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ROLE OF PARENTAL SELECTION IN CLASSICAL *HEVEA* BREEDING IN INDIA

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This paper discusses the role of parental selection in classical *Hevea* breeding programmes based on results from clone evaluation trials. Among the major clonal types examined (W x W, W x A and ortets), W x W origin clones (360 clones) showed an average yield potential of 5.4 kg tree^{-1} yr^{-1}. Yield potential of the W x A hybrids (42 clones) and Wickham origin ortets (165 clones) were 3.7 and 4.5 kg tree^{-1} yr^{-1} respectively.The average yield was higher in clonal families with RRII 105 as the female parent than as the male parent. The same trend was observed in reciprocal crosses also indicating the significance of RRII 105 as a female parent in cross combinations. Among the various cross combinations involving RRII 105 as the female parent, the highest average family yield (7.9 kg tree^{-1} yr^{-1}) and the maximum yield (15.9 kg tree^{-1} yr^{-1}) were recorded in the family of RRII 105 x RRII 118. In the 1982 HP programs, clones in the family of RRII 105 x RRIC 100 recorded 63 per cent average yield improvement over the family of GT 1 x RRII 105 and 90 per cent improvement over the family of GT 1 x RRIC 100. RRII 118 and RRIC 100 are clones known for high growth vigour and yield potential which strongly suggests the critical role of both the parents in *Hevea* breeding programmes.

The average yield potential of the important introduced clones, popular primary clones and secondary clones were 6, 4 and 6 kg tree^{-1} yr^{-1} respectively. The average yield improvement of the tertiary clones (RRII 400 series) over the secondary clones was 17 per cent while that over the primary clones was 75 per cent. Recombination breeding in *Hevea* is rewarding although a yield ceiling seemed to be reaching as evidenced from the decreasing per cent of yield improvement. Further yield improvement and widening of the gene pool is envisaged through new introductions. The recently imported clones, through the international Multilateral Clone Exchange (MCE) programme from the IRRDB member countries, having proven traits for yield, growth and other important secondary attributes are expected to contribute more in the *Hevea* breeding programmes and in the plantation industry.

Keywords: Amazonian accessions, *Hevea brasiliensis* breeding, Ortets, Parental selection

INTRODUCTION

Hevea brasiliensis is an economically important perennial tree crop species. Primarily the species is known for the Natural Rubber (NR) (cis-1, 4-polyisoprene) containing latex present in the phloem tissues (Kush *et al*., 1990). The volume of latex and per cent rubber it contains determines the crop yield. Inherent genetic potential of the tree and its interaction with

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the environment are important for a tree to perform in a given environment (Jayasekera *et al*., 1994). Yield superiority of the tree is sustained through vegetative propagation (bud-grafting). Improving rubber yield in commercially cultivated clones of the species is the main focus in *H. brasiliensis* breeding programmes. Long immaturity period (generally 7 years) and the time taken for determination of yield potential under field conditions make conventional breeding programmes laborious and time consuming. Nevertheless, all the commercially cultivated *Hevea* clones in the rubber growing countries are developed through conventional breeding programmes.

Genetic distance between the genotypes in the gene pool determines the variation in clonal performance, and the variation in turn is essential for breeding programs (Varghese *et al*., 1997). Hybridizations for generating superior hybrids, evaluation of polycross progenies from open cross pollinations in specially designed polyclonal seed gardens, selection of seedling trees with outstanding growth vigour and yield, and introductions are the major classical breeding approaches aimed at crop improvement in *H. brasiliensis*. Introduced exotic clones played a vital role in widening the narrow genetic base and yield improvement in India. This paper focuses on the yield performance of the clones in the SSTs (Small Scale Trials) resulted from Hand Pollination (HP) programs. The significant role of RRII 105 as a parent in cross combinations, the significance of parent selection, contribution of the introduced exotic clones, and the relevance of the recently introduced clones from the IRRDB member countries are also discussed.

