NEW GENERATION CLONES WITH HIGH RUBBER AND TIMBER YIELD EVOLVED FROM THE 1986 HYBRIDISATION IN INDIA

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Progenies of the 1986 hybridisation programme comprising 147 hybrid clones evolved by crossing 17 parents in 33 cross combinations were evaluated in four small scale trials at the Central Experiment Station of the Rubber Research Institute of India. The variability for yield, yield components, timber and growth traits was studied over the immaturity period and the early mature phase. Heterosis of the hybrid clones for yield, girth and bole volume was estimated. The family-wise performance for important traits as well as the clonal performances compared to the 15 parental clones were studied. Estimates of heterosis for yield ranged from 2.4 to 91.5 per cent, girth from 2.3 to 23.8 per cent and bole volume from 5.3 to 94.7 per cent. The family RRII 105 x RRII 118 produced the largest number of heterotic hybrids for rubber yield and girth while the family PB 5/51 x RRII 208 gave large number of heterotic hybrids for bole volume, girth and yield. The study identified six clones *viz*. 86/111, 86/117, 86/122, 86/428, 86/613 and 86/597 as the top most latex yielders and seven clones *viz*. 86/59, 86/468, 86/64, 86/597, 86/522, 86/61 and 86/428 as the top most timber yielders while clones 86/111, 86/428, 86/597, 86/64, 86/599, 86/99, 86/787, 86/59 and 86/79 were latex timber clones in the order of superiority in performance. The present study also confirms the superiority of clones RRII 203, PB 235 and RRII 118 for rubber yield and RRIC 52, RRII 203 and RRII 118 in terms of rubber yield, girth and timber volume.

Key words: *Hevea brasiliensis*, Heterosis, Hybridisation, Latex timber clones

INTRODUCTION

The para rubber tree, *Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg. has been accounted as the most important source of natural rubber (NR). Performance of NR in India has been remarkable and the increase in production could be attributed to the growth in yield which experienced almost three fold increase during the last decade. Sustained productivity is the foundation stone of successful plantation and the productivity of NR plantation could be maximised by the optimum utilization of better environment for growth by adoption of good agronomic practices and use of genetically improved clones (Attanayaka, 1998). Thus, genetic improvement plays an important role in improving the yield potential of the crop and there by enhancing productivity of the genotype.

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The first step in crop improvement is creating a population which contains sufficient variation in the important traits. The variation is evolved naturally through open pollination or artificially through hybridisation and more variation lead to more efficacy of selection. Genetic improvement in *Hevea* is mainly through hybridisation and clonal selection. Controlled hybridisation between selected parent clones, evaluation of F1 hybrids and selection of promising recombinants for commercial planting has been the most important method of developing clones of desirable genetic constitution in NR. In India, breeding work was initiated with the inception of RRII in 1954 and a large number of progenies were evolved and evaluated to identify potential recombinants. The early hybridisation programme spanning 25 years from 1954 resulted in the RRII 100, 200 and 300 series of clones (Nair and George, 1968; George *et al*., 1980; Saraswathyamma *et al.,* 1990; Premakumari *et al*., 1984). Among the clones of RRII 100 series, RRII 105 is a highly successful clone in terms of realized and potential yield. Clones RRII 203, RRII 208, RRII 300 and RRII 308 are selections from the 200 and 300 series, respectively.

The post 1980 hybridisation programmes involved crosses among modern clones which were selected on the basis of yield, secondary attributes and yield components. The most recent RRII 400 series from a set of 23 hybrid clones of cross combination RRII 105 x RRIC 100 were evolved from the 1982 hybridisation programme (Licy *et al*., 2003; Mydin *et al*., 2011). Of these four clones *viz*. RRII 414, RRII 430, RRII 417 and RRII 422 were released for commercial planting during 2005 and 2009. Subsequently, small scale evaluation of 110 hybrid clones developed by the 1983 hybridisation programme involving six cross combinations resulted in identification of 11 promising selections (John *et al*., 2012) which are under advanced stages of evaluation. The present study pertains to the growth and yield performance of a set of 147 clones derived from 1986 hybridisation programme involving 17 parental clones in 33 cross combinations in four small scale trials with the objective of estimating the extent of genetic variability for yield and major yield components and to select clones showing high yield in terms of latex and timber and desirable growth attributes in comparison with popular check clones.

MATERIALS AND METHODS

The 1986 Hybridisation programme

The base material comprised of 1394 seedlings belonging to 56 cross combinations obtained during 1986 hybridisation programme. Seedlings were subjected to preliminary screening for yield and growth attributes following test incision method at the age of one year (Annamma *et al*., 1989). Based on juvenile yield and other growth characters, selected hybrids were cloned for further evaluations in small scale trials during 1989, 1990 and 1992. Out of the total 340 hybrids finally selected, 147 hybrids involving 33 cross combinations among 17 parents were cloned for further evaluation in four small scale trials during 1989. There were 10 cross combinations with RRII 105 as female parent with various male parents. Two cross combinations involved RRII 203 as female parent while six cross combinations had RRIM 600 as female parent. PB clones (PB 5/51, PB 86 and PB 242) were employed as female parent in three cross combinations each. The Brazilian clone IAN 47-873 was the female parent in four cross combinations while Gl 1 was female parent in two cross combinations. Thus a diversity of clones

Table 1. **Details of hybrid clones evaluated in different trials**

Sl. No.	Pedigree	Trial 1 Clones	Trial 2 Clones	Trial 3 Clones	Trial 4 Clones
1	RRII 105 x PR 107	86/25, 86/34, 86/35, 86/36	86/27, 86/32		
2	RRII 105 x RRII 118	86/110, 86/120, 86/121	86/111, 86/117, 86/122, 86/426	86/424, 86/428	86/109
3	RRII 105 x PB 217	86/147, 86/157	86/151, 86/152, 86/155, 86/156		
4	RRII 105 x RRII 208	86/178, 86/304	86/174, 86/300, 86/302, 86/306	86/185	86/179, 86/188, 86/191
5	RRII 105 x PB 5/51	86/660	86/77, 86/79, 86/89, 86/373	86/922	
6	RRII 105 x PB 86	86/211, 86/962			86/400
7	RRII 105 x RRII 203	86/651		86/650	
8	RRII 105 x RRIC 52		86/734		86/718,86/ 727
9	RRII 105 x PB 252		86/576		
10	RRII 105 x IAN 873			86/778	
11	RRII 203 x PB 5/51	86/602, 86/607, 86/613	86/604		
12	RRII 203 x RRII 105			86/589	
13	RRIM 600 x RRII 33	86/134, 86/520	86/136	86/522	
14	RRIM 600 x PB 235	86/160, 86/257, 86/260, 86/266			
15	RRIM 600 x Gl 1	86/228, 86/455, 86/456	86/233, 86/461, 86/516		86/225
16	RRIM 600 x RRIC 52	86/967		86/751	86/968 86/749
17	RRIM 600 x RRII 203	86/10, 86/17, 86/19, 86/23, 86/405	86/16, 86/22		
18	RRIM 600 x IAN 873			86/617, 86/621	
19	PB 5/51 x RRII 208	86/59, 86/60, 86/62, 86/65, 86/71, 86/279, 86/280	86/61, 86/64, 86/73, 86/75, 86/273, 86/668	86/269	86/68, 86/70, 86/72

