PB 311, PB 28/59, RRII 105, PB 235 and PB 217 the range of yield being 1620 kg to 1270 kg/ha/year (Mercykutty *et al.*, 1995). At Chemony estate PB 260 is the highest yielder followed by PB 311 and RRII 105 Table 7, 8.

Table 6. **Performance of clones in on farm evaluation at Koney Estate**

Clone	Girth at opening (cm)	Mean yield (kg/ha/year) over four years
RRII 5	44.71	1498
RRII 105	43.81	1693
RRII 300	45.11	1658
PB 260	53.63	2015
PB 314	49.23	1852
PR 255	43.86	1597
PR 261	44.75	1495
SCATC 88-13	42.15	1467

Table 7. **Performance of clones in on farm evaluation at Shaliacary Estate**

Clone	Girth at opening (cm)	Mean yield (kg/ha/year) over three years of tapping
RRII 51	43.64	1148
RRII 105	45.00	1498
RRII 176	45.98	1217
PB 255	48.60	1032
PB 28/59	47.00	1238
PR 255	44.00	1473
SCATC 88-13	45.56	1095

MULTICLONE PLANTING

One of the remarkable contributions of RRII is the development and release of RRII 105, the very high yielding clone. After its inclusion in Category I in 1980 a major portion of the planted area has been covered by this single clone particularly in the small holding sector. The clone occupies more than

Table 8. **Performance of clones in on-farm evaluation at Chemoni Estate**

Clone	Girth at third year of tapping (cm)	Mean yield over three years of tapping (kg/ha/year)
RRII 5	57.89	703
RRII 105	57.86	859
RRII 203	63.67	627
RRII 206	52.50	506
RRII 208	55.03	543
RRII 300	53.79	692
RRII 308	55.87	424
RRIC 102	57.33	508
PB 260	60.11	1125
PB 310	55.57	635
PB 311	58.38	912
PR 255	53.02	782
PR 261	54.23	733
Nab 17	54.20	652

90% of the total planted area, which leads to a situation of monoclonal planting. Even though monoclonal plantations have an advantage that the population is homogeneous in respect of stand and productivity chances for the outbreak of disease epidemic is more due to the genetic uniformity. Although there is no alarming situation yet, there is an urgent need for planning alternate measures to prevent any possible danger. In order to avoid extensive contiguous belts of a single clone and to obviate the potential risk involved in such monoclone culture, the Rubber Board recommended multiclone planting in 1991. Accordingly necessary changes were made in the planting recommendations. It is advocated to plant only 50% of the proposed area with one of the clones included in Category I. Clones under Category II can be planted up to 50%, selecting 3 or more clones and those under Category III for small scale planting not exceeding 15% of the total area. Field experiments are in progress to ascertain the performance of different clonal composites in comparison to monoclonal stand. Preliminary assessment has elucidated that incidence of disease is comparatively less in multiclone planting.

PERFORMANCE OF EXOTIC CLONES

Among the exotic clones introduced to India, the planting recommendation of the Rubber Board includes three clones in Category I; PB 260 for traditional area and RRIM 600 and GT 1 for non-traditional areas. All the five clones included in Category II are exotic in origin and the remaining clones are listed under Category III. Among the exotic clones in the Categories II and III, PB 255, PB 280, PB 310, PB 312 and PB 314 are the promising high yielders. Mean yield over 10 years of tapping of seven exotic clones along with RRII clones in the large scale evaluation has elucidated that PB 310 (57.76 g/t/t), PR 255 (57.61 g/t/t), RRIM 600 (55.61 g/t/t), and RRII 105 (54.20 g/t/t) are the promising high yielders.

In the trials being carried out for evaluation of clones in grower's plot, RRII 105, PB 260 and PB 314 continued to show high yield. The clones PB 314, PB 255, PB 312, PB 280, PB 311, KRS 163 and PB 260 recorded significant superiority in yield over the control RRII 105 during the first four years of tapping in the large scale evaluation trials laid out during 1989 at RRII experiment station at Kottayam.

