EFFICACY OF POLYCROSS BREEDING IN EVOLVING GENETICALLY DIVERSE *HEVEA* CLONES

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Recognizing the significance of maintaining genetic diversity in rubber plantations, systematic efforts on polycross breeding in rubber were initiated by the Rubber Research Institute of India in 1989. The study also addressed the challenge faced by plant breeders to provide rubber growers with diverse planting materials without compromising on yield. Open pollinated progenies comprising 1680 half sib seedlings from 20 promising parent clones were evaluated in a nursery. The superior seedling progenies were identified and 15 genotypes per progeny from 10 parents were cloned and evaluated in a field trial adopting a compact family block design for a period of 20 years which included 12 years of tapping. The progeny clones numbering 150 were evaluated for rubber yield in the two virgin panels, timber yield and secondary attributes. Thirty five selections from these progenies were classified as dual purpose latex-timber clones and timber–latex clones as well as latex clones and timber clones. In terms of yield in the long term, 25 promising half-sib clones were selected from the progeny of nine genetically diverse parents. Among these, 15 clones exhibited stability in performance over 12 years of tapping. The most promising 12 selections in the pipeline out-yielded the check clone by over 20 per cent with estimated rubber yields of 2820 to 4429 kg ha^{-1} year^{-1}. Clones PB 215, PB 28/83 and Ch 26 were confirmed to be prepotent for rubber yield with more than 25 per cent of their progeny being high yielding. Estimation of stability across years proved clones HS PB 252/132 the highest yielding clone to be inconsistent in performance and HS Ch 26/161 with more than 97 g t^{-1} t^{-1} along with 10 other high yielding clones to be consistent in yield in the long term. The reaction of these clones to TPD, pink disease, abnormal leaf fall and powdery mildew is also discussed.

Key words: Disease reaction, *Hevea brasiliensis*, Latex-timber clones, Polycross, Rubber yield, Stability, Timber yield

INTRODUCTION

The adverse impact of climate change on the productivity of clones and rubber production in general is currently a matter of grave concern. The rubber plantation sector of India and other rubber growing nations are daunted by the challenge of maintaining the profitability of rubber cultivation due to various reasons. Polycross breeding is an approach that can deliver diverse planting material which in turn lends stability of performance under adverse situations. Polycross refers to multiple uncontrolled crossing of several parents (Simmonds, 1986) or in other words, random mating of several selected clones.

The mating system in rubber is one of predominant outcrossing. The consequent heterozygosity and heterogeneity which is

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so characteristic of outbred species has generated enormous variability for economically important attributes of the rubber tree. Exploitation of this variability through systematic breeding efforts over the years has led to the achievement of more than ten-fold improvement in rubber productivity. At the same time, widespread use of vegetative propagation and dependence on a handful of clones, especially in India where it has been as extreme as monoclonal planting of one single clone RRII 105, coupled with monoculture of rubber for maximizing productivity have increased the risk of loss during calamities. Rubber cultivation in India is fast expanding to non-traditional areas characterized by climatic constraints like drought, cold and heavy winds. The traditional rubber growing tract of South–West peninsular India is also witnessing a shift in climatic factors such as skewed rainfall and rising temperature levels (Jacob and Satheesh, 2010; Raj *et al.*, 2010). All these have necessitated breeding for tolerance to climatic vagaries in India.

Genetic improvement programmes in the Rubber Research Institute of India (RRII), geared mainly towards improvement in productivity, until the 1980s, were undertaken by means of hybridization among selected parents followed by evaluation and release of hybrid clones. An examination of the genealogy of parental clones involved in the pedigree of the most popular Indian clones of the RRII 100, RRII 200, RRII 300 and RRII 400 series has revealed that seven primary clones (Tjir 1, Gl 1, Mil 3/2, Hil 28, PB 86, AVROS 255 and RRIC 52) as common parents are involved, the most frequent ones being Tjir 1 and PB 86. The primary reason for repetition of parents was the difficulty in hybridization which led to limited number of crosses with the most easily available high yielding clone as female parent. The near failure of each successive breeding programme to generate clones with substantial yield improvement was partly due to the inability to raise progenies of sufficiently large size by hybridization, a factor which is crucial for efficiency of selection in an outbred system. It was not until the year 2005 that the RRII was able to release the RRII 400 series which combined the high growth vigour and precocity of RRIC 100 with the high yield of RRII 105.

The significance of polycross breeding in rubber lies in its ability to generate planting material of wide genetic diversity. Genetically diverse populations of rubber are buffered against vagaries of climate and as such exhibit greater adaptability to changing environments. Primary clones like GT 1, PB 280, PB 28/59 *etc.* evolved by ortet selection exhibit tremendous potential for adaptability to various situations like high winds and drought. Seedling plantations are now almost extinct, and the ones existing are in the senile stage. Therefore, conventional ortet selection programmes have now almost come to a halt in India. Most of the ortets recently selected from such senile plantations do not yield the expected results, primarily because the selection programme was undertaken based on yield towards the end of its economic phase in the renewed bark.

Recognizing the significance of maintaining genetic diversity in rubber plantations and the challenge faced by plant breeders to provide the rubber grower with a diversity of planting material without compromising on yield, efforts on systematic polycross breeding in rubber were initiated in 1989. The base material for the breeding programme consisted of a population of 40 popular clones of rubber planted in a randomized block design with five trees per plot and three replications at the Central Experiment Station of the RRII (Mydin *et al.*, 1996a). In the fourth year of tapping when yield in the clones had stabilized, a study on rubber yield and its components, comprising a total of 22 variables was undertaken (Mydin *et al*., 1996a) and genetic divergence among the clones was estimated by the Mahalanobis' D^2 statistic employing 22 attributes (Mydin *et al*., 1992). The 40 clones grouped into eight genetically divergent clusters, with volume of latex being the trait that contributed most towards divergence, followed by plugging index and dry rubber yield. The wintering and flowering behaviour of the clones showed 29 out of the 40 clones to be synchronous in flowering (Mydin *et al*., 1992).

