Industrial Crops & Products 103 (2017) 195–201

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Fast track evaluation and selection of *Hevea brasiliensis* clones from a clonal nursery

T. Gireesh*, T. Meenakumari, Kavitha K. Mydin

Division of Botany, Rubber Research Institute of India, Kottayam 686 009, India

A R T I C L E I N F O

Keywords:
Hevea brasiliensis
Half-sibs
Rubber yield
Early evaluation
Shortening breeding cycle

A B S T R A C T

Ten female parents of natural rubber (*Hevea brasiliensis*), introduced from two Southeast Asian countries were allowed to natural cross breeding. After a primary culling of seedlings based on growth and test tap yield in juvenile stage, 20 half-sib (HS) progenies were cloned and evaluated in a clonal nursery trial (CNT) laid out (RCBD, plot size 6 with 3 replication) in a close spacing of 2.5 m × 2.5 m. Four established precocious high yielding clones (RRII 430, RRII 414, RRII 105 and PB 235) were included as control. Superior clones were identified based on the important agronomic traits *viz.*, growth, juvenile yield, tolerance to pink disease and bark thickness within a short span of five years, instead of fifteen years in conventional small scale trials (SST) with a wide spacing (4.9 m × 4.9 m). The results indicated that one of the half-sib progeny of mother clone PB 86 (HS PB 86/57) registered significantly ($P < 0.05$) superior dry rubber yield of 18 g per tree per tapping (g/t/t), and vigorous trunk girth (43 cm) at breast height in the 5th year after planting when compared to that of RRII 105 (11.9 g/t/t; 34.1 cm girth) and on par with RRII 430 (14.9 g/t/t; 31 cm girth) and RRII 414 (14 g/t/t; 38 cm girth), the best among the checks. The second best clone HS LCB 1320/30 also recorded comparable yield and growth with RRII 430 and was better than RRII 414. Three clones (HS PB 86/57, HS BD 5/27 and HS LCB 1320/30) could be selected based on the growth, yield and other secondary traits. None of the trees of HS PB 86/57showed incidence of pink disease and Tapping Panel Dryness (TPD) during field evaluation which deserves attention. The results support superior performance of new genotypes in CNT, saving time and space required to complete the breeding-evaluation cycle. Besides, these clones could be used as improved genetic stocks for initiating new breeding programmes to enrich the genetic base of natural rubber.

1. Introduction

The rubber tree, *Hevea brasiliensis* (Willd. ex Adr. Juss.) Muell. Arg., originated from the Amazonian rain forest, produces important natural polymer which meets most of the world's natural rubber requirements. Breeders achieved high productivity mainly through varietal improvement and fixation of elite genotypes by clonal propagation. Like in any other tree crop, *Hevea* breeding, selection and release of cultivars needs resources like land, labor and time (Tan, 1987; Simmonds, 1989). Wickham germplasm introduced to South East Asia forms the sole basis for the present day genetic resource in India. Evolving new cultivars with high yield potential and other favorable quantitative traits through recombination breeding is a priority area (Licy et al., 2003; Priyadarshan and Clement-Demange, 2004). Yield improvement in any base material requires continuous breeding and selection cycles (Licy et al., 1997). At present, developing improved clones for commercial cultivation through conventional breeding programme needs more than two decades. Often diversity of parents used in the breeding programme determines extent of hybrid vigour of subsequent progenies. Large number of distant crosses and family size is required to enhance recombination frequency and thereby higher variability and selection efficiency in F1 generation. Half-sib progeny selection approach is one of the options adopted in *Hevea* breeding, wherein population size determines the selection efficiency (Mydin, 2011). Relatively high rate of recovery of elite progenies from the half-sib progeny evaluation supports the importance of this approach which can be repeated over the years to consolidate productive seedlings (Gireesh and Pravitha, 2009). However, achieved field production of rubber so far remained low, against the theoretical yield of 7000–12,000 kg/ha (Paardekooper, 1989), mainly due to constraints like long breeding cycle and availability of land resources for laying out wide spaced multilocation trials.

The main objective for genetic improvement in *H. brasiliensis* is to increase the growth and rubber yield of tree using shortest breeding and selection cycles (Mydin et al., 2004). Conventionally, clone evaluation takes long time and involves multiple phases like Small Scale Trials

* Corresponding author.
E-mail address: tgiree@yahoo.com (T. Gireesh).

http://dx.doi.org/10.1016/j.indcrop.2017.04.001
Received 9 November 2016; Received in revised form 31 March 2017; Accepted 1 April 2017

Table 1
Details of female parents and its origin.

Female parents of half-sibs	Details of mother clones and its origin#	Primary selections: [number of progeny clones with clone identity]
BD 5	Primary clone of Indonesia (Bodjong Datar, Java), parents unknown	**2** [HS BD 5/27; HS BD 5/47]
BD 10	Primary clone of Indonesia (Bodjong Datar Java), parents unknown	**1** [HS BD 10/10]
LCB 1320	Primary clone of Indonesia (s' Lands Caoutchouc Bedrijven, Java), parents unknown	**3** [HS LCB 1320/28; HS LCB 1320/30; HS LCB 1320/51]
GT 1	Popular primary clone of Indonesia (Godang Tapen), parents unknown widely cultivated in almost all rubber growing countries	**2** [HS GT 1/26; GT HS 1/56]
PB 86	Primary clone of Malaysia (Prang Besar), parents unknown	**2** [HS PB 86/23; HS PB 86/57]
Ch 32	Inbred (BR 2 × BR 2) clone of Malaysia (Chemara)	**1** [HS Ch 32/5]
Ch 153	Hybrid (Tjir 1 × Ch 5) clone of Malaysia (Chemara)	**2** [HS Ch 153/8; HS Ch 153/33]
PB 230	Primary clone of Malaysia (Prang Besar), parents unknown	**3** [HS PB 230/6; HS PB 230/22; HS PB 230/29]
PB 5/60	Hybrid (PB 56 × PB 24) clone of Malaysia (Prang Besar)	**2** [HS PB 5/60/9; HS PB 5/60/39]
PB 235	Hybrid (PB 5/51 × PB 5/78) clone of Malaysia (Prang Besar)	**2** [HS PB 235/7; HS PB 235/25]
RRII 105*	Hybrid (Tjir 1 × Gl 1) clone of India (Rubber Research Institute of India) recommended for commercial cultivation since 1980	Check 1
RRII 414*	Hybrid (RRII 105 × RRIC 100) clone of India (Rubber Research Institute of India) recommended for commercial cultivation since 2005	Check 2
RRII 430*	Hybrid (RRII 105 × RRIC 100) clone of India (Rubber Research Institute of India) recommended for commercial cultivation since 2005	Check 3
PB 235*	Hybrid (PB 5/51 × PB 5/78) clone of Malaysia (Prang Besar)	Check 4
Total		20 + 4* = 24

