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DIVERSITY AND HETEROSIS BY RECOMBINATION BREEDING OF *HEVEA BRASILIENSIS* IN INDIA

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In a recombination breeding programme, 52 hybrids evolved from three cross combinations of *Hevea* clones were evaluated along with parents for yield and its components under small scale evaluation in Central Kerala, India over six years of tapping. The components of variation and genetic distances among the progeny and parents were estimated based on analysis of 23 attributes. Rubber yield was reiterated as a highly heritable trait. Parent clones RRII 105 and RRII 118 proved to be genetically very divergent and a high recovery of eight heterotic hybrids was obtained from the progeny of this biparental cross. The pedigree of parent clones was found to contribute to diversity and heterosis.

Clonal selection based on yield, girth, yield components and secondary traits led to the identification of eight promising hybrids that exhibited heterobeltiosis for yield to the tune of 43-65 per cent. These were clones 95/323, 95/297, 95/348, 95/351, 95/353, 95/362, 95/442 and 95/448, of which seven were of the parentage RRII 105 x RRII 118. High yielding clones with potential to perform well under drought situations were identified based on yield and its components in the stress period. The low incidence of tapping panel dryness and pink disease in clones 95/297, 95/442 and 95/448 and the steadily increasing trend in yield of 95/448 deserve special mention. The results of this study indicate further scope for exploitation of heterosis in crosses between parent clones with Malaysian and Sri Lankan lineage.

Keywords: Genetic divergence, Heritability, Heterosis, Recombination breeding, Yield components

INTRODUCTION

Hevea brasiliensis, the Para rubber tree is cultivated in India across a wide range of environments, none resembling the ideal sub tropics where this crop originated. Still India is credited with achieving very high productivity of rubber for the last many years. The locally evolved clones adaptable to the traditional rubber growing regions are in a large way responsible for this success. With little scope for expansion of area under rubber in the traditional region, cultivation has extended to the non-traditional areas. Moisture stress in summer and drought compounded with high light intensities limit rubber production in the states of Maharashtra, Odisha and Chattisgarh. North Kerala and South Karnataka in the traditional tract also face such limiting situations in the summer months. Hence, evolving drought tolerant clones is a felt need.

An effort to combine high yield with intrinsic drought tolerance attributes by hybridization resulted in the production of

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a sizeable number of hybrids from which selected individuals were vegetatively multiplied and evaluated for their yield, growth attributes and yield components under ideal conditions. This report pertains to the performance of 52 hybrid clones developed from three cross combinations, in a small scale clonal evaluation trial. For effective selection, knowledge of the heritable component of variation for yield and its components is essential and this has been proved in earlier studies on rubber (Tan *et al.*, 1975; Licy *et al.*, 1992). The genetic distances among parent clones and the variability and heterosis of hybrids generated are discussed in the context of the narrow genetic base of *H. brasiliensis* which still provides for sufficient unexploited genetic variability. Prospects of recombination breeding and clonal selection in rubber are examined in the backdrop of the pedigree of parent clones involved.

MATERIALS AND METHODS

Fifty two hybrids evolved from three cross combinations of parent clones hybridized in 1995 (Table 1) and selected by nursery evaluation based on yield by test tapping were vegetatively multiplied and raised in polybags along with their parent clones. The small scale evaluation trial was laid out in 1999 at the Central Experiment Station of Rubber Research Institute of India situated at Pathanamthitta district of Central Kerala (44-188 m above MSL; latitude $9^0 25'$ N and longitude $76^0 50'$ E). Field planting was done at 4.9 x 4.9 m spacing using two whorled polybag plants. A rectangular lattice design with five trees per plot and three replications was employed. Cultural operations as per the recommended package of practices for rubber were adopted.

Girth of trees was recorded annually from the third year of planting. Tapping following S/2 d3 6d/7 system without stimulation was initiated in 2006, seven years after planting when the trees attained tappable girth. In the year of opening, bark samples were collected in formalin-acetic acid – alcohol (FAA) solution and preserved for structural studies. Observations on thickness and number of laticifers in the hard and soft layers of the bark were recorded from radial longitudinal sections (RLS) of the bark. For the purpose of recording yield from each individual tree, cup coagulation of latex on a normal tapping day was done at fortnightly intervals followed by smoke drying of cup lumps which were later weighed. In the fifth and sixth years of tapping, yield components *viz.*, volume of latex per tree per tapping and dry rubber content (DRC) on a dry weight by volume basis from 20 mL samples of latex were determined during the peak season (October-November) and lean season (March-April). Girth increment rates during immaturity and over six years of tapping were worked out. The incidence of pink disease in the immaturity period and tapping panel dryness (TPD) after six years of tapping the clones were also recorded.

Data on 23 attributes were subjected to analysis of variance applying arcsine transformation in cases of tappability and incidence of pink disease where the data were expressed as percentage of trees involved. This was followed by the estimation of genetic parameters *viz.*, PCV, GCV, broad sense heritability for yield, growth and yield components and heterosis over the better parent for yield and growth. A performance index based on 17 variables comprising yield and yield components was computed following Mydin *et al.* (1990). The performance index of each clone is the sum of weighted averages of the clone with respect to each of the traits, the weights attached to a trait being its environmental

Table 1. **Pedigree of clones evaluated**

Sl. no.	Clone	Parentage	Sl. no.	Clone	Parentage
1	95/30	RRII 105 x RRIM 703	29	95/353	RRII 105 x RRII 118
2	95/31	RRII 105 x RRIM 703	30	95/362	RRII 105 x RRII 118
3	95/34	RRII 105 x RRIM 703	31	95/441	RRII 105 x RRII 118
4	95/211	RRII 105 x RRIM 703	32	95/442	RRII 105 x RRII 118
5	95/213	RRII 105 x RRIM 703	33	95/448	RRII 105 x RRII 118
6	95/216	RRII 105 x RRIM 703	34	95/452	RRII 105 x RRII 118
7	95/217	RRII 105 x RRIM 703	35	95/503	RRII 105 x RRII 118
8	95/264	RRII 105 x RRIM 703	36	95/101	RRII 105 x PB 86
9	95/269	RRII 105 x RRIM 703	37	95/232	RRII 105 x PB 86
10	95/270	RRII 105 x RRIM 703	38	95/220	RRII 105 x PB 86
11	95/272	RRII 105 x RRIM 703	39	95/234	RRII 105 x PB 86
12	95/273	RRII 105 x RRIM 703	40	95/230	RRII 105 x PB 86
13	95/377	RRII 105 x RRIM 703	41	95/318	RRII 105 x PB 86
14	95/385	RRII 105 x RRIM 703	42	95/323	RRII 105 x PB 86
15	95/389	RRII 105 x RRIM 703	43	95/328	RRII 105 x PB 86
16	95/390	RRII 105 x RRIM 703	44	95/332	RRII 105 x PB 86
17	95/392	RRII 105 x RRIM 703	45	95/399	RRII 105 x PB 86
18	95/109	RRII 105 x RRII 118	46	95/403	RRII 105 x PB 86
19	95/293	RRII 105 x RRII 118	47	95/404	RRII 105 x PB 86
20	95/297	RRII 105 x RRII 118	48	95/405	RRII 105 x PB 86
21	95/300	RRII 105 x RRII 118	49	95/464	RRII 105 x PB 86
22	95/305	RRII 105 x RRII 118	50	95/473	RRII 105 x PB 86
23	95/311	RRII 105 x RRII 118	51	95/474	RRII 105 x PB 86
24	95/335	RRII 105 x RRII 118	52	95/477	RRII 105 x PB 86
25	95/336	RRII 105 x RRII 118	53	RRII 118	Mil 3/2 x Hil 28
26	95/345	RRII 105 x RRII 118	54	RRIM 703	RRIM 600 x RRIM 500
27	95/348	RRII 105 x RRII 118	55	PB 86	Primary clone
28	95/351	RRII 105 x RRII 118	56	RRII 105	Tjir 1 x Gl 1

variance. In order to study the genetic diversity, the hybrids and parents were clustered by heirarchical cluster analysis (SPSS, 1999; Romesburg, 2004) using 23 variables.