Twenty promising yielders among the 40 clones were selected for assessment of their prepotency (Fig. 1). Open pollinated fruits were collected from the trees in all the three replications of the selected clones and the germinated seeds comprising 84 per progeny were evaluated in a nursery in randomized block design with four replications and a plot size of 21 half-sib seedlings. Based on growth, 60 seedlings per progeny *i.e*., 15 from each plot of 21 seedlings in each of the four replications were selected by a stratified sampling procedure for test tapping and subsequent nursery evaluation for juvenile parameters. Nine clones were identified as likely prepotents (Mydin *et al*., 1996 b) based on juvenile yield and related traits. Fifteen promising seedlings per progeny were then selected from the progeny of the nine prepotent clones and the same number of promising seedlings were selected from an

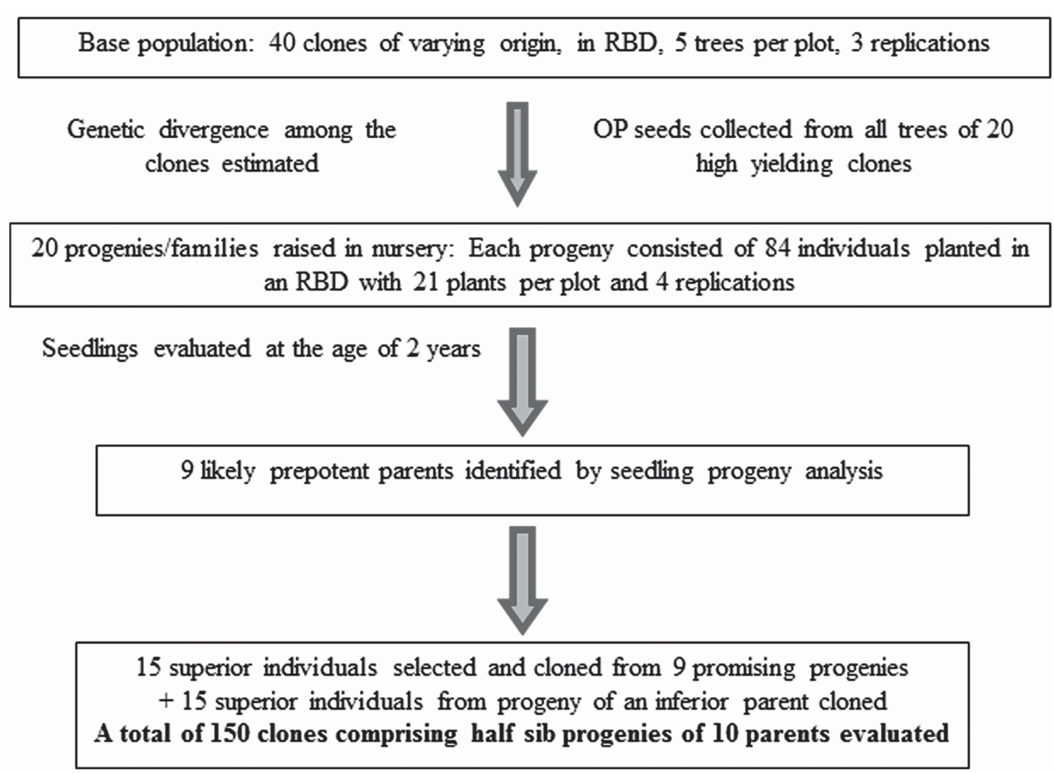

Fig. 1. Genealogy of study material

inferior progeny for cloning and field evaluation (Table 1). Early results on family performances in the initial years of tapping were reported (Mydin *et al.*, 2010). This paper discusses the long term performance of clones evolved from the first systematic polycross breeding programme initiated in the RRII.

Table 1. **Parent clones subjected to polycross progeny analysis**

Parent clone	Country of origin	Parentage
RRII 105	India	Tjir 1 x Gl 1
PB 242	Malayasia	PB 5/51 x PB 32/36
AVT 73	India	Primary clone
PB 252	Malayasia	PB 86 x PB 32/36
PB 217	Malayasia	PB 5/51 x PB 6/9
PB 28/83	Malayasia	Primary clone
PB 5/51	Malayasia	PB 56 x PB 24
PB 215	Malayasia	Primary clone
Ch 26	Malayasia	Selfed progeny of BR 2
PB 5/76 (inferior)	Malayasia	PB 56 x PB 24

MATERIALS AND METHODS

The clonal evaluation was conducted in a compact family block design with three replications of 10 families and 4-5 trees per plot. Planting was done in 1993 and the spacing adopted was 4.9 x 4.9 m. A total of 150 progeny clones were evaluated in two field trials, one trial (Trial 1) with 10 half-sib clones per progeny and the other (Trial 2), with five half- sib clones per progeny. The field trials were laid out at the Central Experiment Station of the RRII at Chethackal in Ranni, Central Kerala. Clone RRII 105 was planted as the high yielding reference clone in both the trials.

The trees were opened for tapping in 2001, following the S/2 d3 6d/7 system without stimulation. Trunk girth of the trees was measured in the year of opening and in the 12th year of tapping when the trees were 18 years of age. The height at forking was also recorded. Yield was recorded from each tree by cup coagulation at fortnightly intervals and weighing of the smoke dried cup lumps. Mean annual yield was then computed. Yield components like volume of latex per tap and dry rubber content (DRC) were recorded by the standard gravimetric method using 20 ml. samples of latex, during the stress period of February to May and during the peak yield period from October to December in three consecutive years. The values of volume yield of latex and DRC were averaged across the years to evaluate clonal performances. Timber yield of the clones was assessed in terms of clear bole volume estimated by the quarter girth method (Chaturvedi and Khanna, 1982). Evaluation of clonal performance within families and between families was done with respect to annual mean rubber yield in panels BO-1 and BO-2 as also in terms of long term yield over 12 years of tapping, timber yield, girth and yield components. The progeny wise recovery of superior clones in terms of rubber yield and timber yield were studied to identify promising parent clones. Disease reaction of the clones with respect to Pink disease in terms of percentage of affected trees in the immaturity phase and intensity of leaf diseases like Powdery mildew and Abnormal leaf fall in the mature phase were recorded in three consecutive years. Tapping panel dryness was recorded in the 12th year of tapping. Partially dried trees with more than 50 per cent dryness of the tapping cut as well as fully dried trees with 100 per cent dryness of the tapping panel were counted.