20	PB 5/51 x RRII 203	86/815, 86/902		86/881, 86/897, 86/898, 86/901	
21	PB 5/51 x RRII 105	86/957		86/908, 86/966	
22	PB 86 x RRII 208	86/481	86/827, 86/829, 86/831, 86/835	86/485	86/491, 86/834
23	PB 86 x RRII 203	86/860, 86/861			
24	PB 86 x RRII 105				86/701
25	PB 242 x RRII 105	86/244	86/44, 86/50, 86/56, 86/787, 86/802, 86/805	86/51, 86/813	86/52
26	PB 242 x PB 86		86/468		86/98, 86/99, 86/103, 86/470
27	PB 242 x RRIM 600		86/594, 86/596		86/597, 86/599
28	IAN 873 x RRII 105	86/2, 86/3, 86/5		86/355	
29	IAN 873 x RRIM 600			86/904, 86/905	
30	IAN 873 x RRIM 612				86/672
31	IAN 873 x RRII 118				86/674
32	Gl 1 x RRIM 600		86/683		
33	Gl 1 x RRII 33		86/738		
	Total hybrids-147	49	49	25	24

were involved as female and male parents in the 1986 hybridisation programme from which the present hybrids were derived. Table 1 lists the details of clones evaluated and their parentage.

Implementation of small scale trials

147 hybrid clones evolved by hybridisation across 17 parents in 33 cross combinations were evaluated in four small scale trials laid out during 1989 at Central Experiment Station of the Rubber Research Institute of India in Ranni, Pathanamthitta district situated at a latitude of 9^0 38^1 N and a longitude of 76^0 55^1 E in South Kerala. The design adopted was simple lattice and spacing was 4.9 x 4.9 m for all the four trials which were laid out adjacent to one another. In trial 1, 49 hybrid clones from 19 cross combinations were planted along with 15 parents in four replications. In trial 2, 49 hybrid clones from 20 cross combinations were planted along with 15 parents in two replications. In trial 3, 25 hybrid clones from 16 cross combinations were planted along with 11 parents and in trial 4, 24 hybrids

resultant of 14 cross combinations along with check clone RRII 105 in two replications each. Clone RRII 105 was the high yielding check in the trials.

Assessment of traits

From the third year of planting onwards, growth in terms of girth at a height of 150 cm from the base was recorded annually. Tapping was initiated in the 8^{th} year after planting when the trees attained tappable girth. The tapping system followed was S/2 d3 6d/7 without stimulation. Yield from individual trees was recorded at fortnightly intervals by cup coagulation and the weight of smoke dried cup lumps were taken for calculating annual mean yield. Yield components *viz*. volume of latex and dry rubber content (DRC) on a dry weight by volume basis from 20 mL samples of latex were determined during the peak yielding season of October to November in the fifth year of tapping. Annual girth measurements were used to estimate growth vigour in terms of girth increment rate during the immature phase, girth at opening and girth increment rate under tapping over the first five years. Timber yield was estimated at the age of 14 years in terms of clear bole volume following quarter girth method using data on girth and forking height (Chathurvedi and Khanna,1982). Data on yield and yield components, growth parameters and timber traits were subjected to analysis of variance to study the magnitude of clonal variation available for effective selection. Standard heterosis for yield, girth and bole volume was also estimated. The 147 hybrids were evaluated in four trials simultaneously with RRII 105 as a common check. Hence, in order to have a comparison across trials, clones in the four trials were compared with clone RRII 105, since an analysis of covariance showed non-significant error variance.

RESULTS AND DISCUSSION

The analysis of variance revealed significant clonal variation for the traits studied indicating scope for selection of superior hybrids. Dry rubber yield, volume of latex, dry rubber content, girth at opening, girth increment rate before and after tapping, forking height and bole volume proved to be distinct clonal characteristics (Table 2) as also reported earlier (Licy *et al*., 2003; John *et al*., 2012; Mydin and Gireesh, 2016). Mean and range in variability among hybrids for characters under study across four trials are presented in Table 2. The mean yield of clones over five years of tapping ranged from 16.2 to 79.1 g t^{-1} t^{-1} across four trials with a general mean to the tune of 32.5 to 35.7 g t^{-1} t^{-1} which was comparable in the four trials.

The mean volume of latex in the hybrids ranged from 37.6 to 508.0 mL t^{-1} t^{-1}, with a general mean to the tune of 117.0 to 180.8 mL t^{-1} t^{-1} in the four trials. Dry rubber content ranged from 29.8 to 54.7 per cent with a general mean between 40.1 to 44.3 per cent across the trials. The growth attributes in terms of girth at opening ranged from 34.6 to 72.6 cm with a general mean ranging from 52.1 to 55.8 cm across trials. The girth increment before tapping ranged from 3.0 to 9.1 cm $year^{-1}$ with a range in general mean of 6.4 to 7.0 cm $year^{-1}$ which was comparable, whereas the range in girth increment under tapping was 1.2 to 6.6 cm $year^{-1}$ with a general mean of 3.3 cm $year^{-1}$.

The forking height which is a measure for timber volume ranged from 2.3 to 6.5 m with a general mean in the range of 4.1 to 4.4 m. The clear bole volume ranged from 0.05 to 0.37 m^3 $tree^{-1}$ with a general mean in the range of 0.13 to 0.21 m^3 $tree^{-1}$.

