EVALUATION OF POLY-CROSS PROGENY POPULATIONS OF *HEVEA BRASILIENSIS* IN THREE AGRO-CLIMATIC ZONES OF INDIA

M.J. Reju[1], Kavitha K. Mydin[1], Meena Singh[2] and Sandeep Kumar[3]

[1]Rubber Research Institute of India, Rubber Board, Kottayam-686009, Kerala, India
[2]Regional Research Station, Dapchari-401 610, Thane, Maharashtra, India
[3]Regional Research Station, Nagrakata-735 225, West Bengal, India

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Open pollinated seeds of *Hevea brasiliensis* were collected from polyclonal seed gardens and multi-clone trials situated in both traditional and non-traditional rubber growing zones in India and evaluated in three agro-climatically different zones *viz.* traditional region (Kerala), drought (Maharashtra) and cold (West Bengal) conditions. Evaluation of these polycross progeny populations resulted in the selection of 146 superior progenies. The minimum dry rubber yield of selections in Kerala was 20 g $t^{-1}10t^{-1}$, West Bengal was 15 g $t^{-1}10t^{-1}$ and Maharashtra was 5 g $t^{-1}10t^{-1}$. Mean dry rubber yield of the selections from each population was significantly different from the mean of each population. The highest number of selections was obtained from the progeny population of Tura followed by Kanyakumari, Nagrakata and Agartala. The final selections were 64, 39, 43 which was 7, 4 and 6 per cent, respectively from Kerala, Maharashtra and West Bengal. Progeny populations originated from the traditional regions outperformed the populations from the non-traditional regions of Maharashtra and West Bengal even when screened in their respective non-traditional climates. Meanwhile, when the progeny populations originated from the non-traditional regions were planted in the ideal traditional climate, they performed better than in their native climates. A clear distinction was obtained between the yield of the progenies with girth below the population mean and the yield of the progenies with girth above the population mean. From a total of 6126 progenies evaluated, a total of 2685 progenies were test-tapped and out of the 146 selections, only two of the selections fell in the below mean girth group while 144 selections (99% of the selected progenies) were in the above mean girth group. A strong association of 49 per cent (R^2) dependence of the population yield on girth was observed. Progenies originated from the drought region showed a high dependence of yield on girth (56%) suggesting vigorous girth as a requirement for economic yield in the drought regions. Rubber plants grown in cool climate was superior in yield and girth than that observed under hot climate. Severe reduction in girth and rubber yield was found under the dry climate while reduction in height of plants was noticed under the cool climate. This study also suggests establishment of new PSGs to obtain recombinants with higher levels of yield and girth growth.

Key words: *Hevea* breeding, Natural rubber, Polycross progenies, Progeny evaluation

INTRODUCTION

Location specific clone development and extension of rubber cultivation to non-traditional regions in India are important research programs of the Rubber Research Institute of India (Sethuraj and Jacob, 2012). Clones of *Hevea brasiliensis* that grow vigorously and yield satisfactorily under

Correspondence: Reju M.J. (E-mail: reju@rubberboard.org.in)

sub-optimal and stressful climatic conditions are a prerequisite for any further extension of rubber growing areas beyond the traditional regions in India. Clones developed in India as well as imported from other rubber growing countries are all originated from elite seedling progenies while budgrafting helped in the multiplication of these elite seedling progenies with their genetic makeup intact. Seeds of *Hevea brasiliensis* produced under hand pollination (HPs) programs, half-sib seeds originated from pre-potent mother clones, and open pollinated (OP) seeds originated from polyclonal seed gardens (PSG) constitute the foundation of clone development programs.

In India, the Rubber Research Institute established PSG in Tamil Nadu, Karnataka and in the north-eastern state of Mizoram with selected clones in specific designs with a view to maximise cross pollination among the component clones for the generation of quality seeds. Importance of polycross breeding and PSGs has already been reported (Mydin, 2014). Apart from PSGs, multi-clone trials consisting of elite clones were also planted in various states in the Regional Stations of the Rubber Research Institute of India. Seeds originated from these PSGs and clone trials offer the possibility of selection of valuable recombinants, as *Hevea brasiliensis* is an open pollinated crop species. Development of clones compatible to regional climatic conditions is the aim of location specific clone development because, although the traits are gene-controlled, their manifestation in the environment are often influenced and altered by the interaction of the environment. Rubber is one such crop species highly influenced by GxE interactions (Meenakumari *et al.*, 2011). With these points in view rubber seeds originated in PSGs and multi-clone trials from ten locations in India were collected, planted and evaluated in three agro-climatically different regions of drought prevailing, cold prone and near ideal climates.

MATERIALS AND METHODS

Open pollinated seeds were collected from both the PSGs and multi-clone trial sites. Seeds from three PSGs, and seven statistically laid out multi-clone trial sites were collected during the seed season of 2013 (July – September). Of the three PSGs, two are in the south Indian states of Tamil Nadu (Kanyakumari district) and Karnataka (Dakshina Kannada district) and the third PSG is in the North-eastern state of Mizoram (Kolasib). The multi-clone trial sites were located in the states of Tripura (Agartala), Meghalaya (Tura), Assam (Guwahati), West Bengal (Nagrakatta), Maharashtra (Dapchari) and Kerala (Chethackal and Kottayam). Seeds originated from Agartala, Guwahati, Kolasib, Nagrakata and Tura represented seeds from humid subtropical climate. Seeds originated from Dapchari represented seeds from dry sub-humid tropical climate, and seeds originated from Kanyakumari, Chethackal, Kottayam and Nettana represented seeds from humid tropical climate. The clonal composition of the PSGs and clone-trials from which seeds were collected are given in Table 1.

The seeds collected from these locations were transported to the three diverse locations for seed germination and field planting. Dapchari in Maharashtra, Nagrakata in West Bengal and Kottayam in Kerala were the locations selected for seedling progeny evaluations. Dapchari ($20^0 04'$N, $72^0 04'$E, and 48 m above MSL) represented a dry and hot climate which often leads to drought conditions. Although heavy rainfall occurs in the region, it is normally restricted from June to September and the rest of the months

Table 1. **Clonal composition**

Polyclonal Seed Gardens			Clone Trials		
Nettana	Kanyakumari	Mizoram	Dapchari	Guwahati & Tura	
RRII 105	RRII 105	RRII 105	RRII 5	RRII 5	GT 1
PB 215	RRII 203	RRII 118	RRII 6	RRII 105	Gl 1
PB 217	PB 217	RRII 300	RRII 105	RRII 118	RRIC 102
PB 242	PB 235	RRIM 600	RRII 208	RRII 203	RRIC 105
PB 252	PB 260	GT 1	RRII 308	RRII 208	
PB 5/51	PB 280	PB 235	PB 260	PB 86	
PB 28/83	PB 310	SCATC 93-114	PB 310	PB 235	
AVT 73	PB 312		PB 311	PB 310	
Ch 26	PR 255		RRIC 52	PB 311	
	PR 261		RRIC 100	PB 5/51	
			RRIC 102	RRIM 600	
			RRIC 105	RRIM 605	
			PR 255	PR 255	
			PR 261	PR 261	