Based on rubber yield over 12 years of tapping and clear bole volume at 18 years the promising clones were classified as latex timber clones, latex clones, timber latex clones and timber clones. Clones which exceeded 58.6 g t^{-1} t^{-1}, the mean yield of the high yielding check clone RRII 105 across both the trials, were classified as high rubber yielders and those with clear bole volume more than 0.15 m^3 $tree^{-1}$ were classified as high timber yielders. Clones superior in rubber yield to clone RRII 105 coupled with high timber yield potential with bole volume of 0.15 m^3 $tree^{-1}$ and above were classified as latex-timber clones, while those with high rubber yield alone but inferior in timber yield were classified as latex clones. Clones which exhibited high timber yield with bole volume exceeding 0.15 m^3 $tree^{-1}$ but were poor in rubber yield were classified as timber clones. Clones with high timber yield and rubber yield comparable with clone RRII 105 were classified as timber-latex clones. Stability in yield over the long term was studied employing Shukla's stability variance (Shukla, 1972).

RESULTS AND DISCUSSION

The variability among ten half-sib progenies for annual mean yield over the first six years of tapping in panel BO-1, the 7^{th} to 12^{th} year of tapping in panel BO-2 and over 12 years of tapping in the virgin panels, summer yield, girth, clear bole volume, and yield components like volume of latex per tap and dry rubber content (DRC) in the two trials is evident from Table 2. Tables 3 and 4, respectively show the variability within each of the 10 progenies with 10 clones per

Table 2. **Variability among the ten progenies for the traits studied**

Trait	General mean		Range		Variance Ratio (VR)		C.D.(P=0.05)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Mean yield- 6 yrs (g t^{-1} t^{-1}) in panel BO-1	35.3	42.1	30-42	31-57	26.0**	12.5**	2.7	8.7
Mean yield 6 yrs (g t^{-1} t^{-1}) in panel BO-2	49.9	59.1	42-56	42-76	2.9**	7.0**	9.1	11.7
Mean yield over 12 years (g t^{-1} t^{-1})	42.6	50.7	35-48	37-66	6.5**	10.8**	5.3	8.8
Girth at opening (cm)	43.9	48.1	40-46	44-56	0.75	1.83	-	-
Girth 12^{th} year (cm)	73.1	76.5	69-78	68-88	2.8**	5.6**	48.3	34.5
Summer yield (g t^{-1} t^{-1}) over 2 yrs	16.4	21.8	12-21	12-38	8.24**	18.4**	2.7	6.2
Volume of latex(ml t^{-1} t^{-1}) -peak period	155.5	170.8	118-218	126-237	2.75*	5.2**	50.4	50.8
Volume of latex(ml t^{-1} t^{-1}) -stress period	75.2	51.80	65-89	13-91	ns	19.2	-	17.9
Dry rubber content (%) peak period	37.6	37.7	34-40	36-40	ns	ns	-	-
Dry rubber content (%) stress period	39.2	38.7	36-42	36-42	ns	3.1*	-	2.9
Clear Bole Vol. (m^3 $tree^{-1}$)	0.11	0.11	0.09-0.13	0.09-0.17	2.70*	3.94**	0.02	0.03

* Significant at P= 0.05; **Significant at P= 0.01

Table 3. **Variability for important traits among 100 clones within the 10 progenies in Trial 1**

Progeny of	Rubber Yield over 12 years (g t^{-1} t^{-1})		Clear Bole Volume (m^3 $tree^{-1}$)		Girth at opening (cm)	
	Mean & Range	V.R.	Mean & Range	V.R.	Mean & Range	V.R.
RRII 105	48.2 (38.2-75.6)	8.26**	0.11 (0.06-0.22)	8.06**	44.1 (39.5-51.1)	3.90**
PB 242	44.6 (28.3-77.2)	10.11**	0.12 (0.09-0.20)	10.26**	42.9 (34.3-53.1)	5.10**
AVT 73	35.4 (20.1-53.8)	11.46**	0.12 (0.07-0.19)	4.46**	44.5 (35.4-52.0)	11.01**
PB 252	38.8 (27.6-54.0)	2.69*	0.11 (0.07-0.17)	3.29*	43.3 (37.6-52.4)	1.93
PB 217	42.3 (30.9-56.6)	1.86	0.12 (0.10-0.17)	2.27	45.8 (38.1-54.5)	2.65
PB 28/83	45.7 (31.3-70.5)	13.84**	0.13 (0.08-0.19)	4.07**	45.5 (37.4-51.2)	2.84
PB 5/51	41.8 (21.7-72.3)	15.51**	0.11 (0.07-0.13)	2.44	43.4 (33.5-51.6)	4.89**
PB 215	47.5 (26.9 -64.4)	4.50**	0.12 (0.06-0.19)	5.22**	45.1 (37.8-53.7)	3.72**
Ch 26	45.4 (25.4-64.6)	4.18**	0.10 (0.07-0.15)	3.97**	45.2 (38.1-50.4)	3.94**
PB 5/76	36.0 (21.2-46.3)	8.19**	0.09 (0.05-0.12)	4.70**	39.5 (33.2-45.6)	4.05**

* Significant at P= 0.05; **Significant at P= 0.01

progeny evaluated in Trial 1 and five clones per progeny evaluated in Trial 2.