*Used as controls in the field evaluation. #Paardekooper (1965); Ang (1982).

Table 2
Growth and secondary traits of clones.

	Clones	Girth (cm)								Bark Thickness (mm)	± SD	No. of Pink disease affected trees#	No. trees with TPD symptoms#
		Yr 3	± SD	Yr 4	± SD	Yr 5	± SD	Yr 6	± SD				
1	HS BD 10/10	21.7	± 1.6	27.8	± 3.1	29.6	± 3.9	34.1	4.9	4.9	0.8	4	4
2	HS LCB 1320/51	20.9	± 2.7	27.5	± 2.9	30.6	± 4.2	36.1	6.0	4.7	0.4	6	1
3	HS BD 5/27	21.6	± 2.0	28.8	± 2.9	32.3	± 3.5	38.8	5.1	5.2	0.5	2	2
4	HS PB 86/57	22.5	± 2.6	29.5	± 5.0	33.7	± 6.6	42.6	5.9	6.1	0.2	0	0
5	HS Ch 153/33	22.9	± 2.8	29.0	± 3.6	30.6	± 5.1	33.7	6.6	4.9	0.3	6	3
6	HS GT 1/56	18.9	± 3.2	25.7	± 3.9	28.8	± 4.2	34.3	5.2	4.4	0.4	0	5
7	HS PB 230/29	16.1	± 3.5	22.3	± 5.1	24.9	± 6.5	31.0	8.0	4.8	0.5	2	1
8	HS PB 5/60/39	17.6	± 1.8	21.4	± 1.9	23.7	± 2.1	28.2	2.8	4.3	0.4	3	2
9	HS PB 230/6	20.9	± 4.1	29.2	± 4.3	32.2	± 5.0	37.5	6.4	5.2	0.5	2	5
10	HS Ch 153/8	18.7	± 2.3	26.0	± 3.0	28.6	± 3.5	33.2	4.4	4.7	0.5	3	5
11	HS PB 230/22	15.8	± 4.1	21.3	± 5.4	23.1	± 6.3	26.9	7.3	3.4	0.2	1	3
12	HS PB 5/60/9	18.6	± 2.6	25.1	± 3.1	28.7	± 4.0	34.5	5.3	5.0	0.9	3	1
13	HS LCB 1320/28	15.3	± 2.9	20.2	± 4.0	21.5	± 5.1	25.2	6.4	3.4	0.3	3	4
14	HS GT 1/26	17.9	± 4.5	23.6	± 5.1	26.4	± 6.1	31.3	7.7	3.8	0.4	3	3
15	HS LCB 1320/30	23.0	± 2.8	30.1	± 3.8	33.0	± 5.8	43.3	6.6	5.2	1.1	3	4
16	HS BD 5/47	17.5	± 3.1	24.0	± 4.2	26.5	± 3.8	32.6	4.0	4.6	0.4	4	5
17	HS Ch 32/5	17.7	± 2.6	23.7	± 3.5	28.3	± 4.9	35.0	6.7	5.0	0.4	2	5
18	HS PB 86/23	21.2	± 1.5	27.3	± 2.2	30.0	± 2.8	33.3	3.9	5.0	0.6	4	2
19	HS PB 235/7	16.1	± 5.1	20.7	± 6.0	23.0	± 7.1	31.4	8.5	4.2	0.2	3	4
20	HS PB 235/25	20.9	± 1.7	30.1	± 2.5	33.5	± 3.7	39.4	5.3	5.1	0.3	4	2
21	RRII 430*	19.4	± 2.3	25.8	± 3.3	27.1	± 3.8	30.6	4.5	4.6	0.5	1	3
22	RRII 414*	19.4	± 2.5	28.0	± 4.6	31.5	± 6.3	38.1	8.5	4.9	0.3	4	0
23	RRII 105*	19.1	± 2.4	24.7	± 3.3	27.8	± 5.5	34.1	7.3	5.0	0.4	3	2
24	PB 235*	19.5	± 2.7	26.2	± 2.9	29.7	± 4.6	36.7	6.6	5.0	0.5	4	1
	CV	7.0	–	6.7	–	6.7	–	9.3	–	8.5	–	–	–
	SE	1.1	–	1.4	–	1.6	–	2.6	–	0.3	–	–	–
	CD ($p < 0.05$)	2.2	–	2.9	–	3.2	–	5.2	–	0.7	–	–	–

*Used as controls in the field evaluation; SD: Standard Deviation; CV: Coefficient of Variation; SE: Standard Error; CD: Critical Difference ($p < 0.05$) in ANOVA; #n = 18 for each treatment.