RESULTS AND DISCUSSION

Clone RRII 105 in cross combinations with three male parents, *viz.*, RRIM 703, RRII 118 and PB 86 produced hybrids with a wide range of variability for yield and yield components and this facilitated clonal selection as shown in Tables 2 to 7. There was significant variability for all the traits studied in the population of 56 clones, with the exception of total bark thickness and dry rubber content in the peak yielding season.

Variability for yield and yield components

Genetic variability is the cornerstone of crop improvement efforts and so is heritability, which delineates the heritable component of variation for the different traits. Yield of the 52 hybrids and their parents over six years of tapping ranged from 22 to 65.6 $gt^{-1}t^{-1}$ with a general mean of 39.8 $gt^{-1}t^{-1}$. Volume of latex (Table 2) exhibited the highest variability with Phenotypic Coefficient of Variation (PCV) of 46.1 followed by yield, girth and the number of latex vessel rows with PCV estimates ranging from 30.9 to 31.5. However, among the important traits studied, the heritable component of variation was highest in the case of dry rubber yield over six years as evidenced by the highest estimate of heritability in the broad sense (H^2) which was to the tune of 0.68 as also reported earlier by Licy *et al.* (1992). Rubber yield has been established to be a highly heritable trait (Tan *et al.*, 1975; Mydin *et al.*, 1992; Narayanan and Mydin, 2011). Girth increment under tapping showed a higher estimate of heritability (H^2=0.58) than either girth at opening or girth increment rate during the period of immaturity (H^2=0.41) indicating the strong influence of the genotype in its response to tapping. The wide variation in estimates of PCV and GCV in the case of volume of latex shows the higher influence of environment in its expression leading to a comparatively lower estimate of heritability (H^2=0.40) than dry rubber yield. Dry rubber content is a more dependable component of yield, less influenced by the environment leading to a high heritability (H^2=0.57) than volume of latex. Among the anatomical parameters, the number of latex vessel rows exhibited a moderate level of heritability (H^2=0.31) while bark thickness had very low heritability.

Diversity among the hybrids and parent clones

High degree of heterozygosity as well as optimum genetic distance among parent clones facilitates selection among hybrids. Measurement of genetic distances helps in identification of diverse parents in order to maximise expression of heterosis (Smith *et al.*, 1990).

The extent of genetic diversity unleashed by crossing the three male parental clones with clone RRII 105 is evident from the variability estimates as well as the dendrogram in Figure 1 where the 56 clones including parents and hybrids

Table 2. **Variability for rubber yield and important yield components**

Trait	Range	PCV	GCV	Heritability (H^2)
Dry rubber yield over 6 years	22.0 - 65.6 $g\ t^{-1}t^{-1}$	30.9	25.4	0.68
Girth at opening	38.9 - 56.3 cm	11.5	7.4	0.41
Girth increment - immaturity	6.1 - 9.7 cm $year^{-1}$	14.1	9.0	0.41
Girth increment on tapping	1.4 - 5.3 cm $year^{-1}$	32.3	24.5	0.58
Total bark thickness	6.0 - 8.3 mm	9.6	3.5	0.13
Total number of latex vessel rows	4.1 - 13.7	31.5	17.5	0.31
Annual mean dry rubber content	31.3 - 45.2 %	8.9	6.7	0.57
Annual mean volume of latex	36.2 - 209.9 mL $t^{-1}t^{-1}$	46.1	28.7	0.40