Clone Trials				
	Kottayam	Chethackal	Nagrakatta	Agartala
RRII 5	PB 310	RRII 52	RRII 105	RRII 5
RRII 105	PB 311	RRII 53	RRII 118	RRII 105
RRII 118	PB 312	RRII 54	RRII 203	RRII 118
RRII 208	PB 314	RRII 55	RRII 208	RRII 203
RRII 300	KRS 25	RRII 105	RRII 300	RRIM 600
RRII 308	KRS 128	RRII 402	RRIM 605	RRIM 703
RRIM 600	KRS 163	RRII 403	RRIM 612	PB 5/51
RRIM 703	PR 255	RRII 407	RRIM 703	PB 86
PB 217	PR 261	RRII 410	PB 86	PB 235
PB 235	SCATC 88/13	RRII 414	PB 235	RRIC 52
PB 255	SCATC 93/114	RRII 417	PB 311	RRIC 105
PB 260	Haiken 1	RRII 422	PB 5/51	GT 1
PB 280		RRII 427	PR 107	Gl 1
		RRII 430	GT 1	Harbel 1
		RRII 434	Gl 1	
		RRII 454	SCATC 88/13	
		PB 330	SCATC 93/114	
			Haiken 1	

in the year are dry. Nagrakatta (26^0 54′N, 88^0 25′E, and 69 m above MSL) represented a low temperature prevailing cool climate from October to February. Kottayam (09^0 32′N, 76^0 36′E, and 73 m above MSL) represented a warm and humid climate ideal for rubber cultivation.

A total of 6,126 seedling progenies were planted for evaluation, of which 1824 seedlings were planted in Kerala in the RRII Campus at Kottayam, 2,196 progenies in the Regional Research Station at Dapchari in Maharashtra, and 2,106 progenies in the Regional Experiment Station at Nagrakatta in West Bengal. Number of seeds that were available for collection from Nettana and Dapchari were few due to heavy incidence of leaf diseases in Nettana and shortage of seeds in general at Dapchari.

Germinated seeds were planted in polybags and kept till all the plants were ready for simultaneous field planting. In the seedling nursery the seeds were planted in two feet spacing in blocks. In the first year of planting, the plants were given lifesaving irrigation. After one year of growth, height of the plants, number of leaves and number of whorls were recorded. When the population attained three years of growth in 2016, the trees were marked for test-tapping. Girth was recorded at 30 cm height from the base. The trees were test-tapped at 20 cm height following S/2 d3 6d/7 tapping system. Latex yield from the first five tappings were discarded and subsequent ten tappings were collected together for drying and yield recording. The oven dried lumps were weighed, and recorded as dry rubber yield in grams per tree in ten tappings ($g\ t^{-1}\ 10t^{-1}$). Difference between the selections and their respective population means, and comparison of population's mean values for girth and yield were computed. The data were subjected to independent 't' test, and association of traits using correlation coefficient (r), coefficient of determination (R^2) and scatter plots (Gomez and Gomez, 1989).

RESULTS AND DISCUSSION

Performance of the progeny populations

Poly-cross progeny populations originated from different agro-climatic conditions were evaluated for dry rubber yield and girth in Kerala, Maharashtra and West Bengal (Table 2). In Kerala, population mean dry rubber yield was the highest in the population originated from Tura (8.1 $g\ t^{-1}\ 10t^{-1}$) followed by the population from Kanyakumari (7.5 $g\ t^{-1}\ 10t^{-1}$) and Agartala (7.3 $g\ t^{-1}\ 10t^{-1}$). The population mean girth was also the highest in the progeny population from Tura (17.6 cm) followed by that of Agartala (16.8 cm) and Kanyakumari (16.4 cm). Progeny population with a higher number of average performers were also noticed in the population originated from Tura. When the populations were evaluated in the dry and hot climate of Maharashtra (Dapchari) the highest girth was recorded in the progeny populations from Kanyakumari (9.9 cm) followed by Nettana (9.5 cm), whereas the highest mean yield was recorded in the progeny population from Nettana (2.0 $gt^{-1}\ 10t^{-1}$) followed by the population from Kanyakumari (1.7 $g\ t^{-1}\ 10t^{-1}$). In the cool climate of West Bengal (Nagrakatta) the highest yield was recorded in the population from Nettana (7.0 $g\ t^{-1}\ 10t^{-1}$) followed by the population from Kanyakumari (6.5 $g\ t^{-1}\ 10t^{-1}$). Girth was the highest in the population from Kanyakumari (14.5 cm) followed by the population from Nagrakatta (14.3 cm). Clonal combinations and the potential of the parents in the PSGs of Kanyakumari and Nettana could have contributed to the performance of the progenies in both the dry climate of Maharashtra and cool climates of West Bengal.

While the lowest yield was zero in all the populations in all the regions of evaluation,