Family-wise performance

The family-wise mean and range of values with respect to yield and yield

Table 2. **Abstract of ANOVA and variability across trials for various traits in the hybrid clones**

Traits	Trial 1			Trial 2			Trial 3			Trial 4		
	Mean	Range	Variance ratio	Mean	Range	Variance ratio	Mean	Range	Variance ratio	Mean	Range	Variance ratio
Yield over five years (g t^{-1} t^{-1})	32.5	16.2-49.3	6.13**	35.7	17.3-79.1	3.38**	33.2	16.3-62.5	2.40**	32.5	16.3-49.7	4.20**
Volume of latex (mL t^{-1} t^{-1})	180.9	63.0-508.0	1.94**	175.5	63.0-380.8	2.47**	117.0	37.6-242.0	3.38**	131.4	60.4-359.6	5.63**
Dry Rubber Content (%)	40.0	32.4-47.8	3.12**	40.2	29.9-54.7	2.28**	41.5	34.6-48.2	2.67**	44.3	37.7-53.6	2.61**
Girth at opening (cm)	52.4	37.4-66.3	6.22**	55.1	42.1-68.8	2.81**	55.4	43.5-72.6	2.89**	52.1	34.6-64.0	5.72**
GI before tapping (cm $year^{-1}$)	6.8	5.2-8.4	3.79**	6.4	3.0-8.5	2.94**	6.8	5.3-9.1	2.02*	7.0	5.2-8.6	2.78**
GI after tapping (cm $year^{-1}$)	3.3	1.5-5.7	2.32**	3.3	1.5-5.7	0.86	3.1	1.2-6.6	2.88**	3.3	2.1-5.7	2.49*
Forking height (m)	4.1	2.9-5.9	2.08**	4.1	2.3-6.2	2.11**	4.1	2.5-6.5	2.22**	4.4	3.3-6.3	3.52**
Bole volume (m^3 $tree^{-1}$)	0.21	0.07-0.37	1.03	0.14	0.06-0.32	2.20**	0.13	0.05-0.28	3.75**	0.15	0.06-0.27	3.22**

*significant at $P < 0.05$; **significant at $P < 0.01$

Table 3. **Family-wise mean and range of yield and its components**

Sl. No.	Cross combination	Yield over 5 yrs (g t^{-1} t^{-1})		Total volume (mL t^{-1} t^{-1})		DRC (%)	
		Mean	Range	Mean	Range	Mean	Range
1	RRII 105 x PR 107	32.7	18.3-43.2	131.4	79.8-158.1	41.6	39.0-45.7
2	RRII 105 x RRII 118	39.2	22.4-79.1	171.8	83.2-380.8	41.3	36.8-44.7
3	RRII 105 x PB 217	33.7	28. 7-47.03	204.7	117.7-269.7	40.6	36.7-44.9
4	RRII 105 x RRII 208	35.9	26.0-45.1	162.7	64.9-280.9	41.9	36.9-53.6
5	RRII 105 x PB 5/51	34.7	23.3-42.8	159.2	80.5-257.2	41.7	39.1-43.8
6	RRII 105 x PB 86	33.6	27.8-41.1	154.0	131.5-175.0	43.1	39.0-45.2
7	RRII 105 x RRII 203	45.8	43.4-48.2	162.3	158.4-166.2	37.3	35.5-39.1
8	RRII 105 x RRIC 52	25.0	22.7-27.9	111.6	76.9-143. 5	42.3	37.2-47.9
9*	RRII 105 x PB 252	27.5	-	136.5	-	43.4	-
10*	RRII 105 x IAN 873	40.9	-	137.2	-	35.3	-
11	RRII 203 x PB 5/51	39.0	24.3-49.3	190.6	121.9-256.2	42.6	39.8-47.6
12*	RRII 203 x RRII 105	24.6	-	79.3	-	35.2	-
13	RRIM 600 x RRII 33	25.2	18.9-32.6	118.8	72.5-163.8	43.3	37.3-47.0
14	RRIM 600 x PB 235	30.3	19.7-37.1	230.9	83.5-508.0	37.7	35.2-41.7
15	RRIM 600 x Gl 1	27.9	16.3-35.1	124.9	83.1-177.4	38.3	33.9-40.3
16	RRIM 600 x RRIC 52	32.8	26.8-37.5	145.3	88.1-271.9	38.1	33.6-42.0
17	RRIM 600 x RRII 203	33.3	27.4-42.0	184.1	83.1-309.5	36.6	32.7-39.3
18	RRIM 600 x IAN 873	28.0	20.5-35.6	102.7	46.1-159.3	36.9	36.8-37.0
19	PB 5/51 x RRII 208	35.2	23.7-48.8	160.4	63.0-343.8	42.5	36.5-48.0
20	PB 5/51 x RRII 203	27.2	17.9-44.2	84.2	39.6-175.7	42.9	39.5-46.0
21	PB 5/51 x RRII 105	38.0	37.1-39.4	187.2	139.0-276.4	37.7	35.8-40.3
22	PB 86 x RRII 208	27.4	20.1-32.5	127.3	60.46-192.0	38.7	30.3-45.4
23	PB 86 x RRII 203	36.0	31.9-40.2	182.5	166.1-199.0	35.8	32.4-39.2
24	PB 86 x RRII 105	23.2	-	62.1	-	41.2	-
25	PB 242 x RRII 105	32.6	23.9-43.1	152.4	37.6-297.4	42.5	35.9-54.7
26	PB 242 x PB 86	36.0	29.9-45.4	229.8	111.7-333.0	44.3	41.2-49.1
27	PB 242 x RRIM 600	43.0	35.0-49.7	175.2	102.6-359.6	41.2	38.9-45.8
28	IAN 873 x RRII 105	29.9	17.2-41.5	153.3	123.3-181.6	42.3	39.7-45.2
29	IAN 873 x RRIM 600	19.7	16.3-23.1	94.6	73.6-115.6	44.0	41.9-46.1
30*	IAN 873 x RRIM 612	22.5	-	73.7	-	46.0	-
31*	IAN 873 x RRII 118	35.2	-	129.2	-	51.0	-
32*	Gl 1 x RRIM 600	30.3	-	140.1	-	39.7	-
33*	Gl 1 x RRII 33	17.3	-	63.0	-	45.7	-