GENOTYPE X ENVIRONMENT INTERACTION

The performance of planting materials depends on their genetic constitution, the environment in the specific localities where these are grown and genotype x environment interaction. The environmental factors that influence the performance of the planting materials are soil type, terrain, pattern of rainfall, severity of wind forces, duration and severity of drought and the occurrence of diseases and pests. RRII 105 performs well in the traditional tracts but it is susceptible to drought in terms of growth. (Saraswathyamma *et al.*, 2000, Rubber Board, 2002). Hence the clone is not suited for drought prone areas. In order to study the above aspects large-scale trials incorporating 12 clones are in progress at five different locations including both traditional and non-traditional tracts.

Availability of exhaustive data on the performance of clones in different locations is the primary prerequisite for recommendation of clones specific to particular environs. However, based on the available information clones suited to different environments are given in Table 9. Recommending clones for a particular environment only indicates that their performance in the specific tract will be comparatively better than other clones currently available.

Table 9. **Clones suitable for different environmental conditions**

Area prone to	Clones suggested
Severe *Phytophthora*	RRII 105, RRIM 628, PB 217
High *Oidium* incidence	RRIM 703, RRIM 600, PB 260, RRII 203
Severe pink	GT 1, RRII 5, RRII 203
Strong wind	PB 217, PB 260, PB 5/51, RRIM 600
Drought	RRIM 600, GT 1, RRII 208, PB 311
Severe *Corynespora*	GT 1, RRIM 600

CYTOGENETICAL STUDIES

Cytogenetical investigations are very important for understanding the genetic system and are essential in chalking out breeding programmes. The chromosome complement in *Hevea* is 2n=2x=36 (Saraswathyamma *et al.*, 1984). Karyomorphological analysis of different clones revealed that structural difference exists among chromosomes of different clones (Sankariammal and Saraswathyamma, 1995). The extent of genetic variability of different clones was studied by chiasma frequency analysis. The clones showing high chiasma frequency can be selected for hybridisation programmes.

Pollen size, stainability and *in vitro* pollen germination studies of different clones was carried out. The result revealed that wide variation exists among clones with regard to pollen size, stainability and germination percentage (Sankariammal *et al.*, 2002). There is marked non-synchrony in flowering among the different clones of *Hevea* (Soman *et al.*, 1996). This causes problems in hybridization programmes involving some parental combinations. In this context, studies pertaining to the storage of pollen grains have been initiated. Preliminary results showed the possibility of long-term storage of pollen under -196°C in liquid nitrogen. Pollen grains recovered after two months of cryo-storage showed germination *in vitro*. Studies on further optimisation of pre-storage conditions and pollination using stored pollen grains in the field are under progress.

ANATOMICAL INVESTIGATIONS

Anatomical and histochemical changes encountered with the process of bark renewal and its nature and consequences were studied, since both virgin and renewed bark are being tapped for latex. The changes encountered with tapping are the deposition of lignin and suberin in the peripheral cells, and enlargement of ray cells near the cutting surface to make the tangential continuity of the wound phellogen with the original phellogen in the virgin bark. Virgin and renewed bark differed in proportion of soft and hard bark, amount and distribution of sclereids, tannin cells and crystals (Thomas *et al.*, 1995).

An attempt was made to manage TPD by removing the unproductive necrotic bark by making uniform tapping like cuts leaving the residual bark together with the cambium undisturbed. Debarked area was coated with a wound dressing compound. Residual bark together with cambium are instrumental in healing and bark regeneration process. Renewed bark was tapped after two years, and there was a continuous latex flow, which indicated that the bark regained productivity. Bark samples were collected and it was observed that the regenerated bark from the debarked area had an average of 13 rows of latex vessels within the soft bark while TPD affected area on rest showed only 6 rows of latex vessels. As a result of debarking, the cambial activity was enhanced resulting in the production of more soft bark in the debarked area, while the cambium beneath the dry 'intact bark' was more or less passive. Another advantage of debarking was that the new derivatives of cambium were easily pushed towards the outside while this activity is retarded by the presence of dry bark (Thomas *et al.*, 1998).