Variability among half sib progenies for yield and its components

There was significant variation between half-sib families and within half-sibs in a family with respect to annual mean yield over the first six years, the subsequent six years and over 12 years of tapping. Annual mean yield over 12 years ranged from 35-48 in Trial 1 and 37.0-66.0 g t^{-1} t^{-1} and Trial 2 and summer yield ranged from 12.0-21.0 in Trial 1 and 12.0-38.0 g t^{-1} t^{-1} in Trial 2. This indicated the possibility of identifying superior progenies as well as selection within superior half-sib families for realization of high yield of rubber. The progenies had uniform girth at opening but showed significant variability in girth 19 years after planting *i.e.*, after 12 years of tapping. The progenies were comparable in terms of forking height which did not show clonal variation within progenies either. Clear bole volume ranged from 0.09-0.13 m^3 $tree^{-1}$ in Trial 1 and 0.09-0.17 m^3 $tree^{-1}$ in Trial 2 with significant variability among the progenies in both the trials. Variability for the trait within progenies was seen in eight progenies in Trial 1 and six progenies in Trial 2.

Yield of the ten progenies over the first six years of tapping in panel BO-1 indicated that progeny of PB 28/83 was superior in both the

Table 4. **Variability for important traits among 50 clones within the 10 progenies in Trial 2**

Progeny of	Rubber Yield over 12 years (g t^{-1} t^{-1})		Clear Bole Volume (m^3 $tree^{-1}$)		Girth at opening (cm)	
	Mean & Range	V.R.	Mean & Range	V.R.	Mean & Range	V.R.
RRII 105	52.9	20.89**	0.11	21.52**	51.8	
	(33.8-85.1)		(0.08-0.16)		(46.5-61.5)	3.67
PB 242	48.4	4.22*	0.14	6.76*	45.1	1.69
	(39.1-70.9)		(0.09-0.17)		(41.3-50.0)	
AVT 73	38.2	4.87*	0.12	2.09	48.7	0.93
	(31.4-62.4)		(0.09-0.15)		(45.4-51.7)	
PB 252	66.1	0.85	0.16	2.16	56.2	1.67
	(56.3-110.7)		(0.09-0.24)		(49.9-65.2)	
PB 217	42.0	34.67**	0.10	4.2*	46.9	15.35**
	(20.4-72.6)		(0.05-0.11)		(30.9-53.2)	
PB 28/83	58.7	1.80	0.11	5.58*	49.9	1.27
	(52.2-63.6)		(0.08-0.13)		(44.6-55.3)	
PB 5/51	47.9	12.18**	0.09	7.09*	43.6	3.82
	(18.4-84.2)		(0.05-0.13)		(35.8-50.6)	
PB 215	54.8	3.9*	0.11	0.54	44.9	0.37
	(41.8-71.4)		(0.10-0.12)		(43.2-47.3)	
Ch 26	60.6	10.40**	0.12	4.10	49.2	1.82
	(28.3-96.0)		(0.06-0.14)		(40.7-52.9)	
PB 5/76	37.2	8.2**	0.09	0.65	44.4	0.57
	(20.5-59.1)		(0.08-0.10)		(40.4-46.8)	

* Significant at P= 0.05; **Significant at P= 0.01

trials, with a mean yield of 40.7 g t^{-1} t^{-1} in Trial 1 and 57.2 g t^{-1} t^{-1} in Trial 2. Progeny of RRII 105 with a mean yield of 41.7 g t^{-1} t^{-1}, PB 215 with a mean yield of 39.2 g t^{-1} t^{-1} and Ch 26 with a mean yield of 39.1 g t^{-1} t^{-1} were comparable to that of PB 28/83 in Trial 1. Over the second six years of tapping in panel BO-2, progeny of PB 242 and PB 215 in Trial 1 were superior with a mean yield more than 55 g t^{-1} t^{-1} and in Trial 2, progeny of PB 252, Ch 26 and PB 215 recorded superior mean yields more than 64.25 g t^{-1} t^{-1}. When averaged over 12 years of tapping in the virgin panels, in Trial 1, the yield of progenies from parent clones RRII 105, PB 215, PB 28/83, Ch 26 and PB 242 were superior, while in Trial 2, progenies of clones PB 252, PB 28/83 and Ch 26 were superior in terms of annual mean yield. The seedling progeny of clones PB 28/83, RRII 105 and Ch 26 were reported to give high mean yield in the juvenile phase also (Mydin *et al.*, 1996) and the present results confirm the prepotent ability of these clones to produce high yielding progeny. The progeny of PB 5/76, proved to be inferior in terms of both yield and girth. Progeny from this parent clone was also selected for cloning, in a random manner, including high, low and medium yielders. But on attaining maturity as clones the performance of the progeny clones were clearly inferior to the rest, reflecting the significance of selection of high yielding parent clones with known progeny performance in any breeding programme. The mean summer yield also reflected the superiority of progenies of RRII 105, PB 28/83, PB 215 and Ch 26. Clone PB 217 is proven to be drought tolerant in terms of its high summer yield in the traditional rubber growing regions of India (Saraswathyamma *et al*., 2000) and the progeny of this clone in both the trials exhibited superiority in terms of mean yield in the summer months.

Tables 3 and 4 provide details of the annual mean yield over 12 years of tapping, girth at opening and timber yield potential in terms of clear bole volume as well as the recovery of superior clones from within each progeny. The reference clone was RRII 105 for annual mean yield and the reference point for high timber yield of the 18 year old clones was fixed as 0.15 m^3 $tree^{-1}$ based on the range of variability for the trait among the 150 clones evaluated.