* Only single individual in the family

Table 4. **Family-wise performance in growth attributes**

Sl. No.	Cross combination	Girth at opening (cm)		GI immature (cm $year^{-1}$)		GI mature (cm $year^{-1}$)	
		Mean	Range	Mean	Range	Mean	Range
1	RRII 105 x PR 107	51.7	38.1-57.5	6.5	5.3-7.6	3.0	2.3-4.0
2	RRII 105 x RRII 118	55.8	48.9-64.4	6.8	5.5-7.9	3.2	2.1-4.6
3	RRII 105 x PB 217	54.3	49.0-57.5	6.4	5.4-7.2	3.2	1.8-5.2
4	RRII 105 x RRII 208	54.5	34.6-68.8	6.7	5.2-7.7	2.6	1.5-4.5
5	RRII 105 x PB 5/51	57.4	50.8-63.6	6.9	5.4-8.5	3.2	2.1-4.1
6	RRII 105 x PB 86	57.5	52.1-64.0	7.3	6.7-8.3	3.0	2.3-3.5
7	RRII 105 x RRII 203	54.4	51.5-57.4	6.6	6.0-7.3	2.8	2.7-2.8
8	RRII 105 x RRIC 52	57.1	53.1-61.0	7.2	6.4-7.9	3.2	2.6-4.4
9*	RRII 105 x PB 252	57.3	-	6.2	-	2.8	-
10*	RRII 105 x IAN 873	58.6	-	6.9	-	2.5	-
11	RRII 203 x PB 5/51	57.4	55.4-59.1	7.1	6.6-7.6	3.5	2.5-4.0
12*	RRII 203 x RRII 105	59.1	-	7.1	-	3.9	-
13	RRIM 600 x RRII 33	54.7	47.4-68.1	6.9	6.2-8.1	3.9	2.9-5.0
14	RRIM 600 x PB 235	50.3	40.4-56.7	6.8	5.3-7.9	2.9	2.4-3.1
15	RRIM 600 x Gl 1	45.0	29.8-53.8	5.6	3.0-6.5	2.7	1.5-4.2
16	RRIM 600 x RRIC 52	53.7	45.9-59.6	6.8	6.1-7.7	3.6	2.9-4.5
17	RRIM 600 x RRII 203	52.7	44.5-59.2	6.7	5.4-7.5	4.0	3.4-5.2
18	RRIM 600 x IAN 873	51.6	49.7-53.5	7.0	6.1-7.8	2.6	1.7-3.4
19	PB 5/51 x RRII 208	55.7	44.2-67.3	7.0	5.3-8.4	3.3	2.1-5.7
20	PB 5/51 x RRII 203	54.7	49.6-59.3	6.5	5.8-7.6	2.2	1.3-3.2
21	PB 5/51 x RRII 105	58.3	53.3-62.1	7.4	6.3-7.9	2.1	1.2-3.1
22	PB 86 x RRII 208	48.5	41.5-58.8	5.8	5.1-6.7	2.5	1.7-3.0
23	PB 86 x RRII 203	54.4	53.8-55.0	7.1	7.1-7.1	3.0	2.5-3.4
24	PB 86 x RRII 105	45.3	-	6.5	-	5.7	-
25	PB 242 x RRII 105	58.5	53.0-62.8	7.0	6.1-7.9	3.4	2.1-4.5
26	PB 242 x PB 86	55.0	51.0-58.7	7.3	6.5-8.6	4.1	3.7-4.7
27	PB 242 x RRIM 600	58.3	55.5-61.3	7.2	6.8-7.7	4.0	3.3-4.7
28	IAN 873 x RRII 105	53.6	45.4-57.6	6.9	5.7-7.7	3.3	2.5-4.0
29	IAN 873 x RRIM 600	49.2	43.6-54.9	5.9	5.3-6.5	1.8	1.7-2.0
30*	IAN 873 x RRIM 612	49.2	-	6.5	-	4.6	-
31*	IAN 873 x RRII 118	57.1	-	8.0	-	3.7	-
32*	Gl 1 x RRIM 600	56.2	-	6.6	-	3.7	-
33*	Gl 1 x RRII 33	56.3	-	6.7	-	5.7	-

* Only single individual in the family

Table 5. **Family-wise performance in timber traits**

Sl. No	Cross combination	Forking ht. (m)		Bole volume (m^3 $tree^{-1}$)	
		Mean	Range	Mean	Range
1	RRII 105 x PR 107	3.8	3.2-4.8	0.11	0.07-0.15
2	RRII 105 x RRII 118	4.0	2.9-5.4	0.13	0.09-0.23
3	RRII 105 x PB 217	3.6	2.9-4.3	0.10	0.06-0.14
4	RRII 105 x RRII 208	3.8	3.2-4.6	0.12	0.06-0.18
5	RRII 105 x PB 5/51	4.5	3.8-5.3	0.15	0.11-0.19
6	RRII 105 x PB 86	4.0	2.9-4.7	0.14	0.10-0.17
7	RRII 105 x RRII 203	4.0	3.9-4.1	0.11	0.09-0.13
8	RRII 105 x RRIC 52	3.6	3.4-3.7	0.15	0.12-0.16
9*	RRII 105 x PB 252	4.0	-	0.11	-
10*	RRII 105 x IAN 873	2.8	-	0.10	-
11	RRII 203 x PB 5/51	4.1	3.4-4.6	0.15	0.11-0.17
12*	RRII 203 x RRII 105	4.0	-	0.15	-
13	RRIM 600 x RRII 33	3.9	3.3-4.6	0.12	0.08-0.25
14	RRIM 600 x PB 235	4.3	3.3-4.9	0.13	0.07-0.19
15	RRIM 600 x Gl 1	3.7	2.3-4.4	0.11	0.07-0.16
16	RRIM 600 x RRIC 52	3.9	2.5-5.2	0.15	0.10-0.17
17	RRIM 600 x RRII 203	4.3	3.4-5.5	0.15	0.12-0.18
18	RRIM 600 x IAN 873	3.9	3.0-4.8	0.10	0.06-0.14
19	PB 5/51 x RRII 208	4.9	3.8-6.2	0.17	0.08-0.37
20	PB 5/51 x RRII 203	4.5	3.0-5.5	0.13	0.09-0.17
21	PB 5/51 x RRII 105	4.1	3.4-4.6	0.13	0.09-0.19
22	PB 86 x RRII 208	3.7	2.9-4.6	0.10	0.06-0.14
23	PB 86 x RRII 203	4.0	3.8-4.0	0.13	0.11-0.15
24	PB 86 x RRII 105	3.3	-	0.15	-
25	PB 242 x RRII 105	4.1	3.2-4.7	0.14	0.11-0.20
26	PB 242 x PB 86	4.6	4.1-5.9	0.21	0.12-0.35
27	PB 242 x RRIM 600	5.0	3.8-6.3	0.21	0.16-0.27
28	IAN 873 x RRII 105	4.0	3.8-4.4	0.15	0.09-0.20
29	IAN 873 x RRIM 600	4.5	4.3-4.6	0.09	0.08-0.10
30*	IAN 873 x RRIM 612	5.3	-	0.22	-
31*	IAN 873 x RRII 118	4.3	-	0.19	-
32*	Gl 1 x RRIM 600	4.0	-	0.15	-
33*	Gl 1 x RRII 33	4.1	-	0.15	-

* Only single individual in the family

components, growth attributes and timber traits are compared in Tables 3, 4 and 5. The performance for yield across 33 families ranged from17.3 to 45.8 g t^{-1} t^{-1}. In terms of yield over five years, the family RRII 105 x RRII 203 was most superior with a mean yield of 45.8 g t^{-1} t^{-1} followed by PB 242 x RRIM 600, RRII 105 x IAN 873, RRII 105 x RRII 118 and RRII 203 x PB 5/51 with 43.0, 40.9, 39.2 and 39.0 g t^{-1} t^{-1}, respectively (Table 3). While in terms of volume of latex, the family RRIM 600 x PB 235 was the best with a mean latex volume of 230.9 mL t^{-1} t^{-1} closely followed by PB 242 x PB 86 and RRII 105 x PB 217 with 229.8 and 204.7 mL t^{-1} t^{-1} respectively, family IAN 873 x RRII 118 was superior with respect to DRC per cent.