MATERIALS AND METHODS

Long term yield data from Indian origin hybrid clones from Wickham clones (360 W x W hybrids) and Wickham clones crossed with Amazonian accessions (42 W x A hybrids) were used for the study. Yield data from indigenous primary clones (165 ortets) were also used. Data for the analysis were collected from published research papers (Mydin *et al.*, 2005; 2016; Meenakumari *et al.*, 2010; Sankariammal *et al*., 2011; John *et al.*, 2013; Mercykutty *et al.*, 2013; Reju *et al*., 2014; 2019; Reju and Mydin, 2019; Mydin and Gireesh, 2016; Mydin and John, 2019; Jacob *et al.*, 2021). Hybrids originated from five major HP programmes (1982, 1986, 1990, 1994 and 1995) were utilized (Table 1). The hybrids were evaluated in the traditional region of Kerala in SSTs (1985, 1990, 1995 and 1999 respectively). Yield recorded for more than six years of tapping was used for the study and calculated in terms of kg tree^{-1} yr^{-1}. The impact of popular clone RRII 105 as a parent in major clonal families was estimated in terms of yield potential of the families with RRII 105 as a parent. Yield potential of certain primary clones that were parents for a number of secondary clones was calculated, and the yield improvement in secondary and tertiary clones was also computed. Yield potential of the existing exotic clones and the significance of the recently imported clones (introductions) have been discussed in view of the crop improvement programs and widening of the narrow genetic base of *H. brasiliensis* in India.

RESULTS AND DISCUSSION

Within the available clonal populations in India, majority are Wickham x Wickham hybrids (W x W) followed by Wickham origin primary clones (ortets) and a limited number of Wickham x Amazonian hybrids (W x A). Average yield among 360 W x W clones was 5.4 kg tree^{-1} yr^{-1} with the maximum yield stretching to 15.9 kg tree^{-1} yr^{-1} (Table 2). Among the primary clones (ortets), the yield

Table 1. **Parental clones, number of cross combinations and clones used for the analysis**

Year of HP	Parental clones involved	No. of cross combinations	No. of hybrids	Year of SST	Location
1982	RRII 105, RRIC 100, GT 1, PR 107, PB 5/51	5	63	1985	RRII
1986	RRII 33, RRII 105, RRII 118,RRII 203, RRII 208, Gl 1, PB 86, PB 217, PB 235, PB 242, PB 252, PB 5/51, PB 28/59, PB 28/83, RRIM 600, RRIM 612, RRIM 703, RRIC 52, IAN 45-873, PR 107	44	228	1990	RRII
1990	RO 24, RO 26, RO 34, RO 87, RO 132, RO 142, MT 196, RRII 105, RRIM 600	9	42	1995	CES Chethackal
1994	RRII 105, RRIM 600, RRIC 52, RRIC 104, PB 86, AVT 73	5	13	1999	"
1995	RRII 105, RRII 118, RRII 203, Mil 3/2, PB 86, PB 217, PB 242, PB 235, PB 28/59, RRIM 703, RRIM 600	9	56	1999	"

potential ranged from 2 kg tree^{-1} yr^{-1} to 10 kg tree^{-1} yr^{-1} with the average being 4.5 kg tree^{-1} yr^{-1}. The lowest average yield was recorded in the W x A hybrids (3.7 kg tree^{-1} yr^{-1}) with 8 kg tree^{-1} yr^{-1} being the maximum value recorded. Average yield of the W x W hybrids was superior to other clonal types. Hence, hybrids originated from the Wickham gene pool may be beneficial in yield improvement. Higher yields in the W x W hybrids may be attributed to the selected parents involved in the HP programmes. In the case of the W x A hybrids, limited number of crosses and poor yield potential of the Amazonian accessions may be the probable reasons for low yield. Among the primary clones, low yields may be ascribed to the unknown parentage of the clones.