Table 2. **Dry rubber yield and girth of the progeny populations**

Zones of evaluation	Origin of the progeny populations	Yield (g t^{-1} 10t^{-1})					Girth (cm)				
		*Mean	Range	SE	SD	CV	Mean	Range	SE	SD	CV
Kerala	Agartala	7.3 (102)	0-86.8	1.18	11.9	162.9	16.8	10.0-34.0	0.5	5.3	31.4
	Chethackal	5.0 (123)	0-66.6	0.73	8.1	161.2	15.6	10.0-33.5	0.5	5.0	31.7
	Dapchari	6.7 (87)	0-32.4	0.83	7.7	114.9	15.5	9.0-28.0	0.5	4.7	30.1
	Guwahati	4.8 (90)	0-40.9	0.68	6.4	133.8	15.7	9.0-32.0	0.5	4.5	28.7
	Kanyakumari	7.5 (100)	0-42.9	0.80	8.0	106.1	16.4	10.0-28.5	0.4	4.4	26.8
	Kolasib	6.5 (114)	0-55.3	0.88	9.4	144.8	16.3	9.5-32.0	0.5	4.8	29.5
	Nagrakata	3.8 (62)	0-21.3	0.57	4.5	117.6	15.2	10.0-28.0	0.6	4.5	29.4
	Kottayam	6.1 (96)	0-44.4	0.81	7.9	129.3	16.1	10.0-32.0	0.5	5.2	32.0
	Tura	8.1 (145)	0-39.0	0.73	8.9	109.3	17.6	10.0-31.0	0.4	4.8	27.3
Maharashtra	Agartala	0.8 (139)	0-12.2	0.16	1.9	231.3	09.2	3.8-17.5	0.2	2.9	31.0
	Chethackal	0.7 (106)	0-07.0	0.14	1.5	207.1	09.1	4.0-17.2	0.2	2.4	26.8
	Dapchari	0.4 (74)	0-04.1	0.11	1.0	240.0	08.1	4.0-15.0	0.3	2.3	28.4
	Guwahati	1.0 (92)	0-09.0	0.19	1.8	178.0	09.4	3.0-16.0	0.3	2.5	26.1
	Kanyakumari	1.7 (136)	0-13.7	0.22	2.6	151.8	09.9	5.3-18.8	0.2	2.7	27.3
	Kolasib	0.6 (129)	0-04.0	0.09	1.1	175.0	08.4	4.6-14.0	0.2	1.9	22.3
	Nagrakata	0.9 (143)	0-07.9	0.15	1.8	196.7	09.4	3.8-18.0	0.2	2.4	26.0
	Kottayam	0.4 (92)	0-03.6	0.09	0.8	210.0	08.6	5.0-13.5	0.2	2.1	24.7
	Tura	1.2 (121)	0-07.9	0.15	1.7	139.2	09.4	5.0-15.2	0.2	2.2	23.5
	Nettana	2.0 (11)	0-07.6	0.80	2.7	133.0	09.5	7.1-12.1	0.5	1.7	18.3
West Bengal	Agartala	4.4 (84)	0-24.6	0.49	4.5	102.3	13.9	6.6-22.8	0.4	3.7	26.8
	Chethackal	4.9 (55)	0-22.0	0.63	4.7	95.3	13.7	6.4-20.8	0.5	3.9	28.4
	Dapchari	5.3 (19)	0-30.2	1.57	6.8	128.9	12.4	6.6-22.1	1.0	4.4	35.7
	Guwahati	5.3 (112)	0-44.2	0.55	5.8	109.4	12.9	5.8-25.1	0.4	3.9	30.3
	Kanyakumari	6.5 (34)	0-30.2	0.98	5.7	88.0	14.5	6.5-23.5	0.8	4.7	32.3
	Kolasib	5.8 (108)	0-34.0	0.67	6.9	119.1	13.4	5.5-27.1	0.5	4.7	35.1
	Nagrakata	6.1 (120)	0-32.2	0.55	6.0	98.9	14.3	3.0-27.2	0.4	4.9	34.1
	Kottayam	4.8 (57)	0-19.8	0.54	4.1	85.6	13.6	5.7-23.8	0.6	4.3	31.7
	Tura	5.3 (101)	0-39.4	0.53	5.3	100.2	13.2	4.3-24.6	0.4	4.2	31.7
	Nettana	7.0 (31)	0-21.2	1.12	6.2	89.0	13.8	5.3-25.8	0.9	4.9	35.3

* Numbers in parenthesis are number of observations

the highest yield varied from 21.3 g t^{-1} $10t^{-1}$ (Nagrakatta) to 86.8 g t^{-1} $10t^{-1}$ (Agartala) in Kerala conditions (Table 3). In Maharashtra, the maximum yield ranged from 4.0 g t^{-1} $10t^{-1}$ (Kolasib) to 13.7 g t^{-1} $10t^{-1}$ (Kanyakumari). In West Bengal, the highest yield varied from 19.8 gt^{-1} $10t^{-1}$ (Kottayam) to 44.2 g t^{-1} $10t^{-1}$ (Guwahati). Dry rubber yield was the primary criterion for selection of progenies. Dry rubber yields were fixed based on mean performance of the populations in their respective zones. This was done to maximise the selections from the progeny populations so that the risk of erosion of valuable genotypes could be minimised. Since the population mean of dry rubber yields and the range of yields were the highest in the traditional state of Kerala followed by West Bengal and Maharashtra; the lowest dry rubber yield fixed for selection in Kerala was 20 g t^{-1} $10t^{-1}$ and that was 15 g t^{-1} $10t^{-1}$ for West Bengal and 5 g t^{-1} $10t^{-1}$ for Maharashtra. While setting this yield criterion for selection, it was also kept in view that the number of selections should be manageable for their further screening in the next stage of clone development which is clonal nursery evaluation.

In Kerala, the highest number of selections were obtained from the progeny population of Tura (17) followed by nine each from Kanyakumari and Agartala (Table 3). In Maharashtra, the highest number of selections were obtained from the Kanyakumari population (12) followed by populations from Nagrakatta (8) and Agartala (5). However, no selection could be obtained from the progeny population of Dapchari despite the fact that the population was originated from the same location. In West Bengal the highest number of selections were from the local population of Nagrakatta (10) followed by the population from Kolasib (8). Higher number of selections from the progeny populations of Kanyakumari and Agartala was observed in both traditional climate of Kerala and in the dry climate of Maharashtra. Number of selections obtained from the progeny populations of Nagrakatta and Kolasib when screened in the local cool climate indicates the importance of specific adaptation in contrary to the performance of local recruits in a dry region. Average dry rubber yield of the selections from each population was different from the mean of each population at one per cent level of significance wherever the number of selections was more than two.

When the pooled data on yield and girth were analysed for the performance of the ten populations across environments, it was found that the highest mean dry rubber yield was recorded in the Nettana population (5.7 g t^{-1} $10t^{-1}$) followed by Tura (5.1 g t^{-1} $10t^{-1}$) and Kanyakumari (4.4 g t^{-1} $10t^{-1}$) and the lowest yield of 3.4 g t^{-1} $10t^{-1}$ was recorded in the population from Chethackal and Nagrakatta (Table 4). The highest girth was recorded in the progeny population from Tura (13.6 cm) followed by Kanyakumari, Kottayam and Chethackal (12.9 cm each). In all, the highest number of selections were obtained from the progeny population of Tura (25) followed by Kanyakumari (23), Nagrakatta (20) and Agartala (18). However, the highest per cent of selections were from Nettana (14%) followed by Kanyakumari (9%) and Tura (7%).