The data on growth attributes revealed that the family RRII 203 x RRII 105 exhibited superior performance in growth with a girth at opening of 59.1 cm followed by RRII 105 x IAN 873 (58.6 cm), PB 5/51 x RRII 105 (58.3 cm) and PB 242 x RRIM 600 (58.3 cm), respectively. The range for this character across families was 45.3 to 59.1 cm (Table 4). IAN 873 x RRII 118 showed high growth rate before tapping with a range of 5.6 to 8.0 cm $year^{-1}$ across families followed by PB 5/51 x RRII 105 (7.4 cm $year^{-1}$), PB 242 x PB 86 (7.3 cm $year^{-1}$) and RRII 105 x PB 86 (7.3 cm $year^{-1}$). Families Gl 1 x RRII 33 (5.7 cm $year^{-1}$) and PB 86 x RRII 105 (5.7 cm $year^{-1}$) recorded maximum growth rates under tapping. Data on timber traits revealed the superiority of the family IAN 873 x RRIM 612 for forking height and clear bole volume (Table 5).

Heterosis for yield, growth and timber

Out of the 33 cross combinations evaluated, 23 families produced progenies with hybrid vigour for yield, girth and clear bole volume whereas, clones RRII 105, RRII 203, RRIM 600, PB 5/51, PB 242, IAN 873 and PB 86 were employed as female parents. Heterosis was exhibited by 22 hybrid clones for yield, 45 hybrids for girth and 14 hybrids for bole volume (Table 6). Heterosis for yield ranged from 2.4 to 91.5 per cent while heterosis for girth ranged from 2.3 to 23.8 per cent only. In case of bole volume, the values ranged from 5.3 to 94.7 per cent. The family RRII 105 x RRII 118 produced the largest number of heterotic hybrids in terms of both rubber yield and girth. The family PB 5/51 x RRII 208 was promising with respect to high recovery of hybrids with heterotic effect for bole volume, girth and yield.

Hybrid clones with more than 20 per cent heterosis over the standard check clone for yield, girth and bole volume are presented in Table 7. Six hybrid clones *viz*. 86/111, 86/117, 86/122, 86/428, 86/613 and 86/597 recorded more than 20 per cent heterosis for yield. Among these, four clones belonged to the family RRII 105 x RRII 118 and one each to RRII 203 x PB 5/51 and PB 242 x RRIM 600. Two of the high yielding selections of the cross RRII 105 x RRII 118 *viz*. 86/111 and 86/428 exhibited high level of heterosis over standard parent for rubber yield. Clone 86/428 showed standard heterosis for yield and bole volume. The trend in yield of these best six clones for the first five years of tapping is depicted in Figure 1. In general, all the clones showed a rising trend in yield from the first to the fifth year. There exhibited a little decline in yield during the fourth year for clones 86/117, 86/122 and 86/613, however all these six high yielding clones were superior to RRII 105 from the third year of tapping onwards.

Four clones *viz*. 86/306, 86/522, 86/59 and 86/64 were the best performers as far as heterosis for girth is concerned. Seven clones *viz*. 86/428, 86/59, 86/64, 86/61, 86/468, 86/597 and 86/522 showed more than 20 per cent improvement in bole volume ranging from

Table 6. **Hybrids exhibiting more than 5 per cent heterosis over standard clone**

Pedigree	Clones	Standard heterosis (%)		
		Yield	Girth	Bole volume
RRII 105 x PR 107	86/34	5.0	-	-
RRII 105 x RRII 118	86/110		8.4	5.3
	86/120		5.0	
	86/111	91.5	11.6	
	86/117	25.2	14.2	
	86/122	20.0	4.3	
	86/428	51.2	15.9	21.1
	86/424	10.0	11.9	
RRII 105 x PB 217	86/157	13.6		
RRII 105 x RRII 208	86/304	9.2		
	86/174		14.4	
	86/306		23.8	
	86/188		6.8	
RRII 105 x PB 5/51	86/660	3.7	6.2	
	86/79	2.4	13.7	
	86/77		14.5	
RRII 105 x PB 86	86/400		15.1	
RRII 105 x RRII 203	86/651	16.8		
	86/650	5.0	3.3	
RRII 105 x RRIC 52	86/734		9.8	
RRII 105 x IAN 873	86/778		5.5	
RRII 203 x PB 5/51	86/602	5.2	2.3	
	86/607		6.3	
	86/613	20.0	5.0	
RRII 203 x RRII 105	86/589		6.3	
RRIM 600 x RRII 33	86/522		22.5	31.6
RRIM 600 x RRIC 52	86/968		7.2	
RRIM 600 x RRII 203	86/16		6.5	
	86/22		6.1	
PB 5/51 x RRII 208	86/59	5.0	20.2	94.7
	86/62		4.3	10.5
	86/64	18.2	21.1	68.4
	86/61		14.2	31.6
	86/668		8.5	
	86/70	14.5		

PB 5/51 x RRII 203	86/902	7.1	6.7	
PB 5/51 x RRII 105	86/957		11.7	
	86/908		7.2	
PB 86 x RRII 208	86/835		5.8	
PB 242 x RRII 105	86/244		5.6	
	86/787	4.3	13.0	5.3
	86/44		5.3	
	86/805		7.4	
	86/51		9.9	
	86/813		12.3	
PB 242 x PB 86	86/468		5.7	84.2
	86/99	9.9	4.4	15.8
PB 242 x RRIM 600	86/596		10.3	
	86/597	20.2		42.1
	86/599	11.3	8.3	10.5
IAN 873 x RRII 105	86/2		3.2	5.3
IAN 873 x RRIM 612	86/672			15.8