Positive estimates of general combining ability (GCA) for annual mean yield were observed in the case of clones PB 28/83, Ch 26, RRII 105, PB 215, PB 252 and PB 5/51 (Mydin *et al*., 2010). The recovery of high yielding clones from the various progenies ranged from 6.7 to 33.3 per cent based on yield over 12 years of tapping in the virgin panels. The parent clone PB 215 gave the highest recovery of 33.3 per cent high yielding clones within its progeny, corroborating the earlier report on GCA. PB 28/83 was the parent with highest recovery of superior seedlings based on test tap yield in the juvenile phase (Mydin *et al*., 1996). In the present study clones PB 28/83 and Ch 26 were second best as parents with 26.7 per cent recovery of high yielding clones in their progeny while PB 242 and PB 252 came third with 20 per cent promising clones. None among the progeny of PB 5/76, was superior in comparison to the checks. Parent clones PB 215, PB 28/83 and Ch 26 with more than 25 per cent recovery of high yielding progeny could be considered prepotent with respect to rubber yield as also proved by their positive estimates of general combining ability reported earlier (Mydin *et al*., 2010).

Clones PB 252, PB 242, RRII 105, PB 28/83, Ch 26 and PB 217 showed positive estimates of GCA for timber yield potential (Mydin *et al*., 2010). This points to the superiority of clones PB 28/83, Ch 26, RRII 105, PB 215, PB 252, PB 217, PB 242 and PB 5/51 as parent material for polycross breeding via polyclonal seed gardens. This result is in confirmation with earlier reports pertaining to the analysis of seedling progeny of these clones (Mydin *et al*., 1996).

Maintenance of high yield in the summer months is an indication of the potential of clones to withstand drought (Raghavendra *et al*., 1984; Vijayakumar *et al*., 1988; Premakumari *et al*., 1993; Narayanan and Mydin, 2015). The recovery of such clones with potential for drought tolerance from within the ten progenies ranged from 6.7-53.3 per cent with more than 25 per cent of the clones in six progenies *viz*. PB 28/83, PB 217, PB 5/51, Ch 26, PB 215 and RRII 105 showing high yield in summer (Table 5).

Dry rubber content in the stress period ranged from 36-42 per cent and in the peak yield season ranged from 34-40 per cent in both the trials with no significant variation among the clones studied. Volume of latex per tap in the stress period ranged from 65-89 ml t^{-1} t^{-1} in Trial I with no significant variation between progenies and from 13-91 ml t^{-1} t^{-1} in the peak season with significant variation. In Trial 2 there was significant variation among progenies in both the peak and stress periods with values ranging from 126-237 ml t^{-1} t^{-1} and 28-91 ml t^{-1} t^{-1} respectively. In the peak season, 12 clones with more than 240 ml t^{-1} t^{-1} within progenies in the two trials gave higher volume yield of latex compared to RRII 105. In the stress period, 42 clones in Trial 1 and 14 clones in Trial 2, with more than 75 ml t^{-1} t^{-1} were better than the check. The two highest yielding clones HS PB 252/132 and HS Ch 26/161 maintained high latex volume yield in both the peak and stress periods.

Reaction to diseases and maladies

A three-year study (Sadanand *et al.*, 2012) evaluated the polycross progeny for their tolerance/susceptibility to abnormal leaf fall (ALF) disease caused by *Phytophthora* spp. and powdery mildew (PM) disease caused by *Oidium heveae.*

Abnormal leaf fall disease

Progenies of PB 215, PB 217 and RRII 105 in Trial 1 and PB 252 in Trial 2 in general exhibited tolerance to ALF disease. The pooled data from Trial 1 of all the three years of evaluation revealed that the clone P 106 evolved from the progeny of RRII 105 was superior with leaf retention of 73 per cent followed by the clone P 131 of the progeny of PB 252 with leaf retention of 70 per cent. From Trial 2, the pooled data of three years showed that clone P 128 of the progeny of AVT 73 was superior with leaf retention of 76 per cent followed by the clones P 75 of the progeny of PB 217 and P69 of the progeny of PB 252 showing leaf retention of 75 per cent. The clone P 132 of the progeny PB 252 and P 172 of the progeny of PB 242 showed leaf retention of 73 per cent over the three year period of assessment indicating moderate tolerance.

Powdery mildew disease

The pooled data on reaction to powdery mildew over a period of three years revealed that only one clone in Trial 1, P 127 the progeny of AVT 73 was observed to be tolerant with 23 per cent disease incidence (PDI), while in Trial 2, the clones P 104 and P 54 evolved from the progeny of 5/76 and the clone P 56 of the progeny of RRII 105 showed less than 25 per cent of PDI and thus were tolerant and promising.

The three year study on 150 clones was able to identify three clones with good tolerance and 33 clones moderately tolerant to ALF disease. However, only four clones were observed to show tolerance to PM disease. None of these proved to be high yielding. However four of the progeny clones (HS PB 252/132, HS PB 252/69, HS RRII 105/106 and HS PB 242/172) which were high rubber yielders proved to be moderately tolerant to *Phytophthora* with more than 70 per cent leaf retention in the field. Two of the high timber yielding clones *viz.* HS PB 252/131 and HS AVT 73/178 showed a high degree of tolerance to *Phytophthora*.

Pink disease

Incidence of Pink disease ranged from 0-33 per cent among clones in Trial 1 and 0-71 per cent among clones in Trial 2. The progeny of RRII 105, clone HS RRII 105/112 which was very high yielding with 44.5 per cent standard heterosis proved to be highly susceptible to the disease, with 71 per cent affected trees (Table 6). However, six high yielding clones evolved from this programme, *viz.* HS PB 252/19, HS Ch 26/160, HS PB 5/51/147, HS PB 242/116, HS PB 242/117 and HS PB 28/83/37 were totally free from Pink disease. Nine high yielders, *viz.* HS Ch 26/161, HS RRII 105/106, HS PB 5/51/82, HS PB 242/172, HS PB 215/93, HS PB 215/

151, HS PB 215/89, HS PB 28/83/80 and HS PB 28/83/191 proved tolerant with less than 20 per cent incidence of pink disease. It is particularly noteworthy that four out of the five (80%) promising clones each evolved from parents PB 242 and PB 215 proved to be tolerant to Pink disease, while of the two high yielding clones evolved from PB 5/51, one was disease free and the other had only nine per cent affected trees (Table 6). The parent clones PB 242 and PB 5/51 showed no incidence of Pink disease, while PB 215 had a low incidence of only 13 per cent affected trees. Among the parent clones, RRII 105 had the highest incidence of 36 per cent affected trees.