Selection process

Initially 1824 seedlings were planted in Kerala and after the completion of three years, 919 plants were ready for test-tapping (Table 5). In Maharashtra, 1043 out of 2196 seedlings came to the test-tapping stage while in West Bengal 721 out of 2106 seedlings came to the test-tapping stage. Most of the remaining plants were either small or lost due to cold damage (in West Bengal). The number of trees that came to

Table 3. **Selection of progenies from varying agro-climatic origins**

Zones of evaluation	Origin of the progeny populations	Dry rubber yield ($g\ t^{-1} 10t^{-1}$)			Number of selections	T - Statistic	T - Table (0.01)
		Population mean	Mean of selections	Range of selections			
Kerala	Agartala	7.3	37.2	21.5-86.8	9	4.84	3.36
	Chethackal	5.0	31.0	21.7-66.6	5	2.92	4.60
	Dapchari	6.7	26.3	20.4-32.4	7	11.35	3.71
	Guwahati	4.8	32.2	23.4-40.9	2		
	Kanyakumari	7.5	26.6	20.5-42.9	9	7.50	3.36
	Kolasib	6.5	37.2	22.0-55.3	7	6.43	3.71
	Nagrakata	3.8	20.9	20.4-21.3	2		
	Kottayam	6.1	31.8	20.8-44.4	6	7.66	4.03
	Tura	8.1	28.5	20.1-39.0	17	14.46	2.92
Maharashtra	Agartala	0.8	08.6	06.2-12.2	5	6.30	4.60
	Chethackal	0.7	06.1	05.3-07.0	4	15.28	5.84
	Dapchari	0.4			0		
	Guwahati	1.0	06.8	05.7-09.0	4	7.60	5.84
	Kanyakumari	1.7	08.5	05.1-13.7	12	9.77	3.11
	Kolasib	0.6			0		
	Nagrakata	0.9	06.9	05.1-07.9	8	18.37	3.50
	Kottayam	0.4			0		
	Tura	1.2	06.7	05.4-07.9	4	10.15	5.84
	Nettana	1.9	05.7	05.7-07.6	2		
West Bengal	Agartala	4.4	19.8	18.0-24.6	4	9.49	5.84
	Chethackal	4.9	18.7	17.0-22.0	3	8.46	9.93
	Dapchari	5.3		0	1		
	Guwahati	5.3	24.6	15.0-44.2	5	3.63	4.60
	Kanyakumari	6.5	24.9	19.6-30.2	2		
	Kolasib	5.8	26.3	17.2-34.0	8	8.63	3.50
	Nagrakata	6.1	22.0	15.4-32.2	10	9.32	3.25
	Kottayam	4.8	17.7	15.6-19.8	2		
	Tura	5.3	24.4	15.0-39.4	4	3.61	5.84
	Nettana	7.0	19.2	17.0-21.2	4	12.58	5.84

Mean value of selections were different at 1% level significance from the population mean

test-tapping amounted to 50, 47 and 34 per cent, respectively in the regions of evaluation in Kerala, Maharashtra and West Bengal. The number of trees that yielded above the population averages were 406, 495 and 362, respectively from the three regions in Kerala, Maharashtra and West Bengal which was 44, 47 and 50 per cent of the trees test-tapped. The number of final selections and their percentages from Kerala, Maharashtra and West Bengal were 64, 39, 43, and 7, 4 and 6 per cent, respectively (Table 5).

Table 4. **Pooled data on yield and girth of progenies based on their place of origin**

Origin of the progeny populations	Number of progenies	Dry rubber yield ($g\ t^{-1} 10t^{-1}$)				Girth (cm)				Number of selections	Percentage of selections
		Mean	Range	SD	CV	Mean	Range	SD	CV		
Agartala	327	3.8	0-86.8	7.6	200.7	12.8	3.8-34.0	5.2	40.7	18	6
Chethackal	284	3.4	0-66.6	6.1	179.3	12.9	4.0-33.5	5.0	38.5	12	4
Dapchari	180	4.0	0-32.4	6.6	164.9	12.3	4.0-28.0	5.3	43.2	8	4
Guwahati	294	3.8	0-44.2	5.5	143.7	12.6	3.0-32.0	4.5	35.5	11	4
Kanyakumari	270	4.4	0-42.9	6.2	139.6	12.9	5.3-28.5	4.8	37.0	23	9
Kolasib	351	4.1	0-55.3	7.1	173.3	12.4	4.6-32.0	5.1	40.9	15	4
Nagrakata	325	3.4	0-32.2	4.9	145.5	12.3	3.0-28.0	4.7	37.8	20	6
Kottayam	245	3.7	0-44.4	5.9	162.4	12.9	5.0-32.0	5.4	41.6	8	3
Tura	367	5.1	0-39.4	6.9	136.9	13.6	4.3-31.0	5.2	38.2	25	7
Nettana	42	5.7	0-21.2	5.9	103.9	12.6	5.3-25.8	4.7	36.9	6	14

The final selection of the number of progenies showed that 93 per cent of the original test-tapped population from Kerala, 96 per cent of the population from Maharashtra and 94 per cent of the population from West Bengal finally got eliminated. Since the number of progenies discarded after the test-tapping of the population was huge in the poly-cross progeny evaluation trial, it become necessary to find an approach that would downsize the progeny population before the test-tapping begins so that time and labour spent on the test-tapping of the whole population could be saved. The approach to downsize the population before test-tapping involved an analysis of the girth and yield of the populations and their interaction in respect of the selections and the rejections. Earlier reports on poly-cross progenies (Mydin *et al.,* 1990; Mydin *et al.,* 1996; Mydin, 2012) have mentioned juvenile girth as a trait with the highest positive correlation on test-tap yield. In the present study, association of traits in terms of correlation coefficient (r) and coefficient of determination (R^2) were computed between dry rubber yield (dependent variable) and girth (independent variable). It was found that there exists a positive and significant correlation between girth growth and dry rubber yield in the open pollinated progenies (Fig. 1). Earlier studies have reported seedling vigour and morphology in the immature nursery stage as associated with mature yield performance (Haskell, 1961 and Tan, 1987). Rubber yield being a complex trait is highly heritable and the yield potential is evident in the early nursery stage of the seedlings (Simmonds, 1989).