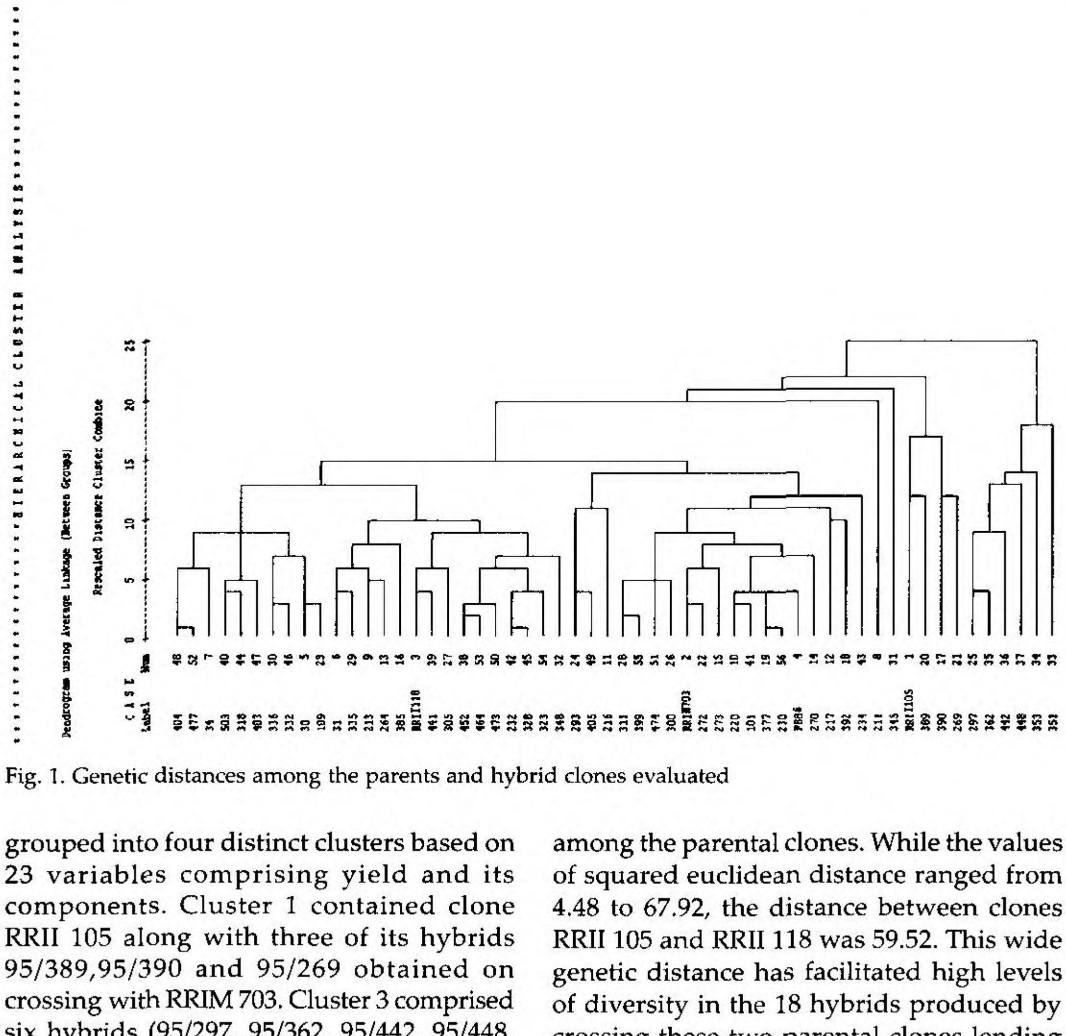

Fig. 1. Genetic distances among the parents and hybrid clones evaluated

grouped into four distinct clusters based on 23 variables comprising yield and its components. Cluster 1 contained clone RRII 105 along with three of its hybrids 95/389,95/390 and 95/269 obtained on crossing with RRIM 703. Cluster 3 comprised six hybrids (95/297, 95/362, 95/442, 95/448, 95/353, 95/351) from the cross RRII 105 x RRII 118. The hybrid 95/345 also the progeny of RRII 105 x RRII 118 formed Cluster 4 by itself. The rest of the hybrids from the three crosses along with parents RRII 118, RRIM 703 and PB 86 formed cluster 2. It is noteworthy that in conformity with an earlier molecular marker based study (Bini, 2013) clones RRII 105 and RRII 118 in the present analysis also have exhibited the maximum genetic distance among the parental clones. While the values of squared euclidean distance ranged from 4.48 to 67.92, the distance between clones RRII 105 and RRII 118 was 59.52. This wide genetic distance has facilitated high levels of diversity in the 18 hybrids produced by crossing these two parental clones lending scope for exercising selection for desirable recombinants among the hybrids as also proved earlier in selection among progeny of the cross between divergent parents RRII 105 and RRIC 100 (Varghese *et al.*, 1997) which resulted in high heterosis in the hybrids. The diversity among various hybrids of the same cross is also further proof of the heterozygosity of parent clones in this predominantly outcrossed species. This study lends support to the view that

Table 3. **Growth parameters of the hybrids and parents**

Clone	Girth (cm)		Girth increment ($cm\ yr^{-1}$)		Tapp-ability (%)	Clone	Girth (cm)		Girth increment ($cm\ yr^{-1}$)		Tapp-ability (%)
	At opening	After 6 years	At imma-turity	Under tapping			At opening	After 6 years	At imma-turity	Under tapping	
95/30	53.7	76.6	8.9	3.8	60	95/362	53.0	85.0	9.0	5.3	31
95/31	47.3	63.1	7.9	2.6	59	95/441	56.3	81.4	9.6	4.2	65
95/34	50.6	61.2	7.8	1.8	50	95/442	50.7	77.8	8.6	4.5	30
95/211	40.1	54.2	6.1	2.4	15	95/448	54.2	75.5	8.8	3.6	55
95/213	47.1	65.4	8.1	3.1	43	95/452	50.3	71.5	8.6	3.5	43
95/216	48.0	59.6	7.8	1.9	60	95/503	50.8	75.8	8.7	4.2	30
95/217	40.0	50.3	6.1	1.7	30	95/101	41.7	62.5	7.4	3.5	28
95/264	42.1	56.9	6.9	2.5	20	95/232	50.0	68.8	8.6	3.1	50
95/269	44.8	61.8	7.7	2.8	19	95/220	45.1	61.7	7.4	2.8	37
95/270	39.5	63.1	6.8	3.9	10	95/234	45.0	64.3	7.7	3.2	40
95/272	45.2	53.7	7.1	1.4	28	95/230	38.9	51.2	6.5	2.0	00
95/273	44.3	57.8	7.0	2.2	30	95/318	55.3	72.6	9.3	2.9	65
95/377	42.6	58.1	7.2	2.6	20	95/323	46.8	67.1	7.9	3.4	15
95/385	46.8	68.7	7.8	3.7	15	95/328	48.7	69.5	8.5	3.5	25
95/389	42.8	56.8	6.8	2.3	20	95/332	49.0	69.1	7.9	3.3	50
95/390	48.1	63.5	8.0	2.6	43	95/399	46.3	64.1	7.8	3.0	20
95/392	44.7	59.7	7.4	2.5	19	95/403	50.2	69.0	9.0	3.2	47
95/109	55.2	73.6	9.2	3.1	65	95/404	51.4	69.5	8.7	3.0	45
95/293	41.9	65.6	6.2	4.0	22	95/405	43.9	61.4	7.3	2.9	20
95/297	56.2	81.7	9.7	4.3	70	95/464	50.9	67.4	8.6	2.8	60
95/300	49.2	58.3	8.3	1.5	35	95/473	49.0	69.5	8.4	3.4	40
95/305	52.2	73.8	9.5	3.6	39	95/474	48.8	65.7	8.3	2.8	54
95/311	47.1	65.4	7.9	3.0	39	95/477	51.4	70.9	8.8	3.3	40
95/335	46.2	62.1	7.8	2.7	55	RRII 118	47.4	62.1	7.7	4.5	55
95/336	51.8	69.7	7.9	3.0	65	RRIM 703	41.2	49.8	6.5	1.4	10
95/345	57.4	72.1	9.5	2.4	50	PB 86	44.0	62.1	7.2	3.0	10
95/348	53.2	68.3	9.0	2.5	50	RRII 105	47.8	57.1	8.2	1.6	37
95/351	55.0	72.8	8.9	3.0	77	G.M.	48.1	66.2	8.0	3.0	38
95/353	53.0	78.8	8.6	4.3	48	CD(P=0.05)	6.96	7.95	1.41	1.03	39

though the genetic base of cultivated clones of *H. brasiliensis* is narrow (Wycherley, 1976; Tan, 1987), the heterozygosity of parents enables generation of sufficient variability even in F1 hybrids produced from biparental crosses, so that effective selection is facilitated. That a rather high degree of genetic variability still exists within the cultivated rubber clones has been proved in conventional genetic analysis despite the