(SSTs), Large Scale Trials (LSTs) and On Farm Trials (OFTs) in which each stage require about 15–20 years and exhaust valuable resources before commercial release of a cultivar (Chandrasekhar et al., 2007). Weak correlations between juvenile-mature phases, perennial nature and time taken (nearly 6–7 years) for maturation of main trunk of the rubber tree for profitable exploitation of latex are major impediments in early identification of elite clones. Bombonato et al. (2016) illustrated that the reliability in the selection of most productive ortets selected in nursery stage will originate more productive clones. At present small scale evaluation trials need more than 15 years, with statistical limitation of inclusion of few test genotypes in fully replicated trials. Mydin et al. in 2004; Sankariammal and Mydin (2010) attempted juvenile clone evaluation with fairly good correlation with mature phase. In order to bring out precocious productive clones, breeding cycle needs to be shortened further. Therefore, it is very important to optimize the evaluation method in the selection of *Hevea* cultivars. In the present investigation, we explore the possibility of fast tracking the breeding cycle and challenging 20 test clones originated as half-sibs, from mother trees introduced from Indonesia and Malaysia with precocious proven check clones by employing a clonal nursery

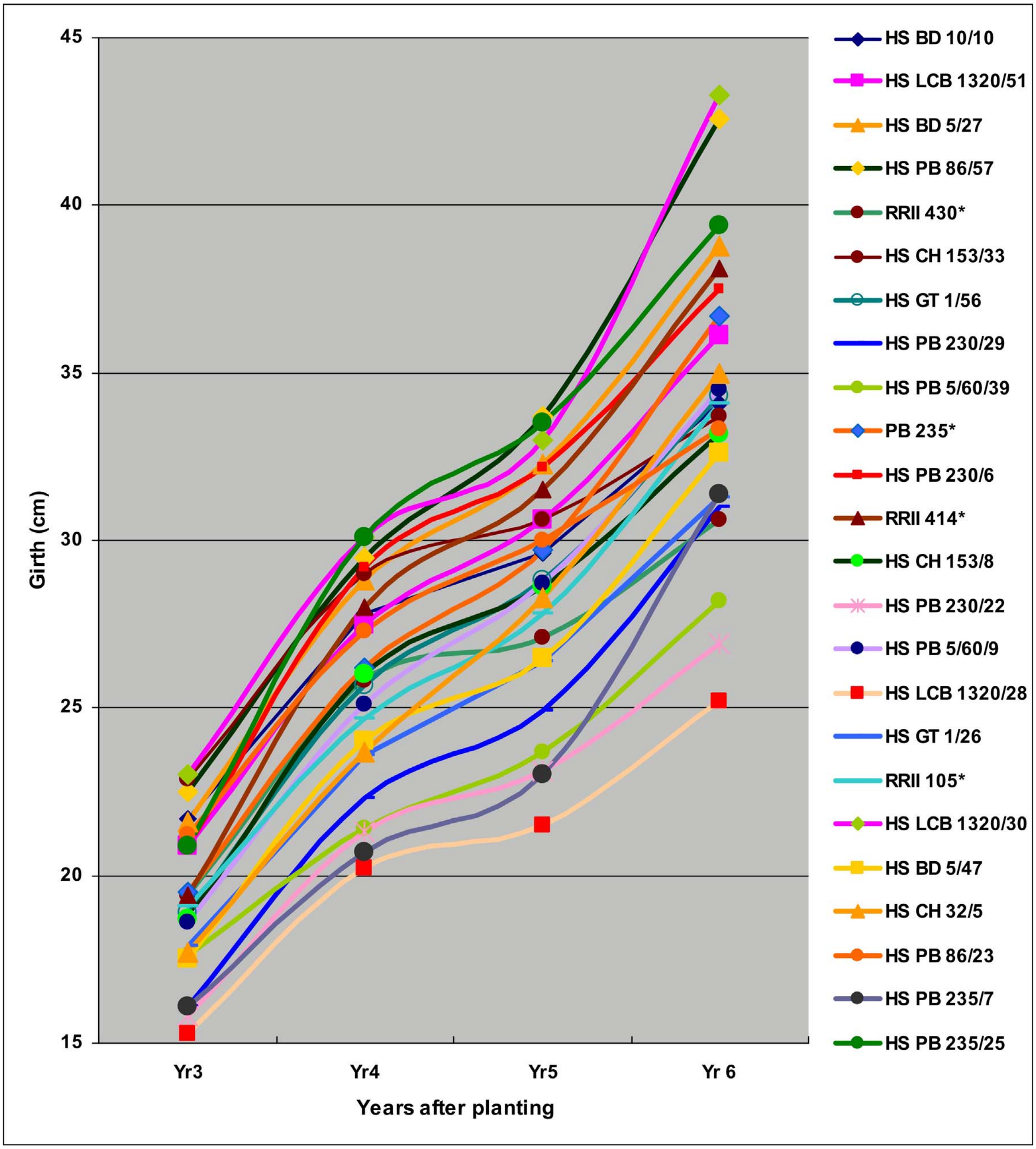

Fig. 1. Growth curve of clones.*Used as controls in the field evaluation.

approach.

2. Materials and methods

2.1. Location and plant material

The study was conducted at Rubber Research Institute of India (RRII) in Kottayam District (Latitude 9 °34′ 33.24″ N, Longitude 76°34′18.57″ E; Altitude 60–68 m) of Southern India. Climatic zone is wet humid with above average rain fall ranging from 3000 to 4000 mm; temperature ranged from 18.4 to 35.5 °C (average: 27.0 °C); and wind speed was 0–9 km/hr as recorded in the RRII meteorology station. The planting materials consisted of twenty genotypes selected from half-sib seedling progenies based on test tap rubber yield at the age of two years in the nursery. The mother trees from which the half-sibs were raised were introduced from secondary centre of origin and planted in the germplasm bank of Rubber Research Institute of India (Mydin, 1992). Four high yielding clones *viz.*, RRII 105, RRII 414, RRII 430 and PB 235 were planted as control in the present experiment for comparison. Origin and details of female parents from where half-sib seeds were collected is illustrated in Table 1. Scions of twenty test clones and four check clones were brown budded onto rootstock of 12 months growth raised in a ground nursery. After successful bud grafting, stumps were uprooted and replanted in polythene bags of lay flat size 55 cm × 25 cm filled with top soil and raised in a nursery. Six month-old plants were transplanted in the field during July 2007 in blocks adopting randomized complete block design with plot size of six plants with three replications with a close spacing of 2.5 m × 2.5 m. Recommended crop management practices were performed at appropriate time periods throughout the experiment (Punnoose and Lakshmanan, 2000).