Scatter plots of rubber yield on girth showed a more clear relation between yield and girth (Fig. 1). The correlation and coefficient of determination values between dry rubber yield and girth were 0.70 and 0.49, respectively. A regression value of 0.49 which is 49 per cent dependence of yield on girth under ideal climate is generally not seen when yield and girth are compared in smaller number of populations or clones. Most of the high yielders in the present study were seen towards the right side of the plots. A still higher dependence of yield on girth was noticed in the population originated from the

Table 5. **Details of progeny populations planted and selected**

Zones of evaluation	Origin of the progeny populations	Number of progenies		Tappability (%)	Progenies with yield above the population mean		Selection of progenies		Per cent of progenies
		Planted	Test-tapped		Number	Per cent	Number	Per cent	
Kerala	Agartala	192	102	53	44	43	9	9	91
	Chethackal	183	123	67	53	43	5	4	96
	Dapchari	185	87	47	39	45	7	8	92
	Guwahati	206	90	44	41	46	2	2	98
	Kanyakumari	196	100	51	48	48	9	9	91
	Kolasib	239	114	48	50	44	7	6	94
	Nagrakata	220	62	28	25	40	2	3	97
	Kottayam	188	96	51	41	43	6	6	94
	Tura	215	145	67	65	45	17	12	88
	Total	1824	919	50	406	44	64	7	93
Maharashtra	Agartala	243	139	57	68	49	5	4	96
	Chethackal	243	106	44	48	45	4	4	96
	Dapchari	243	74	30	33	45	0	0	100
	Guwahati	207	92	44	39	42	4	4	96
	Kanyakumari	243	136	56	68	50	12	9	91
	Kolasib	243	129	53	60	47	0	0	100
	Nagrakata	243	143	59	70	49	8	6	94
	Kottayam	243	92	38	43	47	0	0	100
	Tura	243	121	50	60	50	4	3	97
	Nettana	36	11	31	6	55	2	18	82
	Total	2196	1043	47	495	47	39	4	96
West Bengal	Agartala	288	84	29	43	51	4	5	95
	Chethackal	189	55	29	30	55	3	5	95
	Dapchari	63	19	30	8	42	1	5	95
	Guwahati	288	112	39	56	50	5	4	96
	Kanyakumari	108	34	31	18	53	2	6	94
	Kolasib	315	108	34	51	47	8	7	93
	Nagrakata	288	120	42	59	49	10	8	92
	Kottayam	189	57	30	28	49	2	4	96
	Tura	288	101	35	55	54	4	4	96
	Nettana	90	31	34	14	45	4	13	87
	Total	2106	721	34	362	50	43	6	94

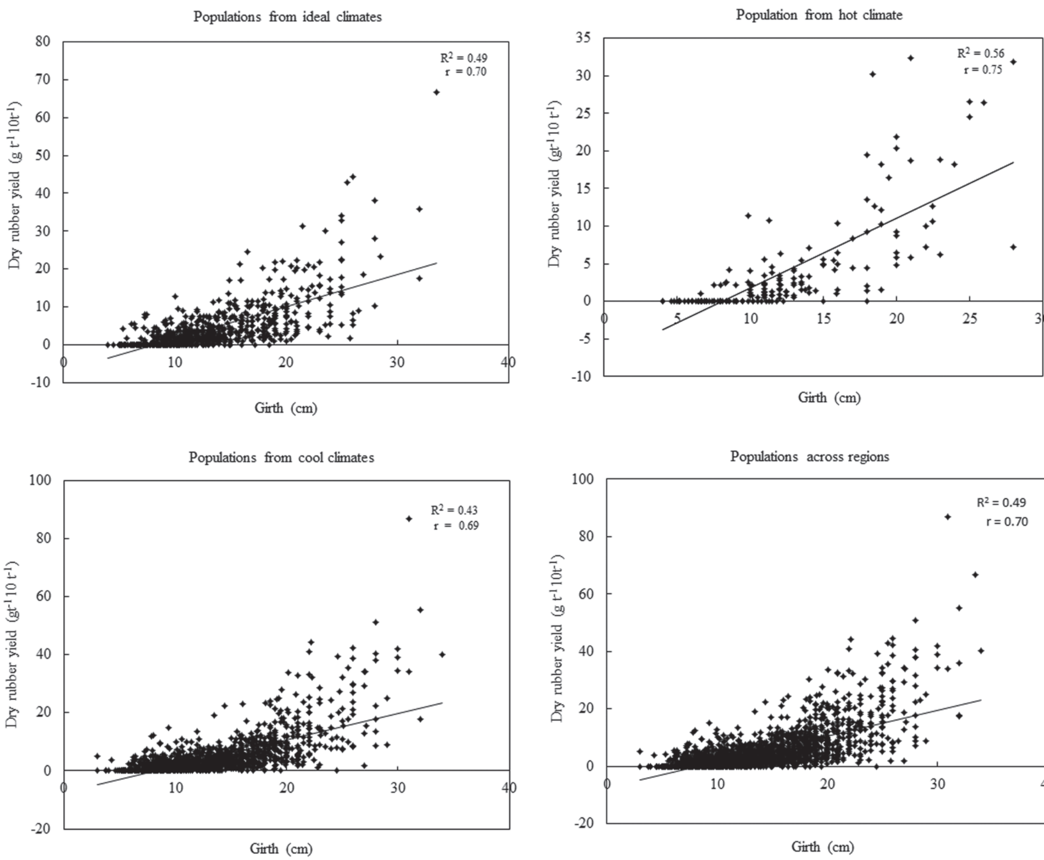

Fig. 1. Dry rubber yield *vs* girth in progeny populations originated from different agro-climatic conditions

drought climate of Maharashtra. Correlation and coefficient of determination values between dry rubber yield and girth were 0.75 and 0.56, respectively which is 56 per cent dependence of yield on girth. In the populations from the cool regions, the correlation and coefficient of determination values between dry rubber yield and girth were 0.70 and 0.48, respectively showing a 48 per cent dependence of yield on girth. This gives an indication that under drought climates, dependence of yield on girth is stronger compared to cool and traditional climates. A 49 per cent dependence on girth growth for yield was found across locations. Approximately 50 per cent contribution of the girth growth towards yields show the importance of girth of the trees in *Hevea* crop improvement programmes, especially when early attainment of tappability coupled with higher yield is a highly desirable attribute. In this study nearly 50 per cent of the yield performance of the population was a function of girth or tree growth.

The progeny populations were divided into two yield groups. The first group consisted of yield of progenies with girth below the population mean and the second group consisted of yield of progenies with girth above the population mean (Fig. 2).