Table 4. **Yield of hybrids and their parents over six years of tapping**

Clone	Mean yield $(gt^{-1}t^{-1})$						
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	6yrs
95/30	21.8	21.6	14.0	24.1	26.9	30.1	23.1
95/31	30.9	27.1	29.7	42.6	58.8	41.9	38.5
95/34	36.8	27.5	22.4	34.1	37.3	38.5	32.8
95/211	29.2	20.9	35.3	66.8	84.6	67.7	50.7
95/213	42.4	26.2	33.7	47.7	44.5	49.5	39.4
95/216	35.4	27.0	23.8	38.3	43.6	41.0	34.8
95/217	37.3	23.3	21.6	34.7	34.0	26.7	32.0
95/264	37.7	23.8	31.4	42.8	55.2	45.7	38.3
95/269	42.0	34.2	26.9	39.1	38.1	41.3	37.9
95/270	31.6	23.5	19.0	25.4	28.3	39.4	27.9
95/272	46.3	34.2	27.6	36.3	32.5	27.8	34.1
95/273	44.8	28.3	24.9	35.1	34.5	25.3	34.6
95/377	47.2	25.7	21.5	38.7	44.2	26.2	34.9
95/385	49.2	41.7	39.5	54.4	66.9	55.9	51.1
95/389	40.7	30.1	25.4	39.7	48.3	42.7	37.8
95/390	20.9	19.5	13.7	22.1	29.1	27.0	22.0
95/392	47.5	32.1	27.4	37.1	32.8	28.7	34.3
95/109	55.8	36.4	39.4	53.9	50.7	38.5	45.8
95/293	24.5	20.9	23.7	32.9	44.7	48.7	32.6
95/297	36.8	34.4	42.8	58.2	82.6	95.5	57.1
95/300	46.7	45.5	36.6	47.4	41.9	44.8	43.8
95/305	47.7	41.4	39.6	55.0	61.7	55.5	50.1
95/311	39.3	32.4	29.6	51.7	53.1	40.2	41.0
95/335	27.7	30.7	37.8	53.0	52.5	34.9	40.1
95/336	30.7	21.7	26.5	34.3	37.8	41.5	32.1
95/345	59.2	35.2	37.2	43.1	38.6	46.8	44.5
95/348	56.2	45.5	50.7	61.3	67.7	60.2	56.7
95/351	49.9	48.7	55.7	63.1	98.2	71.8	64.6
95/353	56.7	54.9	58.9	87.1	74.4	57.7	65.0
95/362	44.0	40.6	42.7	75.2	82.0	82.7	58.3
95/441	32.3	31.2	33.6	51.3	54.7	58.1	43.6
95/442	57.7	39.1	48.2	75.7	75.9	56.5	63.3
95/448	58.0	53.3	58.2	63.8	67.6	93.8	65.6
95/452	43.7	29.6	29.9	36.6	41.2	42.9	37.4
95/503	34.1	22.2	24.9	29.7	27.8	27.4	27.7
95/101	33.3	21.5	22.4	33.5	31.8	17.4	27.5
95/232	66.1	37.5	36.2	42.7	46.9	56.0	47.6
95/220	40.1	31.4	33.5	46.0	43.9	37.7	38.7
95/234	33.8	19.2	16.7	30.8	28.9	31.3	26.8

95/230	34.4	26.1	23.9	32.8	40.5	27.2	30.8
95/318	46.3	27.6	23.6	30.8	31.6	37.3	32.9
95/323	52.3	44.2	43.8	65.5	80.5	80.9	61.2
95/328	38.6	31.7	34.4	47.3	46.8	59.8	43.1
95/332	47.5	32.9	25.2	31.0	34.8	29.5	33.5
95/399	38.3	23.5	21.9	34.2	37.3	39.2	31.9
95/403	26.9	20.5	20.2	27.8	35.3	39.3	28.3
95/404	40.7	31.6	31.7	43.6	39.5	36.2	37.2
95/405	46.9	31.3	38.0	42.0	42.3	53.0	42.7
95/464	35.6	20.1	23.3	44.2	43.5	38.8	32.7
95/473	32.3	24.8	24.0	33.5	41.7	42.9	31.9
95/474	30.4	26.6	26.5	31.2	37.7	35.6	31.3
95/477	33.6	23.5	23.1	27.5	36.9	42.7	31.2
RRII 118	36.4	27.3	29.1	39.0	54.9	50.5	39.5
RRIM 703	26.8	25.9	23.7	40.1	35.8	34.7	31.2
PB 86	34.6	27.5	27.6	28.1	34.0	36.5	32.9
RRII 105	46.6	27.5	27.8	40.0	39.6	57.0	39.8
G.M.	40.4	30.6	31.0	43.3	47.4	46.7	39.8
CD (P=0.05)	12.0	7.7	11.2	17.2	19.8	20.8	11.4

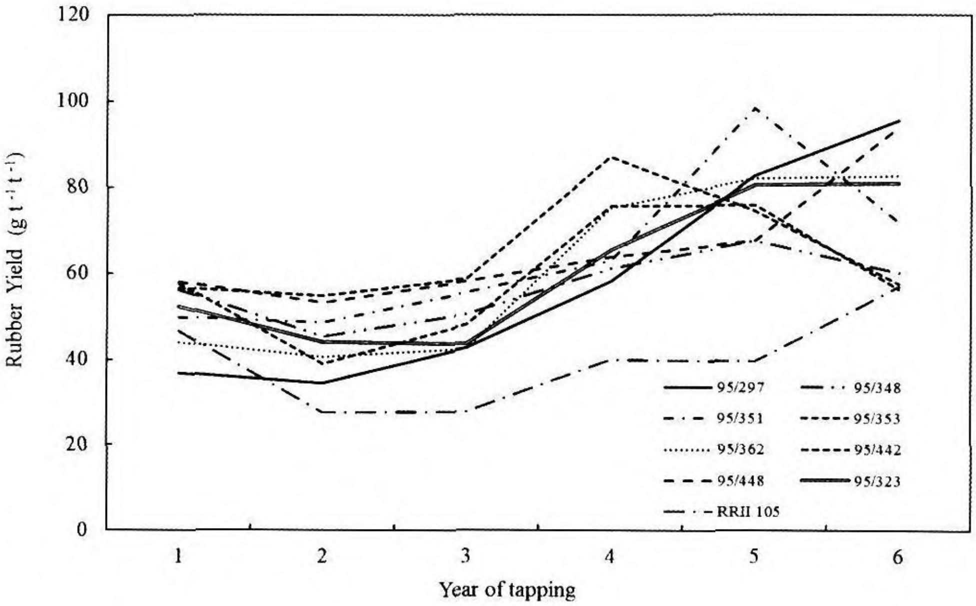

Fig. 2. Trend in yield of promising selections over six years of tapping

small foundation and breeding history of this crop (Markose, 1984; Mydin *et al.*, 1992) and using isozymes (Chevallier, 1988) and DNA markers (Varghese *et al.*, 1997).

Clonal selection based on yield, girth and the components of yield

Girth of clones, growth rate in terms of girth increment and tappability are given in Table 3. Significant variability for these traits enabled the identification of six hybrids (95/109, 95/297, 95/345, 95/351, 95/441 and 95/318) superior to clone RRII 105 for girth at opening and 21 hybrids superior for girth after six years of tapping. Clones 95/ 297, 95/345, 95/351 and 95/441 maintained high girth before and after tapping. Only two clones *viz.*, 95/297 and 95/441 exhibited girth increment rate superior to RRII 105 at the immature phase and under tapping for six years. However, 37 hybrid clones were superior to RRII 105 in terms of girth increment under tapping. Eighteen hybrid clones attained more than 50 per cent tappability by the 7th year, but only two with tappability of 77.0 per cent (95/351) and 70 per cent (95/297) were superior to RRII 105.