Anatomical parameters identified for screening clones against *Phytophthora* leaf fall disease are frequency of petiolar stomata and stomatal aperture index (Premakumari *et al.*, 1988). Differences in the properties of soft bast and proportion of latex vessel rows in the soft bast are also considered as parameters for drought tolerance (Premakumari *et al.*, 1993). Occurrence of an internal core of xylem (intraxylary phloem) in *Hevea* was identified and its influence on girth increment on tapping and thereby resistance to tapping stress was established (Premakumari *et al.*, 1985, Premakumari and Panikkar 1988). Laticifer area index was also observed to be a good indication for early selection of clones having low summer yield (Premakumari, 1992).

Wood anatomical studies were initiated in relation to drought stress. The xylem vessel dimensions of selected *Hevea* clones grown under two agroclimates were compared and certain xylem components related to water translocation were identified. A significant reduction in vessel element length was observed in clones grown under drought condition (Meenakumari *et al.*, 1998). Mean vessel diameter was significantly more for the clones having high girth and it showed significant clonal differences also.

OTHER BREEDING APPROACHES

For generating genetic variability, mutation and polyploidy had been induced in certain clones by chemical and physical means. The tetraploid cytotypes of three clones viz. RRII 105, RRII 116 and PR 107 were produced and they have the chromosome number $2n = 4x = 72$ (Saraswathyamma *et al.*, 1984, Sankariammal and Saraswathyamma 2001). An induced triploid ($2n = 3x= 54$) was produced by crossing diploid with induced tetraploid (Saraswathyamma *et al.*, 1980). A spontaneous triploid (RRII 15) was also identified (Nazeer and Saraswathyamma, 1987). The tetraploids are better yielders than the triploids. Among the mutagen induced plants two clones viz. RRII 50 and RRII 51 were identified as high yielders (Saraswathyamma and Marattukalam, 1996) and they are in the large scale trials for evaluation. The newly evolved cytotypes enrich the genetic reservoir of *Hevea*. There are some clones viz. Ch 2, RRII 35, GT 1 and SCATC 93-114 which are identified as male sterile clones. In RRII 17 both male and female sterility were observed (Saraswathyamma, 1990). The male sterile clones having good fruit set can be utilized for hybrid seed production.

A morphological variant having compact canopy had been identified and confirmed that it is a genetic variant (Markose *et al.*, 1982). The progenies of the variant are being incorporated in the hybridization programme for evolving clones having good yield and compact canopy, which may reduce wind damage and increase planting density. Morphological characterization of 32 clones under recommendation was completed (Mercykutty *et al.*, 2002b). The publication on 'Identification of *Hevea* clones' is a useful guide for extension officers, estate managers, planters, nursery owners, small growers, scientists and researchers.

POLYCROSS BREEDING

The polycross breeding approach was revived during the last decade, in view of the dangers of monoculture in rubber. This approach aims at evolving superior seed material for planting and also for generating superior base populations of seedlings for the selection and cloning of elite individuals, which could be released as primary clones. Prepotency, which is the ability of a parent clone to produce superior progeny even under open pollination, is a prerequisite for the polycross breeding approach. Seedling progeny analysis of 32 popular clones at the RRII, has led to the identification of 13 prepotent parents viz. PB 255, RRII 203, RRII 105, GT 1, PB 260, PB 28/83, PB 217, AVT 73, PB 242, Ch 26, PB 215, PB 252 and PB 5/51 (Mydin *et al.*, 1992, 2002). These have been utilized as components of new polyclonal seed gardens laid out with the purpose of generating good quality polyclonal seeds of improved parentage. The prepotent parents have also been utilized in biparental crossing programmes at the Rubber Research Institute of India. Clonal selection from among progenies of prepotent clones has shown scope for a high recovery of superior clones. In the first year of tapping, 50 superior clones with yield improvement over RRII 105 have been identified among the polycross progenies from prepotent parents. Observations on the promising progenies are being continued for confirming superior traits of the selections.