Table 3
Seasonal yield pattern.

Clones		Test tap yield (g/t/t)										Mean# over all seasons (g/t/t)
		Yr 3 (2010 – 11)				Yr 4 (2011 – 12)				Yr 5 (2012 – 13)		
		Peak	Lean	Mean	± SD	Peak	Lean	Mean	± SD	Peak	± SD	
1	HS BD 10/10	9.0	9.4	9.2	± 2.0	14.2	4.8	9.5	± 1.6	12.6	± 3.7	10.0^{bcdefg}
2	HS LCB 1320/51	7.0	6.5	6.8	± 1.8	11.6	4.1	7.8	± 3.1	14.9	± 3.7	8.8^{bcdefg}
3	**HS BD 5/27**	11.1	9.0	10.1	± 2.7	19.9	8.7	14.3	± 3.4	23.1	± 5.0	**14.4^{ab}**
4	**HS PB 86/57**	12.0	17.4	14.7	± 2.7	19.9	11.4	15.7	± 4.7	27.8	± 6.8	**17.7^{a}**
5	HS Ch 153/33	5.3	6.9	6.1	± 1.3	10.4	4.2	7.3	± 1.8	8.7	± 4.2	7.1^{cdefg}
6	**HS GT 1/56**	11.6	10.6	11.1	± 3.3	19.3	8.6	14.0	± 3.0	19.3	± 3.4	**13.9^{abc}**
7	HS PB 230/29	4.2	5.0	4.6	± 1.0	4.6	2.0	3.3	± 0.8	7.5	± 3.2	4.7^{g}
8	HS PB 5/60/39	6.4	6.1	6.3	± 1.7	10.7	3.8	7.2	± 2.7	14.7	± 3.5	8.3^{bcdefg}
9	HS PB 230/6	7.9	12.3	10.1	± 1.8	16.9	6.4	11.6	± 3.3	15.3	± 5.3	11.7^{abcdef}
10	HS Ch 153/8	6.6	9.5	8.0	± 1.6	11.3	5.5	8.4	± 2.4	11.4	± 2.3	8.9^{bcdefg}
11	HS PB 230/22	6.4	4.9	5.6	± 1.4	7.5	2.1	4.8	± 1.4	8.3	± 4.3	5.8^{efg}
12	HS PB 5/60/9	8.1	10.4	9.2	± 2.1	16.1	5.4	10.7	± 3.1	18.1	± 2.9	$11.6^{abcdefg}$
13	HS LCB 1320/28	5.9	6.9	6.4	± 1.8	7.5	4.6	6.1	± 1.9	7.2	± 2.3	6.4^{defg}
14	HS GT 1/26	9.6	10.2	9.9	± 2.9	16.1	8.0	12.1	± 2.0	16.7	± 3.2	12.1^{abcde}
15	**HS LCB 1320/30**	8.6	12.8	10.7	± 2.4	20.2	5.3	12.8	± 4.4	22.6	± 7.2	**13.9^{abc}**
16	HS BD 5/47	4.9	5.5	5.2	± 1.4	8.3	3.9	6.1	± 1.6	9.8	± 2.1	6.5^{defg}
17	HS Ch 32/5	8.9	9.6	9.2	± 1.9	13.1	4.9	9.0	± 2.4	15.5	± 6.1	10.4^{bcdefg}
18	HS PB 86/23	8.1	11.9	10.0	± 2.4	11.6	5.8	8.7	± 2.7	13.5	± 4.2	10.2^{bcdefg}
19	HS PB 235/7	5.5	5.7	5.6	± 1.0	7.9	3.2	5.5	± 1.6	12.8	± 3.9	7.0^{cdefg}
20	HS PB 235/25	5.7	4.5	5.1	± 1.9	5.2	2.7	3.9	± 1.5	7.4	± 2.5	5.1^{fg}
21	RRII 430*	12.1	14.7	13.4	± 3.4	23.0	6.0	14.5	± 3.6	18.4	± 6.3	14.9^{ab}
22	RRII 414*	8.8	13.9	11.4	± 2.9	21.3	7.1	14.2	± 3.2	20.3	± 5.3	14.3^{ab}
23	RRII 105*	7.6	11.2	9.4	± 1.9	19.1	4.2	11.7	± 3.4	17.3	± 4.8	11.9^{abcdef}
24	PB 235*	9.8	12.5	11.2	± 2.3	21.5	4.9	13.2	± 4.9	16.8	± 4.5	13.1^{abcd}
	CV	21.7	29.4	24.0	–	26.0	41.7	25.9	–	27.7	–	21.3
	SE	1.4	2.3	1.7	–	3.0	1.8	2.0	–	3.4	–	1.8

*Used as controls in the field evaluation, SD: Standard Deviation; CV: Coefficient of Variation; SE: Standard Error; #Means followed by common letters are not significantly different ($p < 0.05$) based on Tukey's Honest Significant Difference test.