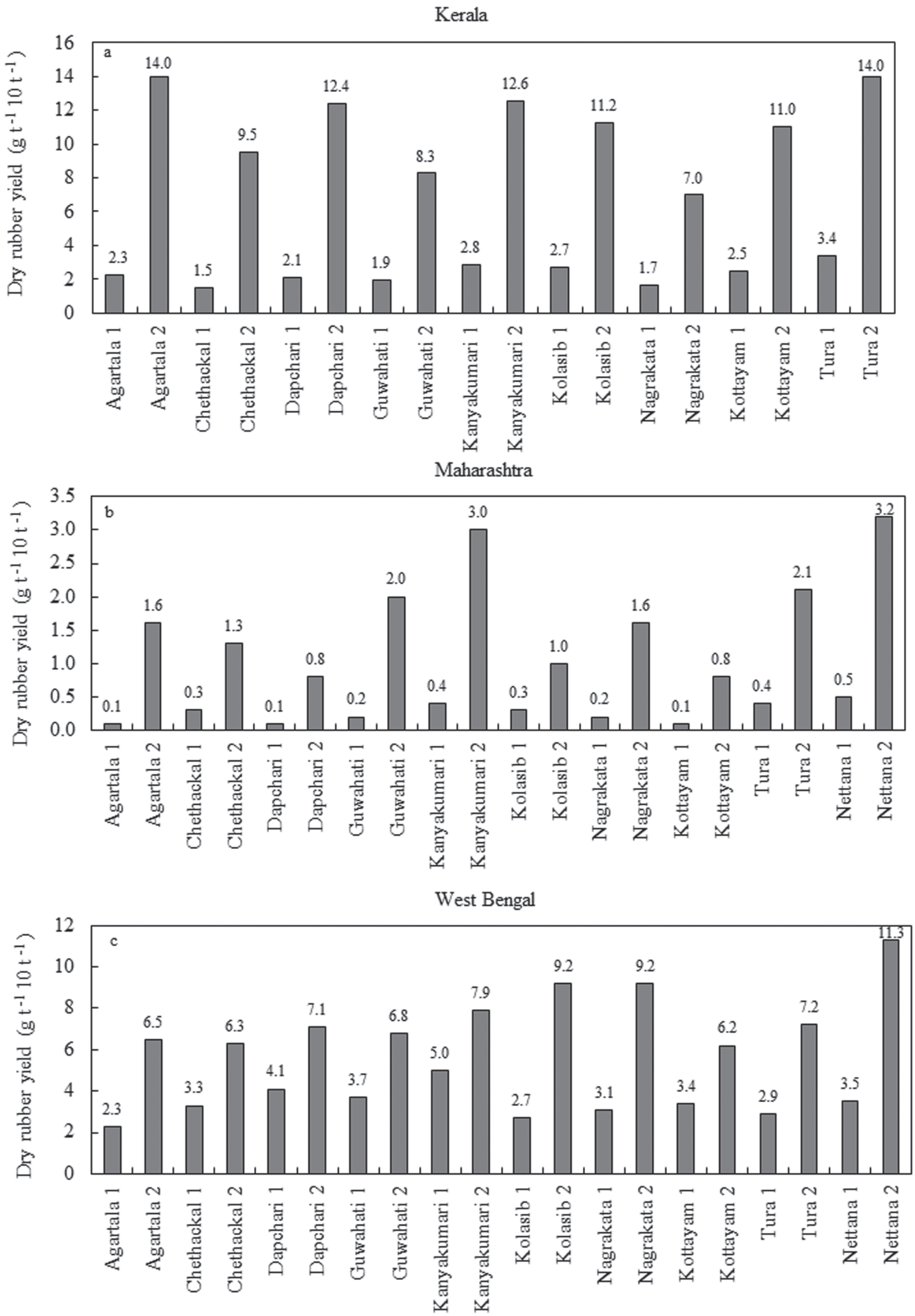

Fig. 2. Yield of progenies from low and high girth categories from three locations

1. Yield of seedlings with girth below population mean 2. Yield of seedlings with girth above population mean

In all the progeny populations evaluated in Kerala, the mean yield of the progenies with girth above the population mean was significantly different from that of the progenies with girth below the population mean (Fig. 2a). In Maharashtra, also the trend was the same except for the population from Nettana, the reason being the smaller size of the population (Fig. 2b). Similarly, in West Bengal, the same trend was obtained except for the population from Dapchari, the reason being the smaller size of the population (Fig. 2c). Thus, there existed a clear distinction between the yield of the progenies with girth below the population mean and that of the progenies with girth growth above the population mean.

Further validation of the association between girth and yield of seedlings was attempted. Out of the 64 selected progenies from the progeny populations evaluated in Kerala, none was found falling in the below mean girth group, hence the percentage of selections belonging to the above mean girth group was 100 per cent (Table 6). In the Maharashtra region, out of the 39 selections, one selection fell in the below mean girth group. Hence the number of high yielders in the above mean girth group was 97 per cent from the progeny populations evaluated in Maharashtra. In the West Bengal region, of the 43 selections, one selection was found in the below mean girth group and the rest in the above mean girth group, hence the number of selections in the above mean girth group was 98 per cent. When the total number of selections out of the 2,685 progenies test-tapped were categorized, out of the 146 selections only 2 of the selections fell in the below mean girth group, thus making the number of the selected progenies falling in the above mean girth group 99 per cent. The risk involved in the chance of missing high yielders in this approach was thus found negligible.

Evaluation of this approach for grouping of progeny population before test-tapping is not an attempt to pick up high yielding progenies before test-tapping based on association with girth growth. Rather identify majority of the low yielders and eliminate them before test-tapping so that labour and time can be saved. The above approach can be applied only in larger populations because an effective population size is required to obtain a genetic gain (Reginaldo *et al.,* 2000).

If the population is smaller and the intention of the breeder is the selection of all the possible genotypes with good performance, then the entire progeny population should be subjected to test-tapping. However, if the population size is unmanageable and larger, then in the light of the present study, the breeder can eliminate all the progenies with girth below the population mean. This method would be useful especially in screening of progenies for latex-timber potential.

Regional influence on yield and girth

The poly-cross progeny populations raised in the traditional region of Kerala gave an average dry rubber yield of 6.4 g t^{-1} $10t^{-1}$ and the mean population girth was 16.3 cm (919 observations) (Fig. 3). In the progeny populations raised in Maharashtra, mean dry rubber yield and girth of the populations were 0.9 g t^{-1} $10t^{-1}$ and 9.1 cm, respectively. The progeny populations raised in West Bengal gave a mean yield and girth of 5.4 g t^{-1} $10t^{-1}$ and 13.6 cm, respectively. Yield and girth of the population in Kerala was significantly different from that of the cool climate of West Bengal also. Similarly yield and girth of the populations grown in the cool climate of West Bengal was also superior to that of the populations in the dry and hot climate of Maharashtra. This difference in the average performances may be attributed to the climatic conditions prevailing