Tapping panel dryness

Incidence of tapping panel dryness in the 12^{th} year of tapping among 110 clones in Trial 1 ranged from 0 to 46 per cent partial dryness and 0 to 33 per cent fully dried trees. In Trial 2, among the 51 clones, TPD affected trees were in the range of 0 to 33 per cent partially dried and 0 to 38 per cent fully dried trees. A total of 34 clones in both the trials showed no incidence of tapping panel dryness. Nine high yielding clones *viz*. HS PB 252/19, HS PB 252/69, HS Ch 26/161, HS Ch 26/199, HS RRII 105/112, HS PB 242/117, HS PB 217/180, HS PB 215/90 and HS PB 28/83/37 were totally free from tapping panel dryness, while four high yielders *viz*. HS RRII 106/106, HS PB 242/116, HS PB 215/47 and HS PB 28/83/80 had a very low incidence of less than 10 per cent PD affected trees. Parent clones PB 5/51, Ch 26, PB 252 and PB 242 showed no tapping panel dryness after 12 years of tapping. In clone PB 28/83, only one tree showed partial dryness.

Table 5. **Promising clones in the various polycross progenies**

Polycross progeny of	In terms of rubber yield* over 12 years of tapping in the virgin panels		In terms of summer yield*		In terms of bole volume* at 18 years	
	Mean Yield* ($g\ t^{-1} t^{-1}$)	No. of Promising clones**	Mean Yield* ($g\ t^{-1} t^{-1}$)	No. of promising clones***	Mean Clear Bole Volume* ($m^3\ tree^{-1}$)	No. of promising clones****
RRII 105	48.22	2	18.47	4	0.11	3
PB 242	44.58	3	16.07	1	0.13	5
AVT 73	35.42	1	12.55	-	0.12	4
PB 252	38.82	3	17.32	1	0.14	5
PB 217	42.31	1	27.53	5	0.11	2
PB 28/83	45.73	4	29.51	8	0.12	3
PB 5/51	41.76	2	17.76	5	0.10	-
PB 215	47.52	5	17.41	4	0.11	2
Ch 26	45.40	4	19.22	5	0.11	1
PB 5/76	35.95	-	15.20	2	0.10	-
Total no. of selections		25		35		25

* Pertaining to 15 clones within each progeny
** Clones with yield more than 58.6 $g\ t^{-1} t^{-1}$ (yield across trials, of RRII 105, the high yielding reference clone)
*** Clones with summer yield more than 21.1 $g\ t^{-1} t^{-1}$ (summer yield of PB 217, the drought tolerant reference clone)
**** Clones with clear bole volume more than 0.15 $m^3\ tree^{-1}$ at 18 years

Table 6. **New generation clones evolved by polycross breeding**

Progeny clone	Yield over 12 years		Timber yield at 18 years	Girth at opening	Important features
	Dry Rubber (g t^{-1} t^{-1})	Standard heterosis (%)	Clear Bole Volume (m^3 $tree^{-1}$)	(cm)	
HS PB 252/132	110.7	88.9	0.24	65.2	LT , Moderate ALF tolerance, high volume yield in peak and stress periods
HS PB 252/19	76.7	30.9	0.16	56.9	LT, Pink nil, TPD nil, high volume yield in stress period
HS PB 252/131	38.5	-	0.18	49.9	T, Pink High (50%), High ALF tolerance
HS PB 252/20	27.9	-	0.17	52.4	T
HS PB 252/69	61.6	5.1	0.15	59.0	TL, TPD nil, ALF tolerance moderate
HS Ch 26/161	97.0	64.9	0.14	51.0	L , Pink Low (20%),TPD nil, stable yielder, high volume yield in peak and stress periods
HS Ch 26/199	68.3	16.5	0.14	52.9	L, TPD nil, high latex volume in peak season
HS Ch 26/160	64.6	10.2	0.08	46.8	L, Pink nil
HS Ch 26/198	58.7	0.13	0.12	51.1	L
HS RRII 105/112	85.1	44.5	0.13	61.5	L,TPD nil, Pink High (71%), high volume yield in summer
HS RRII 105/106	75.6	29.0	0.22	51.1	LT, TPD 7%, ALF moderate, High volume yield in peak season
HS RRII 105/108	48.8	-	0.16	54.2	T
HS PB 5/51/82	85.5	45.8	0.13	47.3	L, Pink Low (9%), high latex volume in stress period
HS PB 5/51/147	72.3	23.4	0.13	50.0	L, Pink nil
HS PB 242/172	77.2	31.7	0.18	51.1	LT, Pink Low (13%), Moderate ALF
HS PB 242/117	70.9	21.6	0.17	50.0	LT, Pink nil, TPD nil
HS PB 242/116	63.8	8.9	0.20	53.1	TL, Pink nil, TPD 9%
HS PB 242/6	49.6	-	0.15	41.3	T, high volume yield in stress period
HS PB 242/119	43.0	-	0.17	46.3	T, Pink nil, high volume yield in stress period
HS PB 217/180	71.6	22.1	0.11	53.2	L, TPD nil, high volume yield in stress period