The yield obtained over six years of tapping showed significant variability (Table 4). In terms of mean yield over six years, 20 clones out of the 52 hybrids from the three cross combinations were promising compared to RRII 105, with 40.1 to 65.6 $gt^{-1}t^{-1}$. Of these, 14 hybrids were of parentage RRII 105 x RRII 118, four of parentage RRII 105 x PB 86 and two of parentage RRII 105 x RRIM 703. Eight hybrids among these exhibited yield in the range of 56.1 to 65.6 $gt^{-1}t^{-1}$ and were significantly superior to RRII 105. The trend in yield of these clones as compared to RRII 105 is depicted in Figure 2. Seven of the best hybrids (95/297, 95/348, 95/351, 95/353, 95/362, 95/442 and 95/448) were of parentage RRII 105 x RRII 118 and one clone *viz.*, 95/323 was of parentage RRII 105 x PB 86. In general, all the clones showed a rising trend in yield from the first to the sixth year of tapping in panel BO-1. The eight high yielding clones were

Table 5. **Performance of clones in the stressed summer months**

Clone	Yield in summer ($gt^{-1}t^{-1}$)	Yield drop in summer (%)	Clone	Yield in summer ($gt^{-1}t^{-1}$)	Yield drop in summer (%)
95/30	11.4	52	95/362	28.5	59
95/31	19.5	54	95/441	22.5	52
95/34	17.3	46	95/442	34.8	45
95/211	30.1	50	95/448	20.7	66
95/213	16.9	57	95/452	19.8	45
95/216	14.3	61	95/503	18.0	30
95/217	13.0	58	95/101	14.5	48
95/264	19.8	52	95/232	26.6	37
95/269	20.5	44	95/220	19.8	51
95/270	13.4	40	95/234	17.7	33
95/272	18.9	45	95/230	17.0	47
95/273	17.6	47	95/318	17.8	41
95/377	16.1	57	95/323	33.9	48
95/385	28.2	49	95/328	26.6	38
95/389	18.4	53	95/332	16.7	49
95/390	9.3	60	95/399	20.5	36
95/392	14.1	57	95/403	17.2	39
95/109	20.2	56	95/404	23.0	40
95/293	15.9	51	95/405	20.6	47
95/297	29.0	51	95/464	17.6	51
95/300	20.7	54	95/473	20.7	37
95/305	30.6	43	95/474	20.7	34
95/311	28.2	38	95/477	16.2	45
95/335	21.2	53	RRII 118	23.0	42
95/336	17.8	43	RRIM 703	18.2	43
95/345	22.2	43	PB 86	18.2	39
95/348	34.2	40	RRII 105	15.2	57
95/351	28.4	60	G.M.	20.9	47.5
95/353	38.85	48	CD(P=0.05)	7.5	12.5

Table 6. **Yield components during the peak and stress periods and annual mean over two years**

Clone	Dry rubber content (%)			Volume of latex ($mLt^{-1}t^{-1}$)			Clone	Dry rubber content (%)			Volume of latex ($mLt^{-1}t^{-1}$)		
	Peak	Stres	Ann.	Peak	Stres	Ann.		Peak	Stres	Ann.	Peak	Stres	Ann.
95/30	39	38	38	42	21	36	95/362	43	41	42	261	75	210
95/31	37	34	35	150	58	132	95/441	41	41	41	160	74	135
95/34	45	37	41	84	44	80	95/442	42	44	43	240	172	195
95/211	45	40	43	101	149	104	95/448	43	46	44	158	49	135
95/213	40	40	40	187	51	139	95/452	41	38	39	117	58	97
95/216	36	45	41	186	52	129	95/503	38	44	41	68	37	62
95/217	35	33	34	89	62	78	95/101	40	39	39	96	48	77
95/264	36	38	37	201	70	146	95/232	38	41	40	143	78	131
95/269	31	32	31	72	55	71	95/220	40	36	38	111	36	81
95/270	41	39	40	98	47	71	95/234	46	37	41	100	48	75
95/272	38	35	36	107	46	89	95/230	39	40	39	96	43	86
95/273	41	38	39	154	61	117	95/318	42	42	42	57	34	48
95/377	37	39	38	117	42	85	95/323	41	40	41	120	97	113
95/385	37	38	37	233	97	200	95/328	40	36	38	139	75	125
95/389	41	34	37	158	69	131	95/332	33	37	35	85	36	76
95/390	39	26	33	57	15	44	95/399	39	35	37	100	85	90
95/392	38	34	36	67	38	61	95/403	41	47	44	88	76	84
95/109	37	37	37	114	38	82	95/404	39	39	39	81	57	65
95/293	45	45	45	112	43	91	95/405	43	45	44	88	55	80
95/297	40	39	39	223	102	183	95/464	41	43	42	96	55	77
95/300	36	36	36	73	47	63	95/473	40	43	42	112	62	89
95/305	38	36	37	161	81	132	95/474	34	36	35	104	54	96
95/311	38	38	38	98	59	86	95/477	40	40	40	107	55	92
95/335	39	40	40	193	47	172	RRII 118	41	42	41	155	52	131
95/336	37	38	37	107	49	89	RRIM 703	36	33	34	131	51	106
95/345	34	39	37	94	72	86	PB 86	37	39	38	111	32	90
95/348	39	41	40	178	82	151	RRII 105	39	35	37	123	66	102
95/351	39	39	39	215	81	178	G.M.	39	39	39	126	61	106
95/353	43	39	41	153	60	138	CD (P=0.05)	ns	6	4	79	37	62

distinctly superior to RRII 105 over all the six years of tapping. Clones 95/351 and 95/448 gave annual mean yields as high as 98.2 and 93.8 $gt^{-1}t^{-1}$ in the fifth and sixth years of tapping, respectively.

The performance of the hybrid clones when examined during the stressed summer months (Table 5), indicated 13 clones with 23 to 38.9 $gt^{-1}t^{-1}$ to be superior to RRII 105 (15.2 $gt^{-1}t^{-1}$) while 12 clones showed a