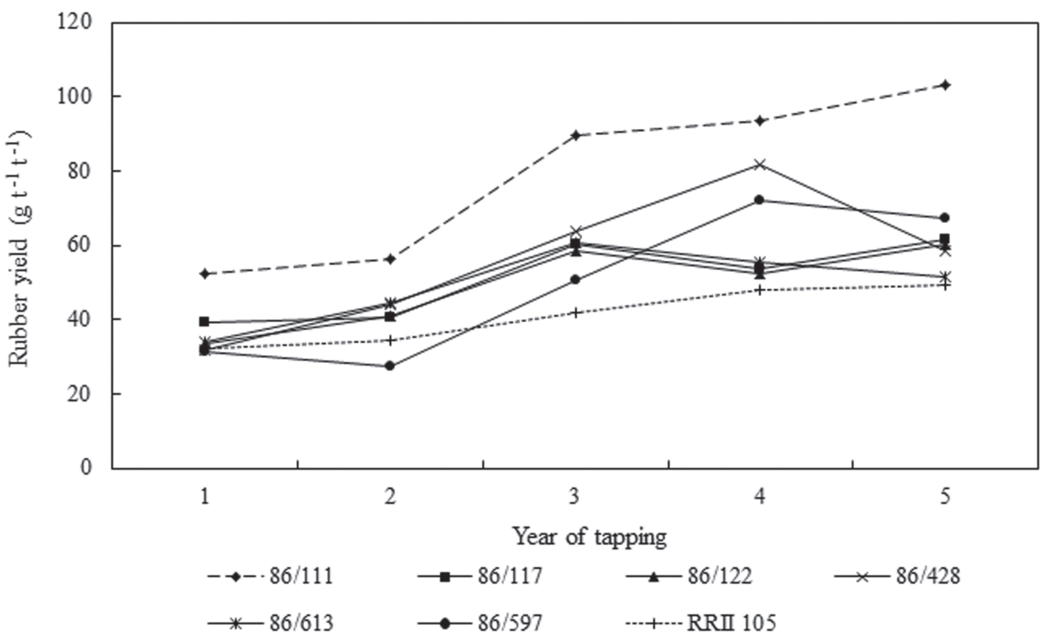

Fig. 1. Trend in yield of selected hybrids

Table 7. **Selected hybrid clones with more than 20 per cent standard heterosis for important traits**

Clone	Rubber yield			Girth				Bole volume			
	Parentage	Mean yield ($g\ t^{-1}\ t^{-1}$)	Heterosis (%)	Clone	Parentage	Mean girth (cm)	Heterosis (%)	Clone	Parentage	Mean bole volume ($m^3\ tree^{-1}$)	Heterosis (%)
86/111	RRII 105 x RRII 118	79.1	91.5	86/306	RRII 105 x RRII 208	68.8	23.8	86/428	RRII 105 x RRII 118	0.23	21.1
86/117	RRII 105 x RRII 118	51.7	25.2	86/522	RRIM 600 x RRII 33	68.1	22.5	86/59	PB 5/51 x RRII 208	0.37	94.7
86/122	RRII 105 x RRII 118	49.1	20.0	86/59	PB 5/51 x RRII 208	66.3	20.2	86/64	PB 5/51 x RRII 208	0.32	68.4
86/428	RRII 105 x RRII 118	62.5	51.2	86/64	PB 5/51 x RRII 208	67.3	21.1	86/61	PB 5/51 x RRII 208	0.25	31.6
86/613	RRII 203 x PB 5/51	49.3	20.0					86/468	PB 242 x PB 86	0.35	84.2
86/597	PB 242 x RRIM 600	49.7	20.2					86/597	PB 242 x RRIM 600	0.27	42.1
								86/522	RRIM 600 x RRII 33	0.25	31.6

21.1 to 94.7 per cent compared to the standard check. The clone 86/59 exhibited high girth increment rate during the immature and yielding phases besides high bole volume indicating its potential for effective biomass partitioning and sustained high yield in the long run. Three of the high timber yielding clones *viz*. 86/59, 86/64 and 86/61 belonged to the family PB 5/51 x RRII 208. The second best clone among the seven was 86/468 with a heterotic effect of 84.2 belonged to the family, PB 242 x PB 86 (Table 7).

Variability in parental clones

Fifteen parental clones each were included in trial I and trial II, 11 parental clones in trial III and the popular check clone RRII 105 in trial IV. The performance of the parental clones in terms of yield, growth and timber traits are presented in Figures 2, 3 and 4. There existed wide range of variability in trial 1 for mean yield over five years from 16.5 g t^{-1} t^{-1} (RRII 33) to 46.2 g t^{-1} t^{-1} (PB 235). Among the fifteen clones evaluated along with hybrids, clone PB 235 showed high yield with 46.2 g t^{-1} t^{-1} over five years followed by RRII 203 (43.0 g t^{-1} t^{-1}). The performance of these clones was on par with the popular check RRII 105 (39.8 g t^{-1} t^{-1}). The mean girth at opening ranged from 40.5 cm (PR 107) to 60.8 cm (RRIC 52). Clone RRIC 52 (60.8 cm), RRII 203 (59.4 cm), RRII 118 (58.6 cm) and PB 235 (55.6 cm) were significantly superior in girth while values for bole volume were on par with RRII 105 (0.10 m^3 $tree^{-1}$). Among the parent clones, RRII 203 recorded the highest timber volume of 0.20 m^3 $tree^{-1}$ followed by PB 235 (0.19 m^3 $tree^{-1}$), RRIC 52 (0.18 m^3 $tree^{-1}$), IAN 873 (0.16 m^3 $tree^{-1}$) and RRII 118 (0.15 m^3 $tree^{-1}$) in trial 1.

Wide variation for yield over five years ranging from 27.9 gt^{-1} t^{-1} (RRII 33) to 60.7 g t^{-1} t^{-1} (RRII 203) was observed among the clones in trial 2. Clone RRII 203 showed significantly superior performance in yield