Since the clone RRII 105 became popular for yield potential, the clone was utilized as a parent in subsequent hand pollination programs in India. In the bi-parental crosses that followed, RRII 105 was used as both female and male parent. Among the 228 recombinants examined in the SSTs from the 1986 hand pollination programmes, 103 were having RRII 105 as its female parent crossed to various male parents of Wickham

Table 2. **Yield potential of major clonal types**

	W x W Hybrids	W x A Hybrids	Primary clones (Ortets)
Mean (kg tree^{-1} yr^{-1})	5.4*	3.7	4.5
Range (kg tree^{-1} yr^{-1})	1.6-15.9	1.6-8.0	2.0-10.0
SD	2.1	1.4	1.6
SE	0.11	0.21	0.1
CV	38	37	35
Variance	4.38	1.9	2.5
No. of clones	360	42	165

* Mean yield of W x W hybrids is significantly different at 5 per cent level over other clonal types

origin while 44 recombinants had RRII 105 as male parent with various Wickham origin female parents. Among the cross combinations, three were reciprocal crosses involving RRII 105 with PB 86, PB 5/51 and IAN 45-873. In the three reciprocal crosses, a pattern was recorded in the families having RRII 105 as the female parent. When RRII 105 was the female parent, the average and the maximum yields improved compared to the crosses where RRII 105 was the male parent (Fig. 1). As a confirmation to the pattern, in the rest of the cross combinations also (16 clones were used as male parents with RRII 105 as the female parent) the average and the maximum yields were higher in families with RRII 105 as the female parent (5.7 kg tree^{-1} yr^{-1} and 15.9 kg tree^{-1} yr^{-1} respectively) compared to the families with RRII 105 as the male parent (4.7 kg tree^{-1} yr^{-1} and 9 kg tree^{-1} yr^{-1} respectively) (Table 3). In studies conducted earlier, it has been shown that RRII 105 is a pre-potent parent capable of transmitting superior traits to its progenies (Mydin *et al.*, 1996; 2002; Sebastian and Saraswathyamma, 2005). Heritability of rubber yield was also established earlier (Simmonds, 1989). Results from the present study reconfirm the prepotency of RRII 105. In light of the present analysis and the earlier studies, it is suggested that yield potential of the recombinants in *H. brasiliensis* is influenced by the female parent with superior yield potential.

In the 1990 HP programs, involving RRII 105 and RRIM 600 as female parents and Amazonian accessions (RO 142 and RO 87) as male parents, in the family of RRII 105 x RO 142, the average yield was 27 per cent more than that in the families of RRIM 600 x RO 142 and RRIM 600 x RO 87. The maximum yield potential was 40 per cent and 32 per cent more in the family of RRII 105 x RO 142 over the families of RRIM 600 x RO 142 and RRIM 600 x RO 87 respectively (Table 4). This indicated that RRII 105 is a better female parent in recombination breeding for yield improvement compared to RRIM 600. All the above results suggest that a clone with a high yield potential should be the female parent to improve the yield potential of the recombinants.

In the present analysis, role of male parents was also recorded to be important with regard to yield improvement in the recombinants. In the HP programs,

Table 3. **Yield potential of clones resulted from crosses involving RRII 105, other Wickham clones and Amazonian accessions (kg tree^{-1} yr^{-1})**

	RRII 105 x other Wickham clones	Other Wickham clones x RRII 105	RRII 105 x Amazonian accessions
Average	5.7*	4.7	4.0
Maximum	15.9	9.0	8.0
Range	1.6-8.0	2.6-9.0	1.6-8.0
SD	2.1	1.4	1.5
SE	0.15	0.19	0.29
Variance	4.5	2.0	2.2
CV	37	30	37
No. of hybrids	193	56	26