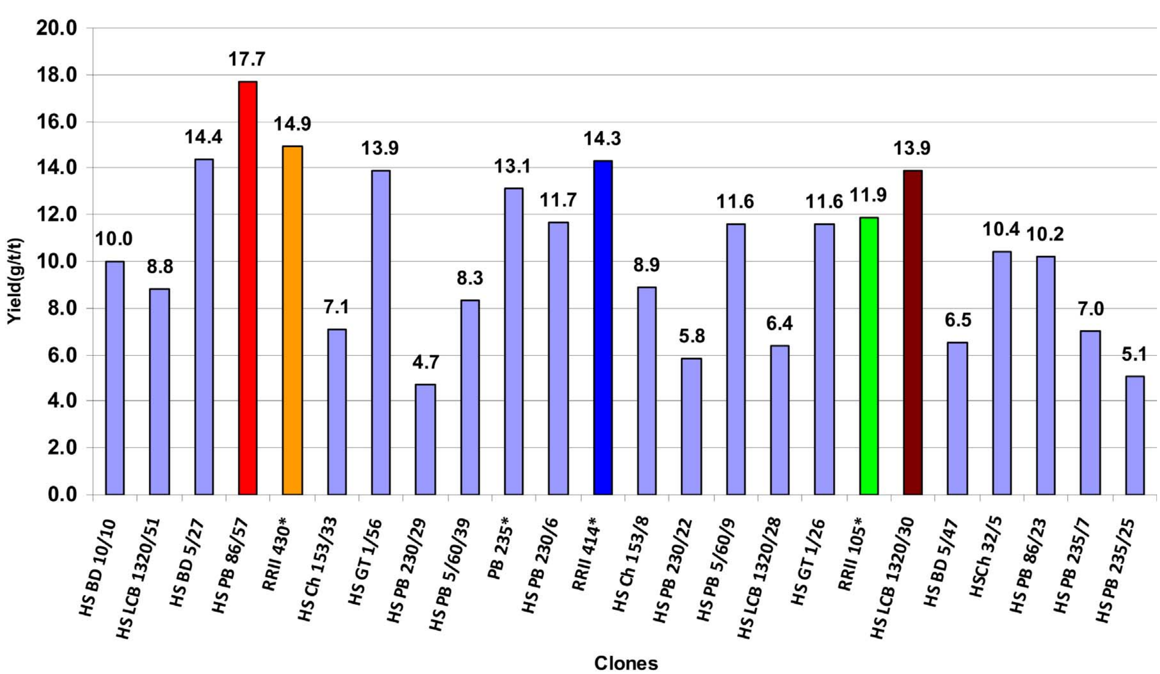

Fig. 2. Mean dry rubber yield over years.*Used as controls in the field evaluation.

2.2. Assessment of growth and rubber yield

Third year after field planting, girth (cm) at breast height (125 cm from the bud union) was measured annually. Guidelines for tapping was marked on the trunk using a miniature template 15 cm above the bud union and test tapping was done using modified Michie-Golledge tapping knife (Chandrasekhar and Gireesh, 2008). Tapping was done for three consecutive years from 3rd to 5th year after planting in two seasons (peak: October to January; lean: February to May) of each year. S/2 d3 6d/7 system (Vijayakumar et al., 2009) of tapping was followed without stimulation. Latex collected after each tapping was coagulated using formic acid (3%, v/v) in the collection cups and cup lumps kept for dry weight determination. After drying, weight of the samples were recorded and expressed as grams per tree per tapping (g/t/t). Bark

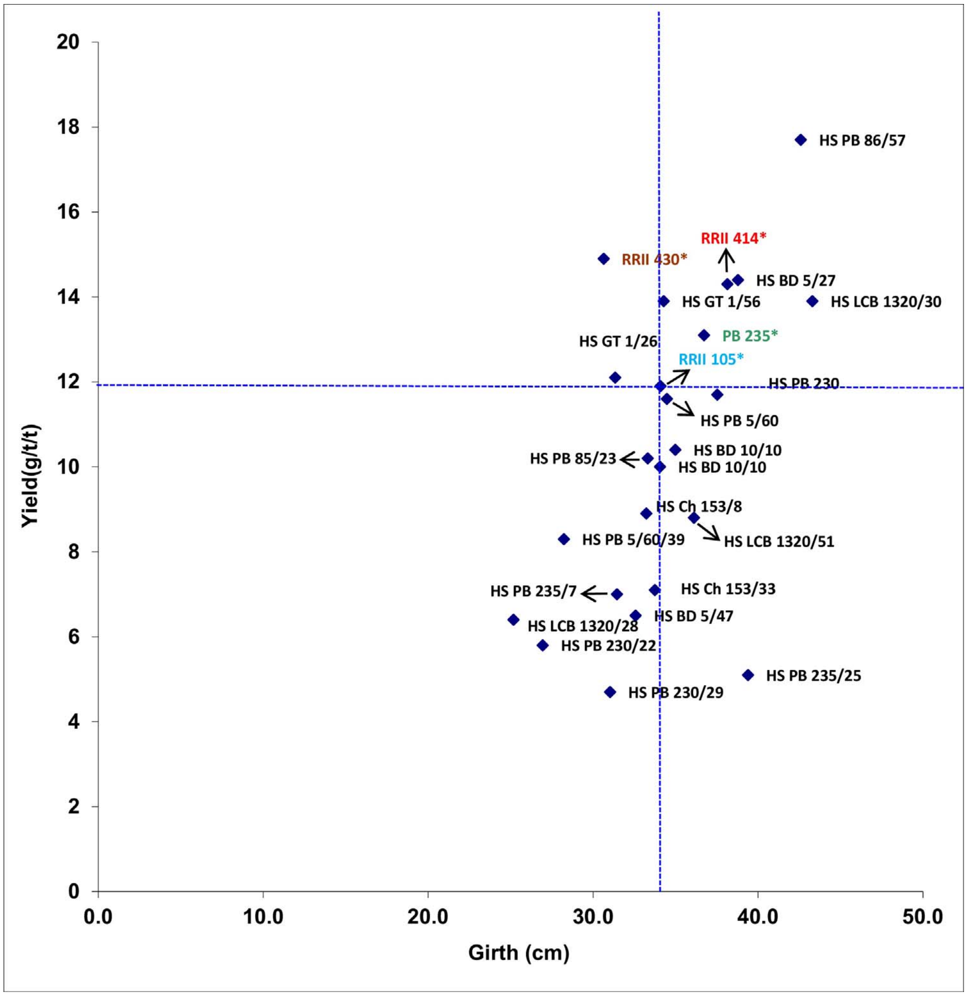

Fig. 3. Girth versus yield of clones.*Check clones; (———) mean values based on most adopted clone RRII 105.

thickness (mm) at breast height of trees were measured using bark gauge and visual scoring was done for incidence of pink disease. Incidence of Tapping Panel Dryness (TPD) was scored during tapping. The data from experiment was collected and effects of different variables were determined using analysis of variance (Microsoft Excel 2010). All comparisons were based on plot means, and standard methods for statistical analysis of data were followed. Tukey analysis (SPSS 16.0) was done to ascertain whether the clones are differing from each other.