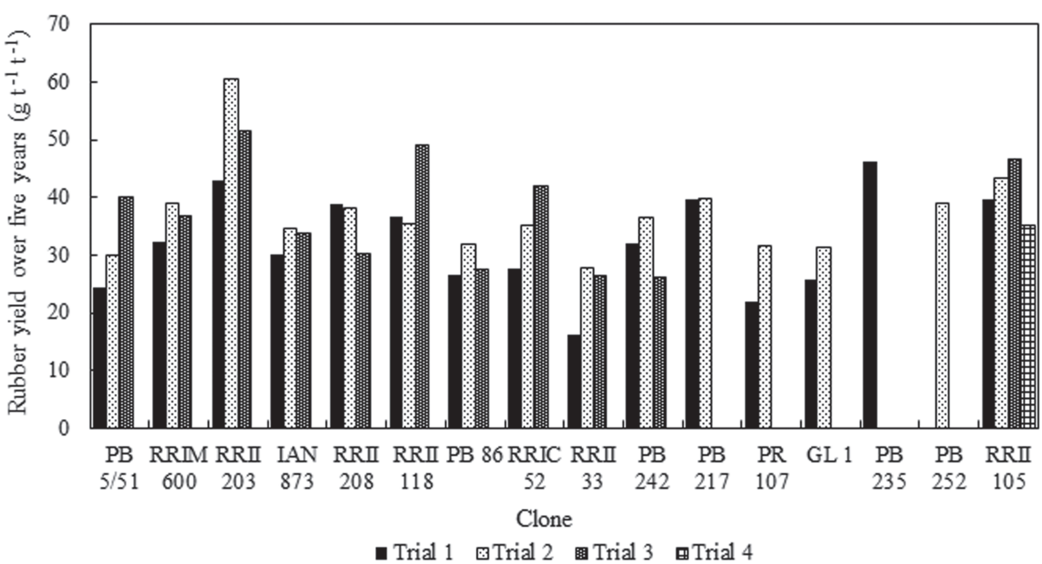

Fig. 2. Rubber yield of parent clones in different trials

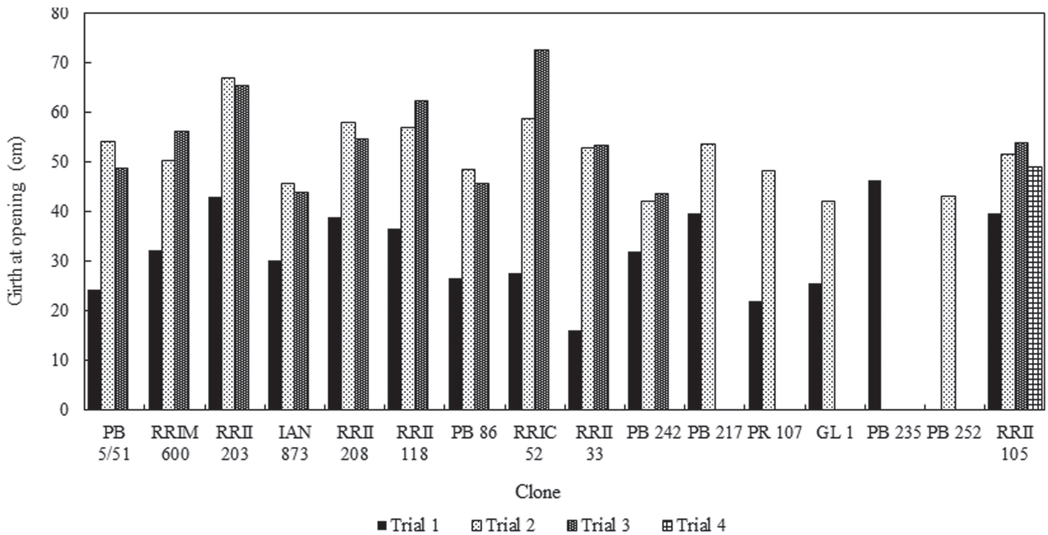

Fig. 3. Girth of parent clones in different trials

coupled with growth and timber traits. Girth at opening ranged from 42.1 cm (Gl 1) to 67.0 cm (RRII 203). Clones RRIC 52 (58.6 cm), RRII 208 (57.9 cm) and RRII 118 (56.9 cm) were the other vigorous clones in trial 2 and clones RRII 203 (0.23 m^3 $tree^{-1}$), RRIC 52 (0.17 m^3 $tree^{-1}$), RRII 118 (0.15 m^3 $tree^{-1}$) and IAN 873 (0.15 m^3 $tree^{-1}$) had high clear bole volume indicative of good timber yield.

Mean yield over five years for clones in trial 3 were on par with RRII 105 (46.8 g t^{-1} t^{-1}). However clone RRII 203 gave maximum yield of 51.7 g t^{-1} t^{-1} followed by RRII 118. Clone RRIC 52 was superior in girth followed by RRII 203 and RRII 118 (49.1 g t^{-1} t^{-1}). Trend for bole volume was also the same in trial 3 with RRIC 52 (0.28 m^3 $tree^{-1}$) being the most vigorous one followed by RRII 118 (0.26 m^3 $tree^{-1}$) and RRII 203 (0.22 m^3 $tree^{-1}$).

The 1986 hybridisation was of significance in that, RRII 105 was employed as a parent in as many as 15 bi-parental cross combinations to produce a large number of hybrids. The 147 hybrids which resulted from 33 cross combinations between parents of diverse origin have produced some very promising clones in terms of rubber yield, growth and timber yield. The cross combination RRII 105 x RRII 118 in particular has yielded more number of promising hybrids in terms of yield and girth. The success of this parental combination in generating heterotic hybrids has also been discussed by Mydin and Gireesh (2016). Clone RRII 105 is of Malaysian and Indonesian lineage, the parents being Tjir 1 and Gl 1 while RRII 118 has Sri Lankan primary clones Mil 3/2 and Hil 28 as parents. The Sri Lankan germplasm / clones are known to be genetically distant from Malaysian and Indonesian clones as also discussed by Varghese *et al*. (1997), utilizing RAPD markers. Mydin and Gireesh (2016) have discussed the genetic distance between RRII 105 and RRII 118 as also elucidated earlier by Bini (2013). Therefore, the high recovery of heterotic progeny from this cross

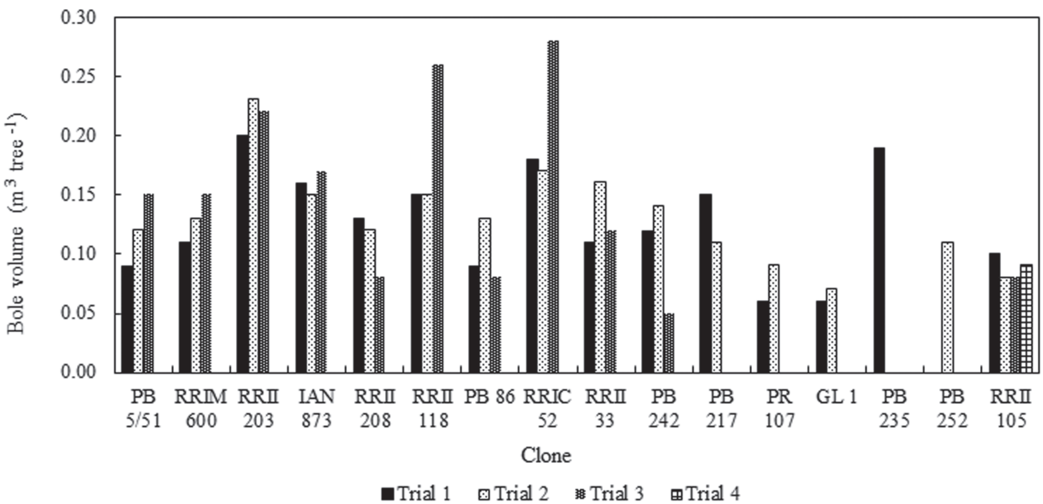

Fig. 4. Bole volume of parent clones in different trials

could be the result of specific combining ability by way of the wide divergence of parents involved (Mydin and Gireesh, 2016). The other promising parents are RRII 203 x PB 5/51 and PB 242 x RRIM 600 for heterotic hybrids for yield whereas the cross combination PB 5/51 x RRII 208 produced maximum number of heterotic hybrids as far as vigour is concerned. The other families which produced vigorous heterotic hybrids are RRIM 600 x RRII 33, PB 242 x PB 86 and PB 242 x RRIM 600. Nursery screening of these progenies, hybrid progeny analysis and evaluation of performance of hybrids in preliminary yield trials also revealed high recovery of superior seedling and hybrids from these families (Annamma *et al.*, 1989; Varghese *et al.*, 1997 and Meenakumari *et al.*, 2016).