* Mean yield is significantly different at 5 per cent over other combinations

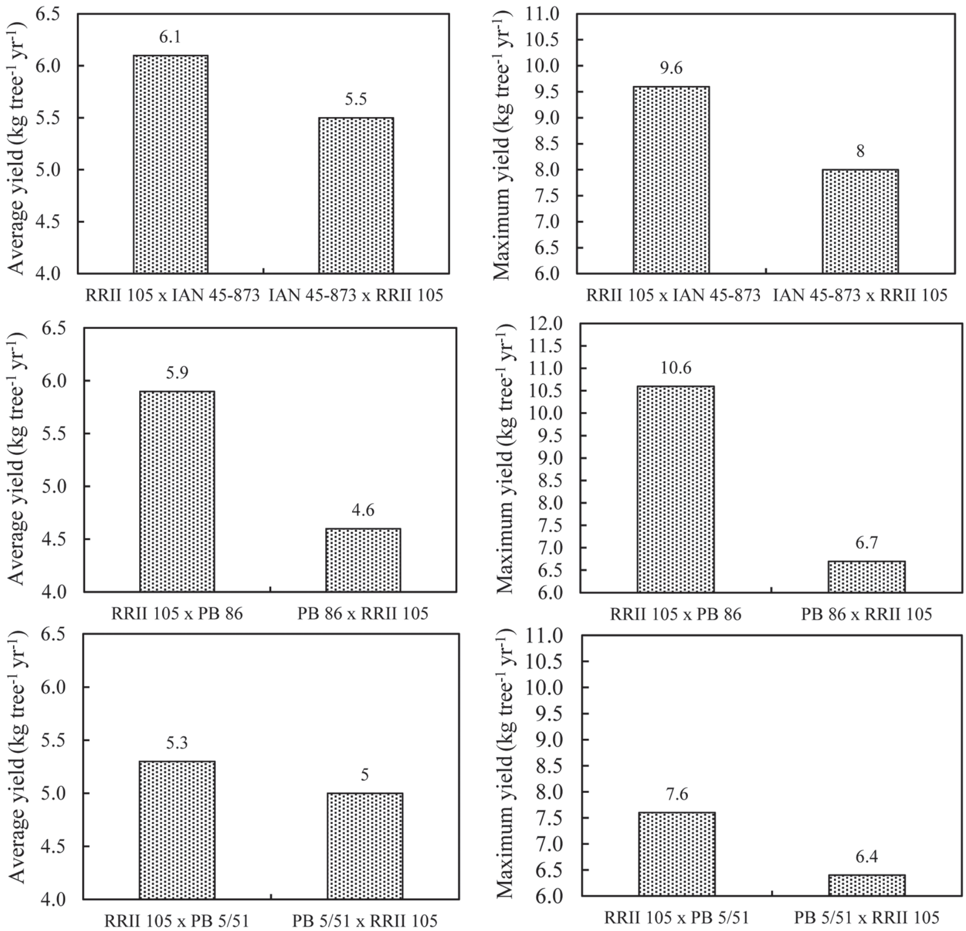

Fig. 1. Yield potential of families resulted from reciprocal crosses involving RRII 105, PB 86, PB 5/51 and IAN 45-873 (kg tree^{-1} yr^{-1})

Wickham clones (RRII 118, RRII 203, RRII 208, PB 86, PB 217, PB 242, PB 5/51, PB 28/59, RRIM 703, RRIC 52 and PR 107) and Amazonian accessions (RO 23, RO 24, RO 26, RO 34, RO 87, RO 132, RO 142 and MT 196) were used as male parents with RRII 105 as the female parent. In all these crosses, the average and maximum yields were higher with the Wickham clones as the male parents than the crosses with Amazonian accessions as the male parents (Table 3). This showed that the Amazonian accessions, even though they are from a diverse genetic makeup, their low yield affected the yield potential of the progenies (RRII 105 x Amazonian accessions) compared to the potential of the clones that resulted from the Wickham clones (RRII 105 x other Wickham clones). This indicated that the male parents also should be superior for yield to ensure a good recovery of superior hybrids with higher yield potentials. It is also assumed that Amazonian accessions are needed only for specific breeding goals.

Table 4. **Yield potential of families from W x A crosses (1990 HP)**

Family	Mean (kg $tree^{-1} yr^{-1}$)	Range (kg $tree^{-1} yr^{-1}$)	No. of clones
Average	5.7 *	4.7	4
RRII 105 x RO 142	4.5	2.0-8.0	10
RRIM 600 x RO 142	3.3	2.2-4.8	4
RRIM 600 x RO 87	3.3	1.6-5.4	12
Yield improvement in the family RRII 105 x RO 142 over RRIM 600 x RO 142	27 %	40% (between the maximum values)	
Yield improvement in the family RRII 105 x RO 142 over RRIM 600 x RO 87	27 %	32% (between the maximum values)	