3. Results and discussion

The rubber tree produces seeds naturally through mixed mating system mainly through out-crossing. Initial selection of elite genotypes from the population based on growth and cloning of genotypes is a primary step in tree improvement. The present clonal trial was performed at 2.5 m × 2.5 m with almost half of the normal spacing (4.9 m × 4.9 m). Data on important agronomic traits showed significant clonal variability across genotypes, indicating ample scope for selection from the experimental population. Among the check clones, RRII 414 showed the highest girth (38 cm) by the 6th year of planting (Table 2). RRII 414 is noted for its high growth vigour leading to early tappability and high timber output (Mydin et al., 2011). Four test clones *viz.*, HS LCB 1320/30, HS PB 86/57, HS PB 235/25 and HS BD 5/27 showed better trunk girth than RRII 414, among which the girth of HS LCB 1320/30 was significantly superior to RRII 414 (Table 2; Fig. 1). Trunk growth is considered as one of the important selection parameters in rubber and the study on the growth is indispensable in realizing the fitness for a particular environmental condition (Hunt, 1982; Chandrasekhar et al., 1998). Early maturing clones are preferred by the growers to reduce the unproductive period and for early return of costs on maintenance of the trees. Farming with fast growing clones with high latex yield and timber production would result in early return from the plantation than the present day cultivars. The selections identified from the present study could be useful for reducing the imaturity period in rubber; as early tapping and high precocious yield from trees are important when the discounted cash flow and return on the investment is considered (Wycherley, 1969).

Latex is produced in specialized laticiferous tissues (latex vessels) of the bark of rubber tree. Functionally, as is the case with girth, bark thickness (BT) is a clonal character showing association with the number of productive latex vessels and thereby influencing latex yield (Gomez, 1982). With respect to BT the controls except RRII 430 recorded 5 mm thickness. HS PB 86/57 exhibited highest bark thickness of 6 mm, significantly superior to that of the check clones. The other high girthing clones (HS BD 5/27, HS PB230/16 and HS LCB 1320/30) also exhibited BT above 5 mm. Desirable secondary traits further enable component level selection of clones.

Clones HS PB 86/57 and HS GT1/56 were found tolerant towards pink disease (*Corticium salmonicolor* Berk. & Br.) while 5–27% trees of other clones were affected (Table 2). Clones tolerant to *C. salmonicolor* is important for commercial rubber growers of humid tropical areas as this causes destruction of main branches resulting in loss of canopy followed by retardation in growth, tappability and subsequent yield loss.

Among the check clones, RRII 430 recorded the highest test tap

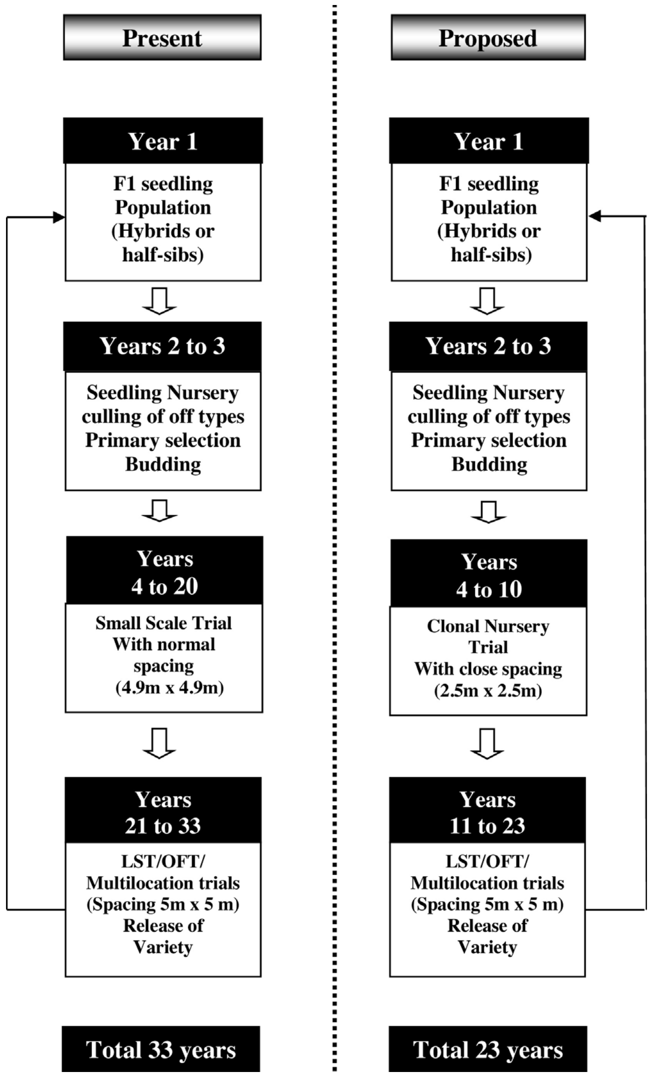

Fig. 4. Breeding cycle.Proposed breeding scheme of *H. brasiliensis* saves 10 years of evaluation period and land resources as the replicated clonal nursery trial can accommodate more test clones when compared to conventional breeding scheme, entire evaluation period takes 33 years right from the crossing to release of improved clones.