Table 6. **Grouping of selections based on girth**

Zones of evaluation	Origin of the progeny populations	No. of progenies test-tapped	No. of progenies with girth below the population mean	No. of progenies with girth above the population mean	No. of selections	No. of selections in the below mean girth group	No. of selections in the above mean girth group
Kerala	Agartala	102	58	44	9	0 (0)	9 (100)
	Chethackal	123	70	53	5	0 (0)	5(100)
	Dapchari	87	48	39	7	0 (0)	7(100)
	Guwahati	90	49	41	2	0 (0)	2(100)
	Kanyakumari	100	52	48	9	0 (0)	9(100)
	Kolasib	114	64	50	7	0 (0)	7(100)
	Nagrakata	62	37	25	2	0 (0)	2(100)
	Kottayam	96	55	41	6	0 (0)	6(100)
	Tura	145	80	65	17	0 (0)	17(100)
	Total	919	513	406	64	0 (0)	64(100)
Maharashtra	Agartala	141	73	68	5	0 (0)	5(100)
	Chethackal	106	58	48	4	1(25)	3 (75)
	Dapchari	74	41	33	0	0 (0)	0
	Guwahati	92	53	39	4	0 (0)	4(100)
	Kanyakumari	136	68	68	12	0 (0)	12(100)
	Kolasib	129	69	60	0	0 (0)	0
	Nagrakata	143	73	70	8	0 (0)	8(100)
	Kottayam	92	49	43	0	0 (0)	0
	Tura	121	61	60	4	0 (0)	4(100)
	Nettana	11	5	6	2	0 (0)	2(100)
	Total	1043	548	495	39	1(3)	38 (97)
West Bengal	Agartala	84	41	43	4	0 (0)	4(100)
	Chethackal	55	25	30	3	0 (0)	3(100)
	Dapchari	19	11	8	1	0 (0)	1(100)
	Guwahati	112	56	56	5	1(20)	4(80)
	Kanyakumari	34	16	18	2	0 (0)	2(100)
	Kolasib	108	57	51	8	0 (0)	8(100)
	Nagrakata	120	61	59	10	0 (0)	10(100)
	Kottayam	57	29	28	2	0 (0)	2(100)
	Tura	101	46	55	4	0 (0)	4(100)
	Nettana	31	17	14	4	0 (0)	4(100)
	Total	721	359	362	43	1 (2)	42 (98)
	Grand total	2685	1422	1263	146	2 (1)	144 (99)

Values in parenthesis are per cent of their respective numbers of selections

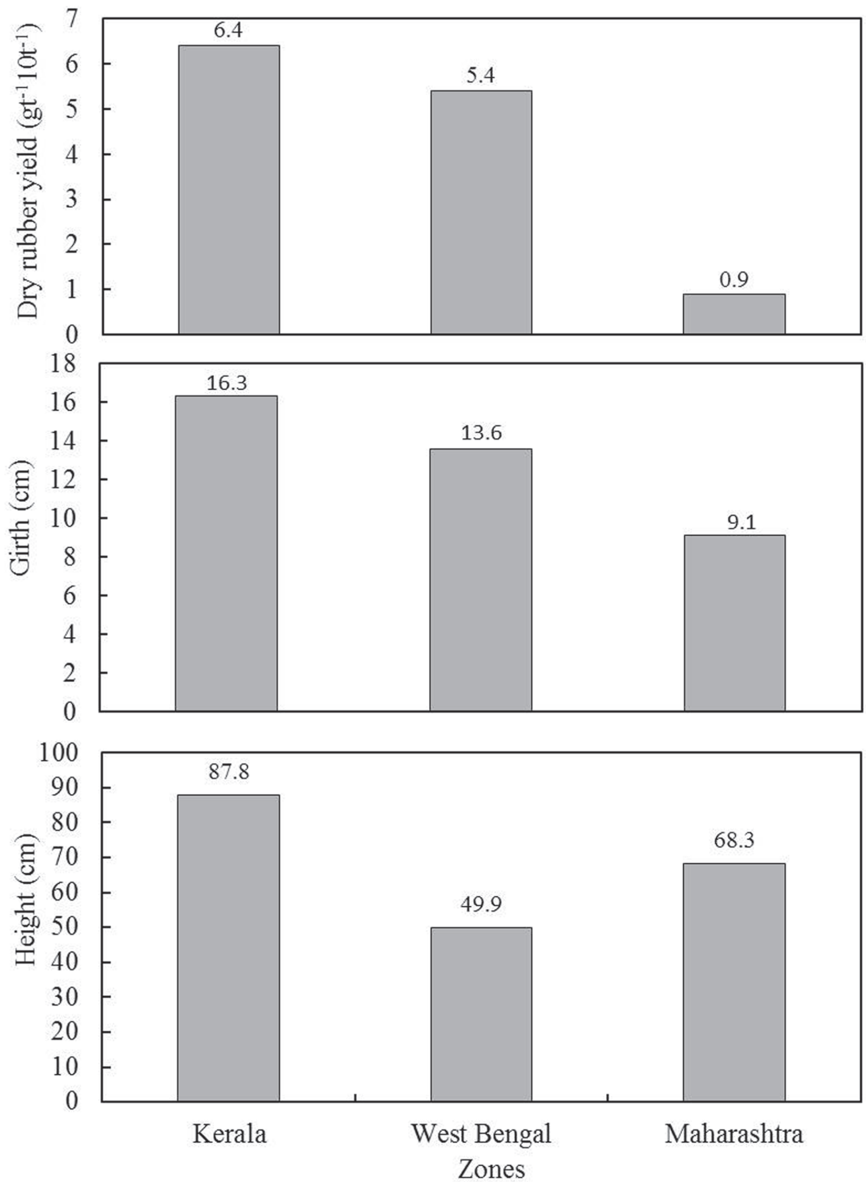

Fig. 3. Zone-wise performance of the progeny populations

in the regions. Height of the seedlings grown under the ideal climatic conditions of Kerala was significantly superior to height of the seedlings grown under the climatic conditions of Maharashtra and West Bengal. In the initial year of the establishment of the progeny populations, growth in terms of height was significantly lower under the cool climate than under the dry climate. However, the dry and hot climate was found adversely affecting the girth of the plants. Climatic influence on rubber yield can thus be clearly established from the difference in the mean yield performance of the progenies from these regions suggesting that dry and hot climate of Maharashtra are less suitable for rubber than the cool climates of West Bengal.