Eight families having RRII 105 as the female parent and eight different Wickham clones as the male parent were tested in the 1986 HP program (Table 5). The highest average family yield (7.9 kg $tree^{-1} yr^{-1}$) and the maximum yield (15.9 kg $tree^{-1} yr^{-1}$) were recorded in the family of RRII 105 x RRII 118. This showed that among the eight Wickham clones used in the crosses, RRII 118 was the best male parent compared to the other clones. In the 1995 HPs, 18 clones from the family of RRII 105 x RRII 118 and 17 clones from the family of RRII 105 x RRIM 703 were also examined. The highest family average and the maximum yields were recorded in the family of RRII 105 x RRII 118 (5.8 kg $tree^{-1} yr^{-1}$ and 7.9 kg $tree^{-1} yr^{-1}$ respectively) compared to that of the family of RRII 105 x RRIM 703 (4.3 kg $tree^{-1} yr^{-1}$ and 6.1 kg $tree^{-1} yr^{-1}$ respectively). Compared to RRIM 703, RRII 118 was a better male parent. Earlier studies have shown that RRII 118 is a clone with vigourous growth and high yield potential whereas RRIM 703 is a poor yielder with medium growth vigour (John *et al.*, 2009; Meenakumari *et al.*, 2015). In another HP program (1982 HPs), PR 107 and RRIC 100 were utilized as male parents. The clones in the family of RRII 105 x RRIC 100 recorded higher family average yield (6.4 kg $tree^{-1} yr^{-1}$) and maximum yield (9.3 kg $tree^{-1} yr^{-1}$) compared to the family of RRII 105 x PR 107 (4.7 kg $tree^{-1} yr^{-1}$ and 6.4 kg $tree^{-1} yr^{-1}$ respectively). RRIC 100 is a clone with vigourous growth and high yield potential

Table 5. **Yield potential of families with RRII 105 as the female parent**

Family	Mean (kg $tree^{-1} yr^{-1}$)	Range (kg $tree^{-1} yr^{-1}$)	No. of clones
1986 HPs			
RRII 105 x PB 86	5.9	2.3 - 10.6	22
RRII 105 x RRII 118	7.9	3.7 - 15.9	13
RRII 105 x PB 5/51	5.3	3.0 - 7.6	13
RRII 105 x IAN 45-873	6.1	3.6 - 9.6	13
RRII 105 x RRII 208	6.2	3.0 - 8.4	11
RRII 105 x PR 107	5.1	2.1 - 9.3	11
RRII 105 x RRIC 52	6.0	3.7 - 8.5	7
RRII 105 x PB 217	6.0	4.1 - 9.3	5
1995 HPs			
RRII 105 x RRII 118	5.8	3.3 - 7.9	18
RRII 105 x RRIM 703	4.3	2.6 - 6.1	17
1982 HPs			
RRII 105 x PR 107	4.7	3.3 - 6.4	5
RRII 105 x RRIC 100	6.4	2.8 - 9.3	25

(Premakumari *et al.*, 1991; Marattukalam *et al.*, 2005; Mydin, 2014). Yield performance is inseparably related to the growth vigour of the tree (Simmonds, 1989). The analysis emphasizes the fact that in *Hevea* HP programs, a female parent with high yield potential and a male parent known for vigourous growth and yield potential would be ideal for yield improvement.

Selection of parents to generate a progeny population of promising recombinants is very important. This was evident in the 1982 HP program where GT 1, RRIC 100 and RRII 105 were selected as parents. GT 1, a primary clone with medium yield potential and relatively high growth vigour was used as a female parent with RRII 105 and RRIC 100 as the male parents (Table 6). The average yield of the family of GT 1 x RRII 105 was 3.9 kg tree^{-1} yr^{-1} and the maximum was 5.2 kg tree^{-1} yr^{-1}. In the family of GT 1 x RRIC 100 the average family yield and the maximum yield were 3.4 kg tree^{-1} yr^{-1} and 5.9 kg tree^{-1} yr^{-1} respectively. When RRII 105 was used in place of GT 1 as the female parent, and RRIC 100 as the male parent, the average and the maximum yields further improved (6.4 kg tree^{-1} yr^{-1} and 9.3 kg tree^{-1} yr^{-1} respectively). The family RRII 105 x RRIC 100 recorded 63 per cent improvement over GT 1 x RRII 105 in terms of average family yield, and 78 per cent in terms of the maximum yield. The family recorded 90 per cent and 57 per cent yield improvement over the family of GT 1 x RRIC 100 in terms of family average and maximum yields. It is pertinent to note that the modern RRII 400 series clones were derived from the progenies of the RRII 105 x RRIC 100 family (Licy *et al.*, 1992; 2003). This proves that selecting high yielding and vigorously growing clones as parents in *Hevea* recombination breeding is a prerequisite to obtain a good recovery of promising recombinants with higher yield and early tappability.