rubber yield of 15 g/t/t followed by RRII 414 (14 g/t/t). RRII 105 recorded relatively lower test tap rubber yield of 12 g/t/t and that of PB 235 yielded 13 g/t/t (Table 3, Fig. 2). The early yield of RRII 414 and RRII 430 was reported to be superior to that of RRII 105, and the present results are in conformity with earlier reports (Licy et al., 1998). Among the test clones, HS PB 86/57 was the best performer with the highest rubber yield of 17.7 g/t/t which is significantly superior to that of RRII 105 and PB 235, better than that of RRII 414 and on par with the highest yielding check clone RRII 430. Six clones recorded test tap yield comparable to RRII 430, of which HS BD 5/27 (14.4 g/t/t) followed by HS LCB 1320/30 and HS GT 1/56 (14 g/t/t each) were the second best performers in terms of dry rubber yield. The superiority of HS PB 86/57 over RRII 430 was more prominent in the lean period than the peak yielding season indicating ability to express latex production in stressful environment. HS PB 86/57 withstood the stress exerted by the seasonal test tapping. A low incidence of late dripping (5.5–16.6%) was noticed whereas none of the trees showed symptoms of Tapping Panel Dryness (TPD).

Clones with high girth and vigour during the initial years of planting with a high girth increment rate have the advantage of early tappability and thereby reduction in immaturity period, which is a boon for the small farmers who predominate the rubber sector. Hence the breeders' priority has shifted from identifying clones with high yield *per se* to clones combining high yield and vigorous growth from preliminary evaluation trials. Combined selection for girth and yield in early evaluation is practiced by rubber breeders (Gouvêa et al., 2013b).The precocity of RRII 400 series clones have already been reported (Mydin and Mecykutty, 2007). Two clones HS PB 86/57 and HS LCB 1320/30 showing high girth and yield was superior to that of all other test clones and controls (Fig. 3). The mother clones of these selections *viz.*, PB 86 and LCB 1320 which originated from secondary center of origin was introduced to India during 1956 (George, 2000) and are medium yielding clones. Stable yield of the half-sibs of these clones indicate possible introgression of genes from unknown male parent. The female parent, PB 86 is known for the tolerance to pink disease (Kothandaraman and Idicula, 2000). Majority of the test clones were clustered in the medium category in terms of both growth and yield. The two half-sibs derived from the mother parents GT 1 and the check clone RRII 430 occupied the high yielding quadrant with moderate growth. HS PB 235/25 could be identified from the high girth category but with relatively low yield. Close-spaced multilocation trials (Gouvêa et al., 2013a) are being used for selecting superior clones and estimating genetic parameters in Brazil. The present study discriminated low girthing and low yielders from the population when compared to check clones RRII 414 and RRII 430 proven for vigorous growth and high yield (Licy et al., 2003).

Proposed breeding scheme (Fig. 4) of *H. brasiliensis* saves 10 years of evaluation period and resources as the replicated clonal nursery trial can accommodate more test clones when compared to conventional breeding schemes, thus reducing the entire evaluation period from 33 years to 23 years. Therefore, by employing CNT approach breeding cycle of *Hevea* could well be shortened to 23 years.

4. Conclusions

We have selected clones with high trunk growth, early maturation, thicker bark and dry rubber yield and demonstrated shortened evaluation period to five years instead of fifteen years in a small scale clone trial which was practiced earlier. The results of the present study indicated that the half-sib progeny of mother clone PB 86 (HS PB 86/57) showed superior juvenile rubber yield of 18 g per tree per tapping (g/t/t) and attained girth of 43 cm which is better than that of RRII 105, the most popular variety, in the fifth year after planting, which is on par with highest yielding control clone RRII 430. Moreover, the performance of clone HS PB 86/57 was superior to that of clones like RRII 414 in terms of secondary traits like tolerance to pink disease and tapping panel dryness symptoms. Clones HS BD 5/27 and HS LCB 1320/30 could also be selected as the second best clones. Therefore, HS PB 86/57, HS BD 5/27 and HS LCB 1320/30 could be identified for further multi environmental/commercial evaluation. The proposed modified breeding scheme reduced the total breeding cycle by 10 years to circumvent the problem of high cost of field evaluation for development of new cultivars.

Acknowledgements

Authors would like to thank Director, RRII and Dr. Y. Annamma Varghese former Joint Director Crop Improvement for motivation, support and encouragements and all those who directly or indirectly supported for managing the trial. Meteorological data provided by Dr. Shammi Raj, Scientist and help rendered by Mr. P. Aneesh, Assistant statistician is also gratefully acknowledged. We owe to the Rubber Board of India for financial assistance.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.indcrop.2017.04.001.

References

Ang, B.B., 1982. Prang besar rubber cultivars. Recommended Prang Besar Rubber Cultivars. Harrisons Malayalam Plantation, Berhad.

Bombonato, A.L., Gouvea, L.R.L., Verardi, C.K., Silva, G.A.P., Gonclaves, P.D.S., 2016. Rubber tree ortet-ramet genetic correlation and early selection efficiency to reduce rubber tree breeding cycle. Ind. Crop. Prod. 77, 855–860.

Chandrasekhar, T.R., Gireesh, T., 2008. Latex as yield may be better than rubber yield in juvenile screening for selection in rubber (*Hevea brasiliensis* Muell. Arg.). J. Rub. Res. 11 (1), 52–58.

Chandrasekhar, T.R., Nazeer, M.A., Marattukalam, J.G., Prakash, G.P., Annamalainathan, K., Thomas, J., 1998. An analysis of growth and drought tolerance in rubber during the immature phase in a dry subhumid climate. Exp. Agric. 34, 287–300.

Chandrasekhar, T.R., Marattukalam, J.G., Mercykutty, V.C., Priyadarshan, P.M., 2007. Age of yield stabilization and its implications for optimising selection and shortening breeding cycle in rubber (*Hevea brasiliensis* Muell. Arg.). Euphytica 156, 67–75.