HS PB 217/30	46.1	-	0.17	46.3	T, Pink Low (7%)
HS AVT 73/125	65.8	12.2	0.14	51.7	L, High volume yield in stress period
HS AVT 73/122	31.8	-	0.19	52.0	T, Pink Low (6.7%)
HS AVT 73/128	44.0	-	0.15	51.3	T, Pink nil, ALF tolerance High
HS AVT 73/173	53.8	-	0.17	48.2	T, Pink Low (6.7%)
HS PB 215/93	71.4	20.3	0.01	43.2	L, Pink Low (17%), high volume yield in peak period
HS PB 215/151	64.4	9.8	0.13	49.2	L, Pink Low (14%)
HS PB 215/47	63.9	9.1	0.17	53.7	TL, TPD 7%
HS PB 215/89	63.9	9.1	0.11	47.3	L, Pink Low (8%), high volume yield in peak period
HS PB 215/90	59.0	0.7	0.19	50.6	TL, Pink Low (20%), TPD nil, high latex volume
HS PB 28/83/80	70.5	20.3	0.16	51.2	LT, Pink Low (7%), TPD 7%
HS PB 28/83/191	63.1	7.8	0.12	48.7	L, Pink Low (20%)
HS PB 28/83/37	61.0	4.1	0.19	46.6	TL, Pink nil, TPD nil
HS PB 28/83/35	44.5	-	0.18	50.7	T, Pink nil
HS PB 28/83/188	61.68	5.3	0.12	49.7	L

Rubber yield threshold-Mean yield of check clone RRII 105 across both trials : 58.6 g$t^{-1}t^{-1}$; Bole volume threshold : 0.15 m^3 $tree^{-1}$ at 18 years
LT: Latex-timber dual purpose clone-very high rubber and timber yield; TL: Timber-latex dual purpose clone -high timber yield and rubber yield on par with RRII 105
L: Latex clone with high latex yield but low in timber yield. T: Timber clone with low latex yield.
TPD: Tapping panel dryness after 12 years of tapping.

Selection of genotypes

A total of 25 half-sib clones derived from nine parents exhibited superiority in annual mean yield, 35 half-sib clones derived from nine parents were superior in terms of summer yield and 25 half-sib clones derived from eight parents were good timber yielders (Table 5). Clones from a diversity of parents of varying lineage as indicated in Table 1 were thus generated by this study.

The superior characteristics of 35 selected clones classified as latex-timber clones, latex clones and timber-latex clones are given in Table 6 and Figure 2. Six dual purpose latex-timber clones with 20.3 to 71.3 per cent improvement in rubber yield over the high yielding check, RRII 105 were derived from the polycross progenies of four different parents *viz*. RRII 105, PB 252, PB 242 and PB 28/83. Among these clones, clone HS PB 252/132 developed from PB 252 is particularly notable for its highest yield of both rubber (110.7 g t^{-1} t^{-1}) and timber (0.24 m^3 $tree^{-1}$). Thirteen clones with promising latex yield, but low timber yield were the latex clones derived from this breeding programme. Of these, five high yielding clones were derived from the progeny of four parent clones (PB 217, PB 5/51, Ch 26 and RRII 105), their

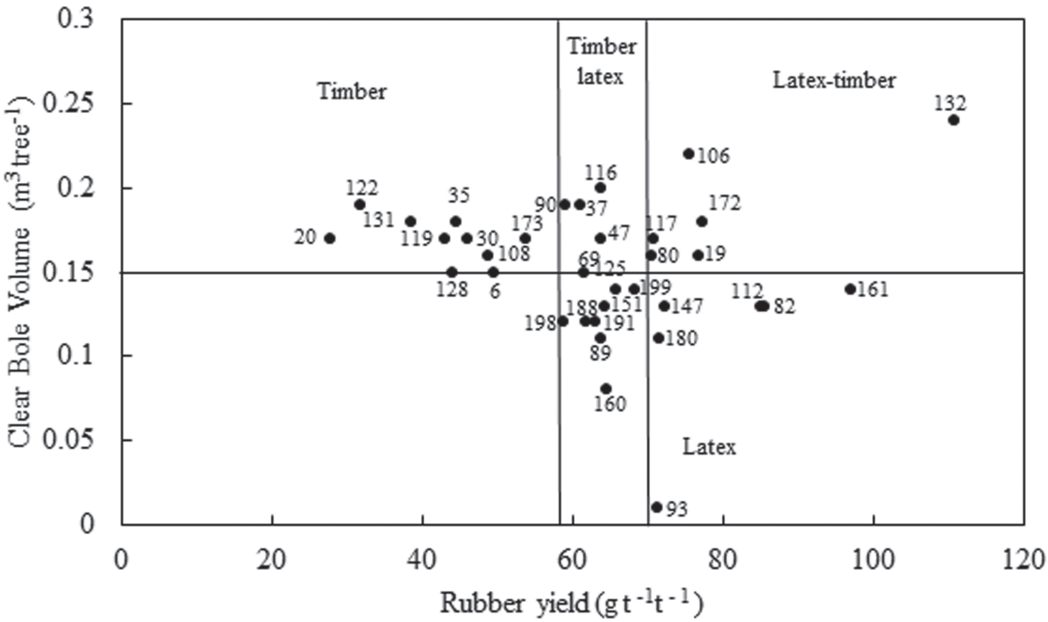

Fig. 2. Latex and timber yield in the elite clones derived by polycross breeding

improvement in yield over the check clone RRII 105 ranging from 20 to 44.5 per cent. Ten clones with high timber yield alone, classified as timber clones were selected from the progeny of six different parents (PB 252, AVT 73, RRII 105, PB 242, PB 28/83 and PB 217) and five clones with high timber yield and latex yield on par with clone RRII 105, classified as the timber-latex clones (Table 6, Fig. 1) were derived from the polycross progeny of four different parents (PB 215, PB 242, PB 28/83 and PB 252).