REDUCTION IN BREEDING AND SELECTION CYCLE

Conventional breeding in a perennial tree like rubber is long and elaborate, which requires about 30-35 years from generating hybrid seedlings up to the release of a clone. Evaluation of clones comprises four-phased selection through nursery, small scale, large scale and onfarm evaluation. Experiments are in progress in almost all the rubber growing countries to reduce the length of breeding and selection cycle. Selections are made based on nursery evaluation and small scale trials are laid out. Incorporating the selections from the small scale trials, large scale and on farm trials are also laid out in the same year by which the breeding cycle can be reduced to 25-30 years. Studies undertaken at RRII have shown that performance index at the age of two years is good enough for selection of clones at an early stage (Varghese *et al.*, 1993). A more reliable method of early evaluation was applied with success, in a hybrid clonal population where the trees were subjected to tapping at an age of four and a half years after field planting. Potential hybrid clones identified through evaluation in the immature phase were confirmed as promising while subjected to normal tapping in the mature phase (Licy *et al.*, 1997). The results suggested that potential clones identified in the immature phase in the small scale trial can go directly to the large scale trial by a possible reduction in the yield testing period by about 6-7 years.

Recent studies (Mydin *et al.*, 2002) have indicated that adoption of clonal nursery evaluation instead of small scale trials will also help in identifying precocious high yielders earlier, thus reducing the time span of the breeding procedure by five years. Early yield along with girth and number of latex vessel rows in the bark is a reliable selection criteria. There is significant correlation among early yield and number of latex vessel rows in the bark and mature yield. (Markose, 1984; Premakumari, 1992; Sethuraj, 1992). These parameters can be assessed in the

Figure 1. Scheme for evolving *Hevea* clones

Years	Steps involved			
1	Hybridization/ortet selection ↓			
3	Nursery evaluation & selection of 10% outstanding plants (first set) ↓	→	20% selections (second set) ↓	
4	Vegetative multiplication of selected plants ↓		Vegetative multiplication ↓	
5	Small scale trial ↓	→	20% clonal nursery evaluation with class I clone as check. ↓	
9	Test tapping at 20 cm height in 3 seasons : April, August, November Recording of reliable secondary attributes ↓		Test tapping at 20 cm height in 3 seasons: April, August, November. Recording of reliable secondary attributes ↓ Selection of promising clones ↓	
10	Selection of outstanding clones	→	Generation of budwood and its multiplication	
11	↓		↓	↓
12	Initiation of tapping ↓		Large scale trial in multi locations	On farm evaluation trial in multi locations
18	Recommendation in Category III ↓		↓ Initiation of tapping ↓	↓ Initiation of tapping ↓
20	Recommendation in Category II ↓		3 years yield ↓	3 years yield ↓
22	Recommendation to Category I based on 10 years yield		5 years yield	5 years yield
	Release of clones			

budgrafted plants at 3-4 years after planting. Evaluation of clones in comparison to clones recommended in Category I may enable further reduction of breeding cycle facilitating the release of clones by 22nd year after hand pollination. A scheme for the same is given in Figure 1.