Table 7. **Anatomical parameters of the clones evaluated**

Clone	Thickness of bark (mm)			No. of latex vessel rows in the bark		
	Soft	Hard	Total	Soft	Hard	Total
95/30	38.5	37.7	38.1	41.8	20.9	36.2
95/30	1.5	5.2	6.7	4.5	2.3	6.8
95/31	1.7	5.9	7.6	5.9	3.3	9.2
95/34	1.8	5.3	7.1	5.5	4.1	9.6
95/211	1.8	5.3	7.2	5.2	2.9	8.1
95/213	2.1	5.3	7.4	6.9	2.2	9.1
95/216	1.3	5.6	6.8	3.1	2.5	5.6
95/217	1.7	5.0	6.7	2.4	1.7	4.1
95/264	2.1	4.9	7.0	7.6	2.3	9.9
95/269	1.5	6.2	7.6	3.9	2.6	6.5
95/270	1.7	5.5	7.2	4.2	2.6	6.8
95/272	1.4	5.4	6.7	5.1	1.7	6.7
95/273	1.3	5.4	6.7	4.1	3.1	6.7
95/377	1.8	4.8	6.6	4.4	2.0	6.4
95/385	1.9	4.9	6.8	8.3	2.9	11.2
95/389	1.9	6.4	8.3	4.8	2.9	7.8
95/390	1.8	5.7	7.5	4.2	4.2	8.4
95/392	2.0	4.1	6.1	6.0	1.3	7.3
95/109	1.5	5.4	6.9	4.7	3.3	8.0
95/293	1.2	5.1	6.3	4.3	3.6	7.8
95/297	1.7	5.6	7.2	6.9	3.0	10.0
95/300	1.6	4.9	6.4	4.3	2.2	6.4
95/305	1.6	4.9	6.5	4.9	2.0	6.9
95/311	1.5	4.6	6.1	5.5	2.1	7.6
95/335	1.7	5.3	7.1	4.4	2.4	6.9
95/336	1.5	4.8	6.4	5.9	3.6	9.6
95/345	1.8	5.3	7.1	8.1	4.7	12.8
95/348	1.8	5.4	7.2	7.6	4.7	12.3
95/351	1.1	5.2	6.2	2.9	4.1	7.1
95/353	1.7	5.4	7.1	7.2	2.6	9.8
95/362	1.6	5.8	7.4	5.9	3.5	9.4
95/441	1.7	5.2	6.9	5.9	2.1	7.9
95/442	1.9	5.2	7.1	6.5	3.2	9.7
95/448	2.0	5.6	7.6	8.4	2.7	11.1
95/452	1.9	5.2	7.1	7.6	2.5	10.2
95/503	1.6	5.1	6.7	6.8	2.4	9.2
95/101	1.5	4.9	6.4	5.4	3.2	8.6
95/232	1.7	5.0	6.7	9.0	2.6	11.6
95/220	1.8	4.5	6.3	5.9	2.4	8.3
95/234	1.7	4.3	6.0	4.8	1.9	6.7
95/230	1.8	5.2	6.9	4.4	2.0	6.4
95/318	1.5	5.0	6.5	4.8	2.1	6.9
95/323	1.8	5.7	7.5	8.3	2.1	10.3
95/328	1.8	5.2	7.1	7.5	2.6	10.1
95/332	1.6	4.5	6.1	6.6	2.6	9.2
95/399	1.3	4.7	6.0	3.6	1.5	6.2
95/403	1.8	4.9	6.7	4.9	2.2	7.1
95/404	1.4	5.3	6.7	6.6	5.1	11.7
95/405	1.3	5.4	6.7	3.9	4.0	7.9
95/464	2.1	5.0	7.1	8.9	2.3	11.2
95/473	2.0	5.4	7.4	8.6	3.9	12.5
95/474	1.6	5.0	6.6	7.2	2.3	9.4
95/477	1.6	5.1	6.7	6.1	4.6	10.7
RRII 118	1.6	5.4	7.1	6.0	2.2	8.1
RRIM 703	1.5	5.5	7.0	5.1	2.6	7.7
PB 86	1.5	5.1	6.6	4.2	3.7	7.9
RRII 105	1.8	6.0	7.8	9.3	4.4	13.7
G.M.	1.7	5.2	6.9	5.8	2.8	8.7
CD (P=0.05)	0.5	0.8	NS	3.0	2.0	3.7

significantly lower yield drop (30 to 44 %) compared to RRII 105 (57%). Among these, clone 95/348, the hybrid of RRII 105 x RRII 118 maintained a high summer yield of 34.2 $gt^{-1}t^{-1}$ coupled with a low drop of 40 per cent in the summer months and holds promise of good performance in drought prone regions. This clone also exhibited a superior mean yield of 56.7 $gt^{-1}t^{-1}$ in BO-1 Panel.

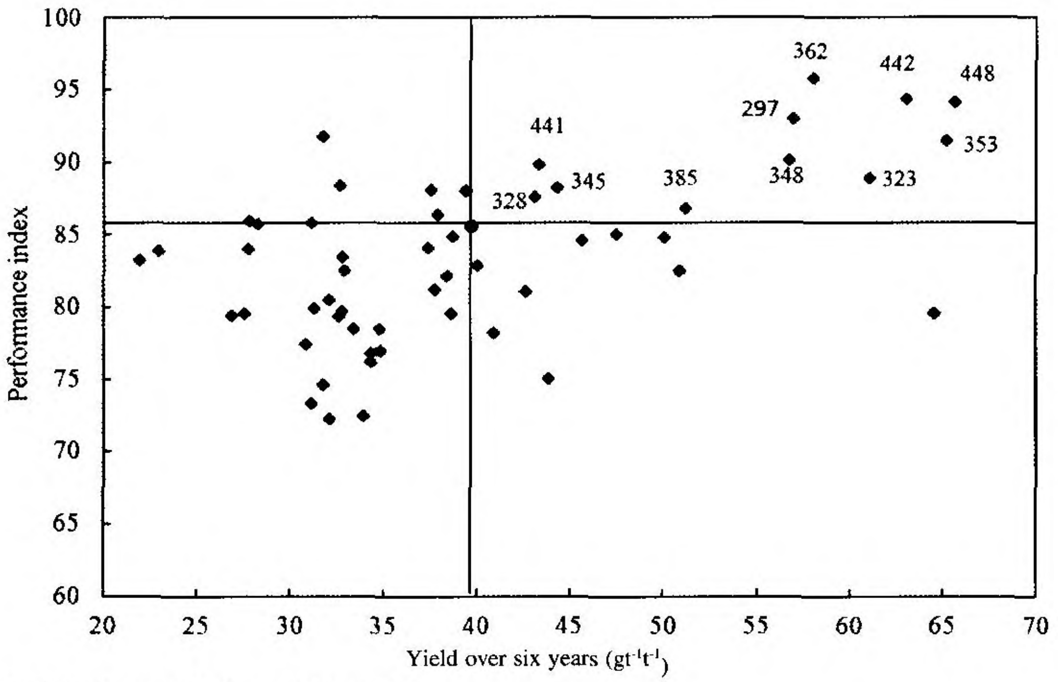

Fig. 3. Performance index vs. rubber yield

Important yield components like DRC and volume of latex when studied during the peak yielding period and stressed summer months (Table 6) also exhibited significant clonal variation. In terms of DRC in the peak period, the clones were comparable to RRII 105. Only 10 hybrids showed superior values in the stress period and 13 were superior in terms of annual mean DRC, compared to RRII 105. Two of the high yielders *viz.*, 95/442 and 95/448 exhibited DRC of 44 and 46 per cent in the stress period and 43 and 44 per cent, respectively in terms of annual mean. In terms of volume of latex, five hybrids were superior during the peak period and during the stress period two hybrids were superior, while in terms of annual mean values four hybrids were superior to RRII 105. Such seasonal variations in yield components have been reported earlier (Licy *et al.*, 1992; Mydin, 1992). Of the hybrids found superior for dry rubber yield, four clones *viz.*, 95/353, 95/362, 95/442 and 95/448 were superior in DRC and four clones, 95/297, 95/351, 95/362 and 95/448 were superior in volume of latex. The high yielding clone 95/442 which maintained high DRC as well as volume of latex in the stress period offers promise of good performance under drought.

Among the anatomical parameters studied (Table 7), there was no clonal variation for bark thickness while the clones showed variability for the number of latex vessel rows in the hard and soft bast layers as also the total number of laticifers. Clone RRII 105 had the highest number of latex vessel rows (13.7) while 13 hybrids were comparable to the check with 10 or more latex vessel rows. Of these, clones 95/297, 95/348, 95/448 and 95/323 were high yielders.