Trans-regional performance of the progeny populations

Progeny populations originated from the ideal climate of the traditional regions showed a mean girth of 16.1 cm in their native traditional climate (Table 7). Although, their growth vigour was substantially reduced when planted in the dry and hot climate of Maharashtra (9.3 cm), their growth was superior to the native population (8.1 cm) from the region. This clearly shows the significance of the origin of seeds in an OP seed collection programme. This was further evident from the performance of the progeny populations originated from the ideal climate in the non-traditional cool climate of West Bengal (13.9 cm) in comparison to the native population of the cool climate (13.5 cm). Growth vigour of the progency populations originated from the cool climate was also

Table 7. **Zone-wise performance of the progeny populations originated from varying agro-climatic conditions**

Origin of the progeny populations	Zones of evaluation								
	Kerala	West Bengal	Maharashtra	Kerala	West Bengal	Maharashtra	Kerala	West Bengal	Maharashtra
	Girth (cm)			Dry rubber yield (g t^{-1} $10t^{-1}$)			Height (cm)		
Traditional regions									
Chethackal	15.6	13.7	9.1	5.0	4.9	0.7	81.3	46.6	72.2
Kanyakumari	16.4	14.5	9.9	7.5	6.5	1.7	95.1	44.5	75.9
Kottayam	16.1	13.6	8.6	6.1	4.8	0.4	93.0	46.2	70.8
Nettana		13.8	9.5		7.0	1.9		41.3	64.0
Mean	16.1	13.9	9.3	6.2	5.8	1.2	89.8	44.7	70.7
Cool regions									
Agartala	16.8	13.9	9.2	7.3	4.4	0.8	89.9	46.9	68.5
Guwahati	15.7	12.9	9.4	4.8	5.3	1.0	73.0	51.2	57.1
Kolasib	16.3	13.4	8.4	6.5	5.8	0.6	82.5	42.2	67.0
Nagrakata	15.2	14.3	9.4	3.8	6.1	0.9	78.0	51.1	74.4
Tura	17.6	13.2	9.4	8.1	5.3	1.2	97.3	51.4	73.2
Mean	16.3	13.5	9.2	6.1	5.4	0.9	84.1	48.6	68.0
Dry region									
Dapchari	15.5	12.4	8.1	6.7	5.3	0.4	87.9	34.4	54.9
General mean	16.1	13.6	9.1	6.2	5.5	1.0	86.4	45.6	67.8
SD	0.75	0.63	0.56	1.42	0.81	0.51	8.25	5.32	7.17
SE	0.25	0.20	0.18	0.47	0.26	0.16	2.75	1.68	2.27
CV	4.62	4.64	6.15	22.82	14.57	53.16	9.54	11.68	10.58

greatly reduced when planted in the dry and hot climate of Maharashtra (9.2 cm) whereas it was better than the native population from Maharashtra with a girth of only 8.1 cm in their local climate.

The superiority of origin of OP seeds was reflected in yield also. Dry rubber yield of the progeny populations originated from the ideal climate, when test-tapped in the hot climate of Maharashtra (1.2 g t^{-1} $10t^{-1}$) was superior to the dry rubber yield of the native population (0.4 g t^{-1} $10t^{-1}$). Similarly dry rubber yield of the progeny populations originated from the cool climate, when test-tapped in the hot climate of Maharashtra, was also superior (0.9 g t^{-1} $10t^{-1}$) to that of the native population (0.4 g t^{-1} $10t^{-1}$). Same trend was also observed from the performance of the progeny populations originated from the ideal climate in the non-traditional cool climate (5.8 g t^{-1} $10t^{-1}$) in comparison to the native population of the cool climate (5.4 g t^{-1} $10t^{-1}$). Seeds originated under the ideal or the near ideal climate can perform better under the stressful climatic conditions than the local recruits of stressful climates.

On the other hand, seeds from the cool climatic conditions exhibited better girth when planted in the traditional climatic conditions of Kerala (16.3 cm) than in their own place of origin (13.5 cm). Similarly seeds from the dry and hot climate of Maharashtra showed tremendous growth improvement in Kerala (15.5 cm) as well as West Bengal (12.4 cm) than in their own place of origin (8.1 cm). This is again evident from the dry rubber yield output also. Seeds from the hot climate performed better in the ideal climate (6.7 g t^{-1} $10t^{-1}$) compared to their native climate (0.4 g t^{-1} $10t^{-1}$). Yield output of the populations from the cool climates in the traditional climate was 6.1 g t^{-1} $10t^{-1}$ compared to their yield output of 5.4 g t^{-1} $10t^{-1}$ in their region of origin. Thus seeds originated under the stressful climatic conditions when grown in ideal climates, their growth and yield potentials were improved. The cool climates are better than the hot climate for planting rubber could be further substantiated.

The study shows that, *Hevea* seeds originated from the most ideal conditions perform better not only in their own place of origin but also under the stressful climatic conditions than the seeds locally produced. It was also seen that seeds generated under severe stress conditions, when planted in ideal or near ideal conditions, exhibited tremendous improvement in performance. Therefore both the origin of seed production and the place of planting of the seedlings are important in *Hevea* crop improvement. In the Indian conditions, *Hevea* breeding programs involving seed production should take place under the most ideal or near ideal climatic conditions. In other words, in breeding for drought and cold tolerance in *Hevea*, seed production and initial screening of progenies should take place under the ideal climates. The progenies that show better performance in the ideal climate may be carried forward for their screening for drought and cold tolerance. A similar approach is in practice in International Maize and Wheat Improvement Centre (CIMMYT) in the area of drought tolerance breeding in maize, where the initial selection is done under near optimum conditions and only advanced lines are tested under drought conditions (Rajaram *et al.*, 1997). There are reports showing that when clones of *Hevea brasiliensis* originated in one country is exchanged with other countries, performance of the clones changed. Clone PB 260 originated in Malaysia has been cited for its better performance in India, as also the underperformance of RRII 105 originated in India in other countries, the reason for the change in performance has been attributed to GxE interactions (Jacob *et al.*, 2013).

Hence change from the place of origin influences the performance of rubber plants.

CONCLUSION

Polycross progeny populations originated from ten different agro-climatic conditions when screened in the three diverse zones of Kerala, Maharashtra and West Bengal resulted in the selection of 146 superior progenies. The highest percentage of selections was obtained from Nettana followed by Kanyakumari and Tura indicating the genetic influence of the clonal combinations in these trials. In the OP progenies, an approach could be formulated by means of differentiating progenies in the population with girth above the population mean from the progenies with girth below the population mean for eliminating poor performers before test-tapping if the population is large. The regional influences on the growth and yield of the progeny populations could be brought out. Performance of the populations in the traditional region was found superior to the performance in the cool and hot climates. Hot and dry climate was found less favourable than the cool climates. Seeds originated from the ideal climate as well as cool climate when planted in the dry climate outperformed that of seeds from the dry climate. Meanwhile, seeds originated from the dry climate of Maharashtra when planted and grown in the traditional and cool climates exhibited a tremendous improvement in their growth and yield performances. This study suggests that both the origin of seed production and the place of growth are important in *Hevea* crop improvement programs. Seed collection, under the most ideal climatic conditions is more effective for crop improvement and the initial screening should be under ideal climatic conditions, and screening for drought and cold tolerance may be carried out in such stressful climates thereafter. Alternatively seeds produced under the stressful climates may be screened under the most ideal climate for the better expression of the inherent attributes of such *Hevea* genotypes.

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