Primary clones such as PB 86, PB 5/51, PB 28/59 and Gl 1 (Malaysia), Tjir 1 and GT 1 (Indonesia) Mil 3/2 (Sri Lanka) were progenitors for a large number of modern clones in the rubber growing countries today (Mydin and Saraswathyamma, 2005). The average yield of these clones was 4 kg tree^{-1} yr^{-1} (Table 7). Primary clones, especially Tjir 1, PB 86 and GT 1, were

Table 6. **Family yields of the cross combinations involving GT 1, RRIC 100 and RRII 105 (1982 HP)**

Family	Mean (kg tree^{-1} yr^{-1})	Range (kg tree^{-1} yr^{-1})	No. of clones
GT 1 x RRII 105	3.9	2.8-5.2	12
GT 1 x RRIC 100	3.4	1.6-5.9	19
RRII 105 x RRIC 100	6.4 *	2.8-9.3	25
Yield improvement in the family			
RRII 105 x RRIC 100 over GT x RRII 105	63 %	78% (between the maximum values)	
Yield improvement in the family			
RRII 105 x RRIC 100 over GT x RRIC 100	90 %	57% (between the maximum values)	

* Mean yield is significantly different at 5 per cent level over other families

Table 7. **Yield of tertiary and secondary clones over primary clones**

Clone	Yield potential in India (kg tree^{-1} yr^{-1})	Clone type
Tjir 1	4	Primary
Mil 3/2	4	
PB 86	4	
Gl 1	4	
GT 1	5	
PB 28/59	6	
PB 5/51	4	
Mean	4	
RRIM 600	5	Secondary
PB 260	6	
RRII105	6	
Mean	6	
Yield improvement of secondary clones over primary clones	**50%**	
RRII 414	7	Tertiary
RRII 417	7	
RRII 422	7	
RRII 429	7	
RRII 430	7	
Mean	7	
Yield improvement of tertiary clones over primary clones	**75%**	
Yield improvement of tertiary clones over secondary clones	**17%**	

popular clones before the arrival of the secondary clones. The primary clones were gradually replaced with secondary clones such as RRIM 600, RRII 105 and PB 260. With these popular secondary clones, there was an average yield improvement of 2 kg tree^{-1} yr^{-1} which was 50 per cent more than the primary clones. The continued crop improvement programs resulted in the development of the next generation tertiary clones such as the clones in the RRII 400 series. Average yield improvement of the tertiary clones over the secondary and the primary clones were 17 per cent and 75 per cent respectively. The yield improvement showed that as the directional selection process continued for yield, there was a tremendous improvement in the tertiary clones over the primary clones. This showed that classical recombination breeding is the most important approach for yield improvement in *Hevea*. This success may be attributed to the inheritance of genes linked to the rubber production in the tertiary clones. Moreover, promising genotypes (donor parents) with high yield potential, is essential for yield improvement. However, comparatively less yield improvement of the tertiary clones over the secondary clones (17%) shows that the directional selection process within the available limited gene pool would slow down further yield improvement. To overcome this logjam, widening of the present gene pool with genotypes having high yield potential is imperative.