BREEDING FOR BIOTIC AND ABIOTIC STRESS

In connection with screening clones for powdery mildew resistance 20 clones representing gene pools of diverse origin were established in a nursery employing RBD along with spreader rows of the susceptible clone PB 5/51. The plants were screened by visual scoring on a 0-5 scale at the peak time of the season. The disease intensity was evaluated and expressed as per cent disease intensity (PDI). Data for three years were analysed and stability of clones with respect to intensity of powdery mildew under varying weather conditions in different years was estimated. Eight clones, germplasm accessions *viz*, RRIC 52, AC/S 12 14/186, PR 261, RO/CM/10 44/7, RRIM 703, AC/S/12 40/59, PB 86 and IAN 45-873 possessing high degree of tolerance combined with stability in response to the disease reaction were identified (John *et al*., 2000) which renders potential for further breeding programme for tolerance to diseases. The result of field screening 25 clones of indigenous and exotic origin for four consecutive years when analysed for genotype x year interaction and stability of clones in terms of percent disease intensity (PDI) showed, six clones *viz*., SCATC 93-114, RRIM 703, Hai Ken 1, RRII 208, RRII 5 and PB 310 to be stable sources of resistance (John *et al*., 2001).

In view of the expansion of rubber cultivation to non-traditional areas, some of which are drought prone, a programme on breeding for drought tolerance, was initiated. Hybridization programmes involving drought tolerant parent clones were undertaken along with ortet selection from seedling stands in drought prone areas such as Dapchari in North Konkan. The hybridization programme involved crosses between 13 selected parents in 16 cross combinations. The resultant 1008 hybrid seedlings were in evaluation in the nursery for test tap yield, out of which 259 hybrids have been selected as promising high yielders. Among the selections, 150 hybrids have been cloned and planted in eight small scale trials for preliminary evaluation of their yield potential under optimum conditions in the traditional area. On detailed study of their anatomical and physiological parameters related to drought tolerance, promising selections will be identified for large scale testing in drought prone areas.

STUDIES ON PROPAGATION

A new type of budding called bench grafting was developed for rubber. This involves pulling out stock plants from nursery and budding them indoors. Budded plants are immediately planted in bags along with the polythene bandage. After the stipulated time the polythene bandage is removed and the buds are allowed to sprout and grow. Both green buds and brown buds can be used for bench grafting. Even though budding success was about 10% less, field performance of the bench grafted plants was comparable to nursery-grafted plants. The advantage of this method is that budding can be done even under circumstances such as rain, which hinders budding in nurseries (Marattukalam and Varghese, 1993 and

2000). Seeds stored at room temperature loses their viability rapidly (within 7 days). Storage of seeds under water was tried to over come this problem. Fresh seeds stored under ambient conditions in water gave 45% germination even after 20 days and growth of the seedlings was also comparable (Mercykutty *et al.*, 1996). It was observed that spraying of 1.0% hydrogen cyanamide with 25 g of rock phosphate (soil application) increased early sprouting and subsequent growth in polybags (Mercykutty *et al.*, 2002b). Experiments on young budding techniques are in progress. Field experiments on different propagation methods have elucidated that polybag plants show better growth than seed at stake plants and budded stumps in the field. Nicking of snag buds enhances the growth of scion. Stock scion studies indicated that high yielding clones like RRII 105 recorded higher yield and vigorous clones like RRII 118 and RRII 203 attained more vigour on different types of stocks.

INCORPORATION OF WILD GERMPLASM

In India, currently a total of 4548 wild germplasm accessions collected from the centre of origin are being conserved (Varghese *et al.*, 2002) along with 215 Wickham collections. Since the genetic base of cultivated *Hevea brasiliensis* is narrow, broadening genetic variability is very essential for further crop improvement. This can be attained only by crossing the Wickham material with promising wild accessions.

In India, this is being done on a regular basis. First attempt involving seven wild accessions has produced 43 clones. Two small scale trials were laid out in 1995. During the 6th year after planting 21 clones showed higher girth than the popular clone RRII 105 with standard heterosis ranging from 2.62 to 74.29%. Another set of nine superior accessions from wild germplasm was incorporated in hybridization programme with two popular Wickham clones RRII 105 and RRIM 600 and the resultant 400 hybrid seedlings from 14 cross combinations are under evaluation.