Heterosis of more than 20 per cent for yield is considered to be adequate for commercial exploitation of crop varieties (Rai, 1979) and is the bench mark for selecting rubber clones from SSTs. The wide range of variability for yield, girth and timber yield has enabled the selection of promising hybrids. The heterosis estimates for yield ranged from 2.4 to 91.5 per cent and for girth ranged from 2.3 to 22.5 per cent and bole volume from 5.3 to 94.7 per cent. A total of 52 promising hybrids showing more than five per cent heterosis for these traits have been identified. These hybrid clones were plotted in a scatter diagram based on yield and bole volume (Fig. 5). This has enabled the classification of 37 promising clones into high latex yielding clones, latex timber clones and timber clones. The 17 latex clones identified are 86/117, 86/122, 86/70, 86/613, 86/650, 86/651, 86/157, 86/304, 86/424, 86/660, 86/602, 86/902, 86/60, 86/34, 86/23, 86/5 and 86/594. The nine latex timber clones 86/111, 86/428, 86/597, 86/64, 86/599, 86/99, 86/787, 86/59, 86/79 and eleven timber clones 86/468, 86/522, 86/61, 86/672, 86/62, 86/160, 86/957, 86/2, 86/110, 86/470 and 86/674.

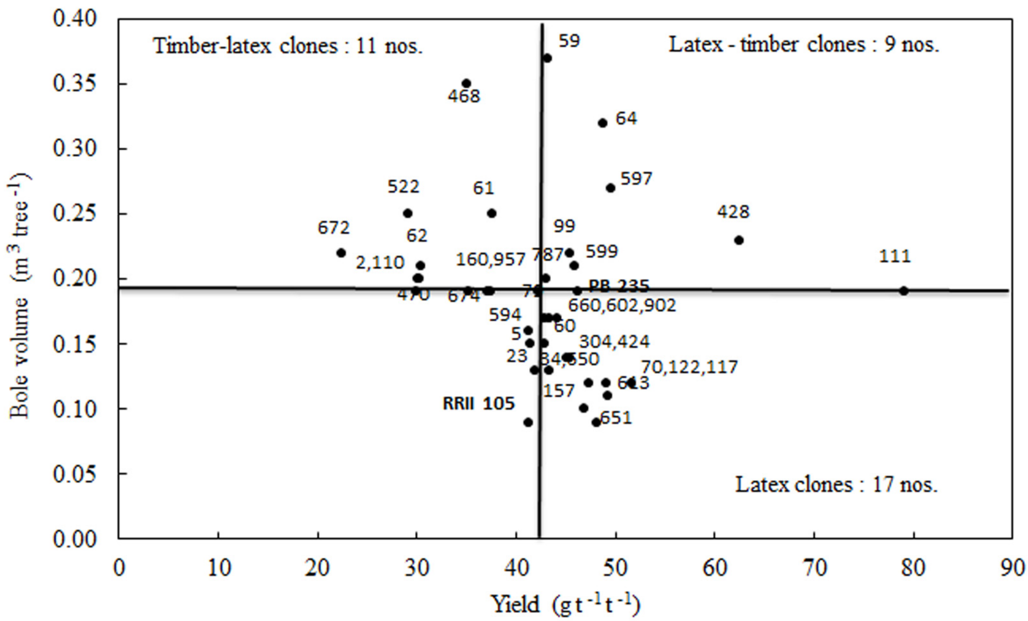

Fig 5. Classification of promising hybrids based on latex and timber yield

High rubber yield being the most important character required in newly evolved clones, it was taken as the primary selection criterion. Clones giving better latex yield than the high yielding check RRII 105 that emanated from the study are 86/111, 86/117, 86/122, 86/428, 86/613 and 86/597. Nine clones which were high in rubber yield also exhibited high timber yield as shown in quadrant II of Figure 5 and can be designated as latex timber clones. Among the ancillary products from rubber plantations rubber wood is the major by-product in enhancing the net farm income (Viswanathan *et al.*, 2002). Yield and vigour in rubber are hardly separable (Simmonds 1989). The yield of timber obtained from a rubber tree comprises mainly of the clear bole volume (Najib *et al.*, 1995). Another group of high timber yielding clones which did not have promising rubber yield (quadrant III of Fig. 5) are the timber clones evolved from the hybridisation programme. The timber latex clones and timber clones had promising bole volume in comparison with the check clone PB 235.

The parents used in this hybridisation programme consisting of 16 popular clones of diverse origin were also evaluated in the four trials. RRII 203 emerged as the high yielding Indian clone which proved superior to RRII 105 in both rubber and timber yield. Earlier reports also have indicated the superiority of RRII 203 (Saraswathyamma *et al.*, 1990; Gireesh *et al.*, 2005). Clone RRII 118 was the second best high yielder among the parents. Supremacy of clone RRII 118 in terms of growth and yield is reported from the traditional and non-traditional regions (Priyadarshan *et al.*, 2000; Reju *et al.*, 2002;

John *et al*., 2009; Meenakumari *et al*., 2013). The Sri Lankan clone RRIC 52 emerged as the most vigorous one. The vigorous habit of clone RRIC 52 corroborates with the reports by Fernando, 1973 and Narayanan and Mydin (2015).

CONCLUSION

Bi-parental crosses have the advantage of combining characteristics of parent clones and are therefore very relevant in *Hevea* breeding. Parental combinations based on genetic diversity and individual characters like rubber yield, timber yield and their components can ensure the success of a breeding programme as evidenced by the results of the present study. The divergent parents RRII 105 and RRII 118 produced a large number of superior hybrids for yield and clone PB 5/51 and RRII 208 produced superior hybrids for growth and timber yield. The study identified six clones *viz*. 86/111, 86/117, 86/122, 86/428, 86/613 and 86/597 as the top most latex yielders and seven clones *viz*. 86/59, 86/468, 86/64, 86/597, 86/522, 86/61 and 86/428 as the top most timber yielders while nine hybrids 86/111, 86/428, 86/597, 86/64, 86/599, 86/99, 86/787, 86/59 and 86/79 were the latex timber clones. These clones are already in the final stage of multi locational testing in participatory trials in Kerala, Tamil Nadu and Karnataka and the best among them after the final evaluation hold promise for release. The present study also confirmed the superiority of clones RRII 203, PB 235 and RRII 118 in terms of yield and RRIC 52, RRII 203 and RRII 118 in terms of yield, girth and timber volume.

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