Stability in yield over the long term

Yield stability as estimated by a given stability measure should be repeatable in time (across environments or years) to be of practical interest for genotype selection and recommendation. Shukla (1972), in defining stability, used stability variance to estimate a component of the G × E interaction corresponding to each genotype. According to this model, a genotype is stable if its stability variance is equal to within environment variance. A significant deviation of a genotype's regression coefficient from zero will be indicated by a large stability variance. Shukla's stability statistic also provides additional information on stability by using covariate to remove the linear effect of environment from GEI. The remainder of the GEI variance can be partitioned into a component, Si 2 (adjusted stability variance), assignable to each genotype, and the significance of this component can be tested by an approximate F test and this is particularly effective when the number of genotypes tested is large (Fernandez, 1991). A nonsignificant stability variance for yield of a clone therefore indicates the stability of the clone across years. Both mean value and consistency of performance should be

Table 7. **Stability in yield of promising clones over 12 years of tapping**

Trial 1				Trial 2			
Clone	Shukla's stability variance	F	Mean yield (g $t^{-1} t^{-1}$)	Clone	Shukla's stability variance	F	Mean yield (g $t^{-1} t^{-1}$)
4	242.83	3.44**	57.5	112	531.31	4.28**	88.2
56	50.48	0.71ns	46.0	117	702.83	5.66**	70.9
106	316.32	4.47**	75.6	125	613.63	4.94**	64.1
107	23.64	0.33ns	42.7	19	1881.96	15.16**	75.1
109	120.23	1.70**	55.9	69	34.36	0.28ns	61.1
111	42.56	0.60ns	42.8	132	1316.53	2.92**	110.7
113	59.21	0.84ns	44.0	131	2303.70	18.55**	56.3
116	172.80	2.44**	63.8	136	142.84	1.15ns	56.9
121	206.78	2.93**	57.0	180	127.78	1.03ns	72.6
172	600.90	8.50**	77.2	81	419.52	3.38**	56.2
128	51.15	0.72ns	44.0	188	126.70	1.02ns	62.3
173	181.29	2.56**	53.8	190	17.05	0.14ns	57.9
22	128.32	1.82**	54.0	191	247.10	1.99ns	63.6
134	26.67	0.38ns	46.2	82	281.49	2.27**	83.6
27	95.95	1.36**	56.6	83	77.05	0.62ns	56.4
28	60.16	0.85ns	43.1	89	33.93	0.27ns	64.0
30	47.97	0.68ns	45.9	93	83.76	0.67ns	70.8
31	34.50	0.49ns	45.8	161	148.53	1.20ns	97.0
75	5.39	0.08ns	46.1	198	49.10	0.40ns	57.6
33	62.59	0.89ns	47.3	199	70.67	0.57ns	69.0
35	24.58	0.35ns	44.5	52	353.16	2.84**	55.9
37	67.47	0.95ns	61.0			GM	52.2
80	176.86	2.50**	70.5				
139	37.33	0.53ns	46.6				
38	211.74	3.00**	58.6				
43	231.59	3.28ns	57.2				
147	179.59	2.54**	72.3				
47	109.87	1.55**	63.9				
90	126.43	1.79**	59.0				
150	84.79	1.20ns	47.6				
151	23.12	0.33ns	64.4				
156	223.01	3.15**	54.5				
157	81.52	1.15ns	53.9				
158	74.38	1.05ns	52.7				
160	79.04	1.12ns	49.92				
162	144.61	2.05**	64.60				
		GM	42.57				

considered for genotype selection. Among the 150 clones evaluated for stability in yield over 12 years, 102 clones proved stable. These included both high yielders and low yielders. When considered against the population mean yields in the two trials (Table 7), 20 promising yielders in Trial 1 and 12 promising yielders in Trial 2 exhibited stability of performance. Among clones in the high yield category (rubber yield >58.6 g $t^{-1} t^{-1}$), 11 clones were stable in terms of long term yield in both the trials put together (Table 7). These are clones HS Ch 26/161, HS PB 252/132, HS PB 217/180, HS PB 215/93, HS Ch 26/199, HS PB 215/151, HS PB 215/89, HS PB 28/83/191, HS PB 28/83/188, HS PB 252/69 and HS PB 28/83/37. Clones HS RRII 105/112 and HS PB 5/51/82 which gave yields exceeding 80 g $t^{-1} t^{-1}$ were not stable indicating significant influence of the environment over the years. These clones with potential for very high yields could be further tested in multi environment trials to detect adaptability to specific locations. Among the 11 stable yielders, three clones each were half sib progeny of parentage PB 215 and PB 28/83 and two were half sibs derived from Ch 26. This is a further indication of the worth of the three prepotent clones as parent material for future breeding programs.

CONCLUSION

The advantage of resorting to polycross breeding is the relative ease of obtaining large families of naturally crossed rubber seedlings from a diversity of parents for greater efficiency of selection. The nine female parents from which the 25 high yielding clones were evolved exhibited significant genetic variability for economically important attributes and belonged to two genetically divergent clusters (Mydin *et al*., 1992; Mydin *et al*., 1996a). The first systematic polycross breeding programme of the Rubber Research Institute of India initiated in 1989 has thus resulted in the development of 37 promising clones of which 12 clones were significantly high rubber yielders showing more than 20 per cent improvement in yield over the high yielding check clone RRII 105. The presently evolved clones exhibited rubber yields ranging from 70.5-110.7 g $t^{-1} t^{1}$ which works out to an estimated 2820 to 4429 kg $ha^{-1}year^{-1}$. Estimation of stability across years proved clone HS PB 252/132 with 110.7 g $t^{-1} t^{-1}$ to be inconsistent in performance while HS Ch 26/161 with 97.4 g $t^{-1} t^{-1}$ along with 11 other high yielding clones were consistent in yield in the long term. While the highest rubber yielding clone HS PB 252/132 was also the highest timber yielder and was moderately tolerant to abnormal leaf fall, clone HS Ch 26/161 had a very low incidence of pink disease with no tapping panel dryness. These clones are now under evaluation in farmer participatory multi locational trials which form the final phase of their evaluation prior to release. Clones PB 215, PB 28/83 and Ch26 were confirmed to be prepotent for rubber yield with more than 25 per cent of their progeny being high yielding.

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