Introduction of exotic clones played a pivotal role in widening the narrow genetic base and yield improvement in India (Table 8). The first introduced clone as per records was the Indonesian clone Tjir 1 (prior to 1950). PB 86 and Gl 1 were introduced prior to 1956 (Mydin and Saraswathyamma, 2005). A number of important exotic clones *viz*. RRIM 600 (1962), PB 217 (1962), PB 5/51 (1963) and GT 1 (1963) followed in the subsequent years. These exotic clones laid the foundation of the Indian rubber plantation industry. The average yield potential of the important introductions was 6 kg tree^{-1} yr^{-1} and the range varied from 4 to 8 kg tree^{-1} yr^{-1}. Introduced clone PB 260 is in category 1 of the Indian clone recommendations for the traditional regions.

Table 8. **Yield potential of earlier introductions that contributed to the Indian rubber plantation industry and the later introductions in various stages of evaluations**

Clone	Country	Year	Yield potential (kg $tree^{-1}$ yr^{-1})	Clone	Country	Year	Yield potential (kg $tree^{-1}$ yr^{-1})
Tjir 1	Indonesia	Prior to 1950	4	KRS 25	Thailand	1984	6
Mil 3/2	Sri Lanka	Prior to 1956	4	KRS 163	Thailand	1984	7
PB 86	Malaysia	Prior to 1956	4	KRS 128	Thailand	1984	6
Gl 1	Malaysia	Prior to 1956	4	PB 255	Malaysia	1985	7
RRIM 600	Malaysia	1962	5	PB 280	Malaysia	1985	7
PB 217	Malaysia	1962	5	PB 314	Malaysia	1985	8
PB 5/51	Malaysia	1963	4	PB 330	Malaysia	1985	7
GT 1	Indonesia	1963	5	IRCA 18	Cote d' Ivoire	1991	6
PB 28/59	Malaysia	1963	6	IRCA 109	Cote d' Ivoire	1991	7
PB 235	Malaysia	1964	5	IRCA 111	Cote d' Ivoire	1991	6
PB 242	Malaysia	1964	4	IRCA 130	Cote d' Ivoire	1991	8
RRIM 703	Malaysia	1966	5	IRCA 230	Cote d' Ivoire	1991	6
RRIC 100	Sri Lanka	1972	6	RRIM 712	Malaysia	1993	7
PB 310	Malaysia	1979	5	RRIM 722	Malaysia	1993	8
PB 260	Malaysia	1979	6	RRIM 728	Malaysia	1993	6
PB 311	Malaysia	1979	6				
Mean							6.0
Range							4.0-8.0

Other introductions such as PB 255, PB 280 and PB 314 have been upgraded recently and certain other clones are in various stages of evaluations for further upgradations (Mydin *et al.*, 2019). In this context, the recently imported clones through Multilateral Clone Exchange (MCE) program from among the IRRDB member countries is expected to offer a great chance for further widening the genetic base of the present *Hevea* gene pool as well as improvement in the yield potential of future generations of clones in India (Jacob *et al.*, 2013). Forty three clones were introduced from 10 countries (Table 9). These clones having proven traits for yield, growth and other important secondary attributes in their respective countries of origin offer dual advantages of direct selection for commercial cultivation as well as parents for evolving next generation *Hevea* clones.

CONCLUSION

Crop improvement was achieved through conventional *Hevea* breeding programs in India. In the initial years of plantation industry, primary clones played a key role and laid the foundation of Indian rubber plantation industry. With the advent of the secondary and tertiary clones, yield potential further improved. In the Indian crop improvement programs, hybrids that originated from W x W crosses showed higher yield potential compared to the ortets and the W x A hybrids. In crosses where RRII 105 was the female parent, yield potential of the recombinants was higher.