Table 8. **Tapping panel dryness and pink disease**

Clone	TPD (%)	PD (%)	Clone	TPD (%)	PD (%)
95/30	25.0	9.1	95/362	33.3	7.7
95/31	16.7	0.0	95/441	0.2	0.0
95/34	10.0	0.0	95/442	0.5	0.0
95/211	0.0	8.3	95/448	0.3	0.0
95/213	7.7	15.4	95/452	0.1	8.3
95/216	10.0	0.0	95/503	0.1	0.0
95/217	0.0	0.0	95/101	11.1	7.7
95/264	20.0	0.0	95/232	0.0	0.0
95/269	0.3	18.2	95/220	12.5	9.1
95/270	0.0	18.2	95/234	10.0	16.7
95/272	0.0	9.1	95/230	14.3	0.0
95/273	0.1	18.2	95/318	0.0	0.0
95/377	0.0	0.0	95/323	9.1	0.0
95/385	0.3	15.4	95/328	16.7	0.0
95/389	0.0	7.7	95/332	8.3	0.0
95/390	0.1	9.1	95/399	50.0	0.0
95/392	0.4	8.3	95/403	10.0	0.0
95/109	0.0	16.7	95/404	18.2	0.0
95/293	0.0	0.0	95/405	10.0	9.1
95/297	0.1	0.0	95/464	33.3	0.0
95/300	0.3	0.0	95/473	8.3	8.3
95/305	0.2	0.0	95/474	0.0	0.0
95/311	0.0	0.0	95/477	16.7	0.0
95/335	0.0	0.0	RRII 118	0.0	8.3
95/336	0.0	8.3	RRIM 703	0.0	0.0
95/345	0.0	15.4	PB 86	15.4	0.0
95/348	23.1	0.0	RRII 105	9.1	0.0
95/351	9.1	8.3	G.M.	12.5	4.7
95/353	40.0	25.0		19	

The performance indices of clones (Fig. 3) ranged from 72-96, with clone RRII 105, the high yielding check clone exhibiting an index of 85.6. Nineteen clones among the 54 hybrids were better in performance with respect to yield and its

Table 9. **Heterosis of hybrids over the better parent for rubber yield, girth and tappability**

Clone	Parentage	Heterobeltiosis (%)		
		Yield	Girth	Tapp-ability
95/30	RRII 105 x RRIM 703	-	12.3	63
95/31	RRII 105 x RRIM 703	-	-	59
95/34	RRII 105 x RRIM 703	-	5.9	36
95/211	RRII 105 x RRIM 703	27.4	-	-
95/213	RRII 105 x RRIM 703	-	-	17
95/216	RRII 105 x RRIM 703	-	0.4	63
95/217	RRII 105 x RRIM 703	-	-	-
95/264	RRII 105 x RRIM 703	-	-	-
95/269	RRII 105 x RRIM 703	-	-	-
95/270	RRII 105 x RRIM 703	-	-	-
95/272	RRII 105 x RRIM 703	-	-	-
95/273	RRII 105 x RRIM 703	-	-	-
95/377	RRII 105 x RRIM 703	-	-	-
95/385	RRII 105 x RRIM 703	28.4	-	-
95/389	RRII 105 x RRIM 703	-	-	-
95/390	RRII 105 x RRIM 703	-	0.6	18
95/392	RRII 105 x RRIM 703	-	-	-
95/109	RRII 105 x RRII 118	15.1	15.5	18
95/293	RRII 105 x RRII 118	-	-	
95/297	RRII 105 x RRII 118	43.5	17.6	28
95/300	RRII 105 x RRII 118	10.1	2.9	-
95/305	RRII 105 x RRII 118	25.9	9.2	-
95/311	RRII 105 x RRII 118	3.0	-	-
95/335	RRII 105 x RRII 118	0.8	-	-
95/336	RRII 105 x RRII 118	-	8.3	18
95/345	RRII 105 x RRII 118	11.8	20.1	-
95/348	RRII 105 x RRII 118	42.5	11.3	-
95/351	RRII 105 x RRII 118	62.3	15.1	40
95/353	RRII 105 x RRII 118	63.3	10.9	-
95/362	RRII 105 x RRII 118	46.5	10.9	-
95/441	RRII 105 x RRII 118	9.5	17.8	18
95/442	RRII 105 x RRII 118	59.0	6.1	-
95/448	RRII 105 x RRII 118	64.8	13.4	0.2
95/452	RRII 105 x RRII 118	-	5.2	-

95/503	RRII 105 x RRII 118	-	6.3	-
95/101	RRII 105 x PB 86	-	-	-
95/232	RRII 105 x PB 86	19.6	4.6	36
95/220	RRII 105 x PB 86	-	-	-
95/234	RRII 105 x PB 86	-	-	9
95/230	RRII 105 x PB 86	-	-	-
95/318	RRII 105 x PB 86	-	15.7	76
95/323	RRII 105 x PB 86	53.8	-	-
95/328	RRII 105 x PB 86	8.3	1.9	-
95/332	RRII 105 x PB 86	-	2.5	36
95/399	RRII 105 x PB 86	-	-	-
95/403	RRII 105 x PB 86	-	5.0	26
95/404	RRII 105 x PB 86	-	7.5	22
95/405	RRII 105 x PB 86	7.3	-	-
95/464	RRII 105 x PB 86	-	6.5	63
95/473	RRII 105 x PB 86	-	2.5	9
95/474	RRII 105 x PB 86	-	2.1	46
95/477	RRII 105 x PB 86	-	7.5	9

components over six years of tapping as indicated by their performance indices. Eleven clones 95/297, 95/348, 95/323, 95/353, 95/362, 95/442, 95/385, 95/345, 95/441, 95/328 and 95/448 with yields higher than the high yielding check RRII 105 (39.8 $gt^{-1}t^{-1}$) maintained good general performance as indicated in Figure 3. The high yielding selections *viz.*, 95/297, 95/348, 95/323, 95/353, 95/362, 95/442 and 95/448 with the exception of 95/353 were among the best general performers. The low summer yield of clone 95/353 presumably led to its low performance index, though the mean yield was high.

Pink disease and TPD

Among the clones evaluated, 29 were free from pink disease and 32 showed no tapping panel dryness in panel BO-1. In general 12 per cent of the trees showed symptoms of TPD and only 4.7 per cent of the trees were affected by pink disease (Table 8). The incidence of TPD ranged from 0-50 per cent and that of pink disease ranged from 0-18.2 per cent. Among the high yielders, five clones *viz.*, 95/297, 95/348, 95/442, 95/448 and 95/323 were totally free of pink disease. In the high yielding clones 95/297, 95/442 and 95/448, only less than one per cent of the trees showed signs of TPD, but the high yielding clones 95/348, 95/353 and 95/362 exhibited high incidence of TPD.

Heterosis for yield and growth

Among the parent clones, RRII 105 was the high yielding check clone and the better parent in terms of both girth (Table 3) and yield (Table 4) for all the hybrids evaluated. Tappability among the parent clones was highest in clone RRII 118 (55%) which was the better parent for 18 of the hybrids evaluated.