MOLECULAR APPROACHES

The perennial nature of *Hevea* and its long breeding and selection cycle make the conventional genetic analysis very difficult. Molecular markers like Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) and micro satellites are attractive tools in breeding programmes for better estimates of genetic value of clones. In a recent study (Varghese *et al.*, 1996, Venkatachalam *et al.*, 2002) the applicability of RAPD marker for genetic analysis of *Hevea* was evaluated in a set of 37 clones which facilitated identification of genetically divergent clusters based on genetic relationship. Among the different clones tested RRII 5, RRII 105, RRII 203, RRII 208, PB 28/59, PB 86, PB 217, PB 255, PB 311, PB 280, RRIC 100, SCATC 88-13 and KRS 25 displayed a mean genetic distance of above 0.50 indicating the possibility of exploiting hybrid vigour.

HEVEA BREEDING SUBSTATIONS

Two breeding substations have been established, one in Kanyakumari district of Tamil Nadu and the other in Dakshin Kannada District of Karnataka. Kanyakumari district of Tamil Nadu is characterized by a favourable climate conducive for rubber cultivation, noted for rare occurrence of *Phytophtora* diseases and good seed set. For hybridization programme two breeding orchards consisting of a total of 51 clones were established. By regular pruning and pollarding of branches, canopy of the clones are manipulated in such a way to facilitate easy access for hand pollinations. In order to identify clones suitable to the specific area 12 field experiments are in progress in different large estates viz., Arasu Rubber Coporation, Vaikundam estate, New Ambadi and Velimalai estate. The older clones showing very good performance in this region are PB 28/59, PB 86 and Tjir 1. Among the modern clones, the performance of RRII 105, PB 260, PB 217, and PB 235 is encouraging. The clone RRII 105 though susceptible to drought in terms of growth, yield is not much affected. To overcome some of the drawbacks of polybag planting a root trainer nursery system is being perfected where the materials are raised in special cup like containers, 'root trainers' made of polypropylene. (Soman and Saraswathyamma, 1999)

The mandate of *Hevea* breeding substation at Nettana in Dakshina Kannada is to identify clones suited to that location. Experiments on evaluation of cultivated clones, and parental clones, evaluation of prepotent clones, studies on exploitation system and disease management especially for *Corynespora* leaf fall are in progress. It has been observed that the growth of the trees is relatively slow especially in early years due to the exposure of plants to scorching sunlight during dry months (March – May). It was also observed that under natural conditions casualty occurred in RRII 105 and RRII 300 during third year of planting whereas PB clones PB 235, PB 255 and PB 311 showed high level of drought endurance (< 3% casualty). Among the clones under evaluation PB 235, RRII 118, RRII 203 recorded better growth than RRII 105. Early yield trend of clones showed PB 235 and PB 260 performing better followed by RRII 105 and PB 311. The incidence of *Corynespora* leaf fall disease was low in clones RRIM 600, GT 1, PB 311 and PB 216 moderate in PB 235, PB 260 and RRII 203. Very high incidence of disease is observed in RRII 105, PR 255 and PR 261. Natural seed set was seldom achieved due to the adverse influence of environment resulting in high rate of incidence of diseases.

Systematic breeding and selection have enabled to develop clones having a production potential of about 4000 kg per hectare per year. With a view to reducing the cost of production and generating an additional income, emphasis is being shifted to latex timber clones and clones with compact canopy. Multidisciplinary approaches in planning and implementing research projects are essential, which will ultimately lead to evolving clones suited to growers in estate as well as small holding sector. It is worthy to mention that high yield in a clone is definitely limited by biotic and abiotic stresses. In any biological system 'ideal type' is only a breeders fantasy, the same is the case in rubber also. But in rubber we have clones having high production potential along with above average tolerance to stresses, both biotic and abiotic. Promising clones having high yield along with desirable secondary attributes such as compact canopy, high volume of wood, above average tolerance to diseases and environmental stresses will reduce the cost of production.

We have evolved several promising clones having desirable secondary attributes. After ascertaining their long term performance, outstanding clones will be released to the growers in the near future.

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