George, P.J., 2000. Germplasm resources. In: George, P.J., Jacob, C.K. (Eds.), Natural Rubber Agromanagement and Crop Processing. Rubber Research Institute of India, Kottayam, pp. 47–58.

Gireesh, T., Pravitha, M., 2009. Juvenile selection in progenies from controlled pollinations of new generation clones of *Hevea brasiliensis*. Nat. Rub. Res. 22 (1 & 2), 81–92.

Gomez, J.B., 1982. Anatomy of Hevea and Its Influence on Latex Production. Malaysian Rubber Reseach and Development Board, Kuala Lumpur, pp. 75.

Gouvêa, L.R.L., Silva, G.A.P., Verardi, C.K., de Oliveira, A.L.B., Goncalves, E.C.P., Scaloppi-Junior, E.J., de Moraes, M.L.T., de Souza Goncalves, P., 2013a. Rubber tree early selection for yield stability in time and among locations. Euphytica 191 (3), 365–373.

Gouvêa, L.R.L., Silva, G.A.P., Verardi, C.K., Oliveira, A.L.B., de Souza Goncalves, P., 2013b. Simultaneous selection of rubber yield and girth growth in young rubber trees. Ind. Crop. Prod. 50, 39–43.

Hunt, R., 1982. Plant Growth Curves, the Functional Approach to Plant Growth Analysis. Edward Arnold, London.

Kothandaraman, R., Idicula, S.P., 2000. Stem diseases. In: George, P.J., Jacob, C.K. (Eds.), Natural Rubber Agromanagement and Crop Processing. Rubber Research Institute of India, India, pp. 129–148.

Licy, J., Saraswathyamma, C.K., Varghese, Y.A., Premakumari, D., Sethuraj, M.R., 1997. Developments in breeding work to produce high yielding resistant and fast growing clones in India. In: Seminar on Modernizing the Rubber Small Holding Sector. Pedang, Indonesia. .

Licy, J., Panikkar, A.O.N., Premakumari, D., Saraswathyamma, C.K., Nazeer, M.A., Sethuraj, M.R., 1998. Genetic parameters and heterosis in rubber (*Hevea brasiliensis*) Muell Arg. 4. In: Mathew, N.M., Jacob, C.K. (Eds.), Early Versus Mature Performance of Hybrid Clones. Development in Plantation Crops Research. Allied Publishers Limited, New Delhi, pp. 9–15.

Licy, J., Saraswathyamma, C.K., Premakumari, D., Meenakumari, T., Meenattoor, J.R., Nazeer, M.A., 2003. Genetic parameters and heterosis in rubber (*Hevea brasiliensis*) Muell. Arg. V. Hybrid vigour for yield and yield components among the RRII 400 series clones in small scale evaluation. Indian J. Nat. Rub. Res. 16 (1 & 2), 75–80.

Mydin, K.K., Mecykutty, V.C., 2007. High yield and precocity in the RRII 400 series hybrid clones of rubber. Nat. Rub. Res. 20 (1 & 2), 39–49.

Mydin, K.K., Licy, J., Varghese, Y.A., John, A., Nair, R.B., Saraswathyamma, C.K., 2004. Clonal nursery evaluation for shortening the breeding cycle in *Hevea brasiliensis*. Nat. Rub. Res. 17 (1), 60–66.

Mydin, K.K., 1992. Genetic Divergence, Prepotency and Inbreeding Depression in Para Rubber (*Hevea brasiliensis* Muell. Arg.) PhD Thesis. Kerala Agriculture Universitypp. 59.

Mydin, K.K., 2011. Polycross breeding towards evolving genetically diverse *Hevea* clones for sustainability. In: IRRDB International Rubber Conference 2011. Chiag Mai, Thailand. .

Mydin, K.K., Thomas, V., Mercykutty, V.C., 2011. Yield and related attributes of certain new generation clones of *Hevea brasiliensis* under large scale evaluation. J. Rub. Res.Inst. Malay 14 (3), 167–183.

Paardekooper, E.C., 1965. Planting Manual No. 11. Rubber Research Institute of Malayapp. 30–47.

Paardekooper, E.C., 1989. Rubber. In: Webster, C., Baulkwill, W.J. (Eds.), Longman Scientific and Technical, England, pp. 349–414.

Priyadarshan, P.M., Clement-Demange, A., 2004. Breeding *Hevea* rubber: formal and molecular genetics. Adv. Genet. 52, 51–115.

Punnoose, K.I., Lakshmanan, R., 2000. Nursery and field establishment. In: George, P.J., Jacob, C.K. (Eds.), Natural Rubber Agromanagement and Crop Processing. Rubber Research Institute of India, India, pp. 129–148.

Sankariammal, L., Mydin, K.K., 2010. Clonal nursery evaluation of wickham x amazonian hybrids in rubber (*Hevea brasiliensis*) willd. ex adr. de juss. muell. Arg.). In: National Conference on Developmental Biology-NACON D Bio 2010, September 15–17, IISc. Bangalore, India. .

Simmonds, N.W., 1989. Rubber breeding. In: Webster, C.C., Baulkwill, W.J. (Eds.), Rubber. Longman Scientific and Technical, England, pp. 85–124.

Tan, H., 1987. Strategies in rubber tree breeding. In: Abbott, A.T., Atkin, R.K. (Eds.), Improving Vegetatively Propagated Crops. Academic Press London, pp, pp. 28–54.

Vijayakumar, K.R., Gohet, E., Thomas, K.U., Xiaodi, W., Sumarmadji Rodrigo, L., Thanh, D.K., Sopchoke, P., Karunaichami, K., Said, M.A.M., 2009. Special communication: Revised international notation for latex harvest technology. J. Rubb. Res 12 (3), 103–115.

Wycherley, P.R., 1969. Breeding of *Hevea*. J. Rub. Res. Inst. Malay. 21, 38–55.