Heterobeltiosis which is the improvement achieved over the better parent, was estimated for rubber yield, girth and tappability (Table 9). Heterobeltiosis was exhibited by 20 hybrid clones for yield, 29 hybrids for girth and 22 hybrids for tappability. Estimates of heterobeltiosis for yield ranged from 0.8 to 64.8 per cent with 11 hybrids showing more than 20 per cent improvement over the better parent. Among these eight clones were of parentage RRII 105 x RRII 118. Heterobeltiosis for girth ranged from 0.4 to 20.1 per cent only while heterosis for tappability ranged from 0.2 to 76.4 per cent with 11 hybrids showing more than 20 per cent improvement in tappability compared to the better parent. Two of the high yielding selections of the cross RRII 105 x RRII 118 *viz.*, 95/351 and 95/297 exhibited high levels of heterosis over their better parent in terms of both rubber yield and tappability. Crossing between widely distinct heterozygous genotypes exposes very few common recessives, so that F1 vigour is markedly enhanced above the average, resulting in heterosis (Simmonds, 1986). Among the eight promising hybrids identified in this study, seven with heterobeltiosis ranging from 42.5 to 64.8 per cent were selections from progeny of the cross between the two divergent parents RRII 105 and RRII 118. This wide genetic distance between the two Indian clones RRII 105 and RRII 118, as also elucidated earlier by Bini (2013) using molecular markers could be attributed to the pedigree of these two clones. While RRII 105 is a hybrid of the Indonesian primary clone Tjir 1 with the Malaysian primary clone Gl 1 both of which were evolved from the few seedlings received from the original consignment of Wickham material that reached South East Asia, the clone RRII 118 is a hybrid of two Sri Lankan primary clones Mil 3/2 and Hil 28. As discussed by Wycherley (1976) and later by Tan (1987), of the over 2000 seedlings from the original Wickham collection that was brought to Asia in 1876-'77, Sri Lanka received a majority of the material, while Malaya and Indonesia received only a few seedlings. In due course Sri Lanka as well as Malaysia developed as secondary centres of diversity of this species and there is a high probability of the genetic material evolved from this base population, over the years in Sri Lanka being distinct from that in Malaysia and Indonesia. Therefore, the high recovery of heterotic progeny from this cross could be the result of specific combining ability by way of the wide divergence of parents involved. Such a phenomenon on crossing clone RRII 105 with a Sri Lankan clone RRIC 100 was reported earlier by Licy *et al.* (1992) and Varghese *et al.* (1997). This indicates the necessity for repeating these two cross combinations and raising larger sized of progenies for still more effective selection in the recombination breeding programs.

CONCLUSION

The present study demonstrated the extent of variability that can be unleashed by biparental crosses among divergent parent clones and scope for selection for yield and growth in rubber. Repetition of crosses between parent clones evolved from Malaysian and Sri Lankan lineages could result in better recovery of heterotic progeny. The hybrids evaluated were developed from drought tolerant parents and could therefore be subjected to screening for intrinsic drought tolerance traits. The promising selections which have confirmed high yield potential could be screened for drought tolerance in further field evaluations in drought prone environments. The eight high yielding clones *viz.*, 95/297, 95/348, 95/323, 95/353, 95/362, 95/442, 95/351 and 95/448 with consistently high yield over all the years of tapping in panel BO-1 compared to RRII 105 could also be put to multilocational testing in participatory trials to identify location specific clones. The low incidence of TPD and pink disease in clones 95/297, 95/442 and 95/448 and the steadily increasing trend in yield of 95/448 deserve special mention. Hybrid clones 95/348, which maintained high summer yield coupled with a low yield drop in summer months, along with clone 95/442 which maintained high DRC and volume of latex in the stress period offer promise of good performance in drought prone regions.

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REFERENCES

Bini, K. (2013). *Development of a genetic linkage map using molecular markers in Para rubber tree (Hevea brasiliensis).* Ph.D. thesis, University of Kerala, Thiruvananthapuram, Kerala. 121 p.

Chevallier, M.H. (1988). Genetic variability of *Hevea brasiliensis* germplasm using isozyme markers. *Journal of Natural Rubber Research,* 3: 42-53.

Licy, J., Panikkar, A.O.N., Premakumari, D., Varghese, Y.A. and Nazeer, M.A. (1992). Genetic parameters and heterosis in *Hevea brasiliensis.* 1. Hybrid clones of RRII 105 x RRIC 100. *Indian Journal of Natural Rubber Research,* 5(1&2): 51-56.

Markose, V.C. (1984). *Biometric analysis of yield and certain yield attributes in the Para rubber tree.* Ph.D. Thesis, Kerala Agricultural University, Kerala, India.

Mydin, K.K. (1992). *Genetic divergence, prepotency and inbreeding depression in Para rubber (Hevea brasiliensis* Muell. Arg.). Ph.D. Thesis, Kerala Agricultural University, Trichur, India, 351 p.

Mydin, K.K., Gopinathan Nair, V., Sethuraj, M.R., Panikkar, A.O.N. and Saraswathy, P. (1992). Genetic divergence in rubber (*Hevea brasiliensis* Willd. ex Adr. de Juss. Muell. Arg.). *Indian Journal of Natural Rubber Research,* 5(1&2) : 120-126.

Mydin, K.K., Gopinathan Nair, V., Sethuraj, M.R., Panikkar, A.O.N. and Saraswathy, P. (1992). Estimates of genetic parameters for yield and certain yield components in rubber. Gregor Johann Mendel Foundation International Symposium, Calicut, Kerala.

Mydin, K.K., Gopinathan Nair, V., Panikkar, A.O.N., Saraswathy, P. and. Sethuraj, M.R. (1990). Prepotency in rubber I. Early estimation through juvenile traits. *Proceedings National Symposium on New Trends in Crop Improvement of Perennial Species, R.R.I.I., Kottayam,* pp. 114-123.

Narayanan, C. and Mydin, K.K. (2011). Heritability of yield and secondary traits in two populations of Para rubber tree (*Hevea brasiliensis*). *Silvae Genetica,* **60**(3): 132-139.

Romesburg, H.C. (2004). *Cluster Analysis for Researchers.* Lulu Press, North Carolina. 334 p.

Simmonds, N.W. (1986). Rubber Breeding. In: *Rubber* (Eds. C.C. Webster and W.J. Baulkwill). Longman, London.

Smith, O.S., Smith, J.S.C., Bowen, S.L., Tenborg, R.A. and Wall, S.J. (1990). Similarities among a group of maize inbreds as measured by pedigree, grain yield, heterosis and RFLPs. *Theoretical and Applied Genetics,* **80**: 833-840.

SPSS (1999). *SPSS Base 10.0 Application Guide.* SPSS Incorporated. 426 p.

Tan, H., Mukherjee, T.K. and Subramaniam, S. (1975). Estimates of genetic parameters of certain characters in *Hevea brasiliensis. Theoretical and Applied Genetics,* **46**: 186-190.

Tan, H. (1987). Strategies in rubber tree breeding. In: *Improving Vegetatively Propagated Crops* (Eds. A.I. Campbell, A.J. Abbott and R.J Atkin.) Academic Press, London, pp. 27-62.

Varghese, Y.A., Knaak, C., Sethuraj, M.R. and Ecke, W. (1997). Evaluation of random amplified polymorphic DNA (RAPD) markers in *Hevea brasiliensis. Plant Breeding,* **116**(1): 47-52.

Wycherley, P.R. (1976) Rubber. In: *Evolution of Crop Plants* (Ed. N.W. Simmonds). Longman, London, 77-80.