Table 9. **Clones imported from the IRRDB* member countries**

Imported from	No. of clones	Year of Import	Clone	Parentage	Origin
Cambodia	5	2015	FDR 4575	FDR 18 x Fx 3032	Liberia
			FDR 5788	Harbel 8 x MDF 180	Liberia
			CDC 312	Avros 308 x MDX 40	Guatemala
			PMB 1	*Incognito*	Brazil
			FDR 5665	Harbel 62 x MDX 25	Liberia
China	5	2014	Hongshan 67-15	Primary clone	China
			Zhanshi 8-67-3	Tianren 31-45 × PR 107	
			CATAS 7-33-97	RRIM 600 × PR 107	
			Reyan 7-20-59	RRIM 600 × PR 107	
			Baoting 936	RRIM 600 × Haiken 1	
Cote de Ivoire	4	2016 & 2017	IRCA 41	GT 1 x PB 5/51	
			IRCA 317	GT 1 x PB 5/51	
			IRCA 331	GT 1 x RRIM 600	
			IRCA 733	PB 5/51 x PR 228	
Ghana	5	2016	FDR 5597	Harbel 68 x TU 42-525	Liberia
			FDR 5802	Harbel 67 x CD 47	Liberia
			CDC 56	MDX 91 x RRIM 614	Guatemala
			MDX 624	AVROS 1581 x MDF**?**	Guatemala
			CD 1174	AVROS 1581 x MDF 315	Guatemala
Indonesia	3	2015	IRR 5	Primary clone	Indonesia
			IRR 104	BPM 101 x RRIC 110	
			IRR 119	RRIM 701 x RRIC 110	
Myanmar	2	2016	ARCPC 2(4)	BPM 24 x PB 260	Myanmar
			ARCPC 6(22)	PB 260 x RRIC 100	
Philippines	1	2016 & 2017	USM 1	Primary clone	Philippines
Sri Lanka	5	2016 & 2017	RRISL 208	RRIC 101 x RRIM 600	Sri Lanka
			RRISL 211	RRIC 101 x RRIM 600	
			RRISL 2001	RRIC 100 x RRIC 101	
			RRISL 203	RRIC 100 x RRIC 101	
			RRISL 219	PB 28/59 x RRIC 102	
Thailand	5	2014	RRIT 226	PB 5/51 x RRIM 600	Thailand
			RRIT 251	Primary clone	
			RRIT 408	PB 5/51 x RRIC 101	
			RRIT 3604	PB 235 x RRIM 600	
			RRIT 3904	RRII 203 x PB 235	

...*continued*

Vietnam	8	2014	RRIV 1	RRIC 110 x RRIC 117	Vietnam
			RRIV 5	RRIC 110 x RRIC 117	
			RRIV 103	RRIC 110 x RRIC 123	
			RRIV 106	RRIC 110 x PB 252	
			RRIV 107	RRIC 110 x RRIC 104	
			RRIV 109	PB 235 x RRIC 123	
			RRIV 114	RRIC 121 x PB 235	
			RRIV 124	RRIC 121 x RRIC 115	

*IRRDB- International Rubber Research and Development Board

The study showed that in *Hevea* breeding programs, a female parent with high yield potential is required for yield improvement in the recombinants.

The study also showed that a male parent of vigorous growth and high yield potential would generate promising recombinants with high yield potential. Crosses involving clones RRII 105 x RRIC 100 that generated the RRII 400 series are classical examples of the need to have high yielding as well as vigorous growing clones as parents in *Hevea* recombination breeding. The introduced clones prior to 1950 till 1995 played a critical role in the Indian *Hevea* breeding programs especially in terms of the widening of the narrow genetic base and the plantation industry. Hence it is also expected that the recently imported clones from the IRRDB member countries will be a great advantage to the further widening of the Indian *Hevea* gene pool, and in the crop improvement programmes.

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REFERENCES

Jacob, J., Othman, R., Mydin, K.K., Lam, L.V., Tuy, L.M., Woelan, S., Teerawatanasuk, K., Weiguo, L., Seneviratne, W.M.G., Omokhafe, K.O. and Mathurin, O.K. (2013). International clone exchange and genetic enhancement research in *Hevea brasiliensis*. *Rubber Science*, **26**(1): 1-12.

Jacob, J., Reju, M.J., Meenakumari, T. and Gireesh, T. (2021). Law of diminishing marginal returns and yield ceiling in natural rubber. *Rubber Science*, **34**(1): 1-15.

Jayasekera, N.E.M., Karunasekera, K.B. and Kearsey, M.J. (1994). Genetics of production traits in *Hevea brasiliensis* (rubber) I: Changes in genetical control with age. *Heredity*, **73**: 650-656.

John, A., Varghese, Y.A. and Mushrif, S.K. (2009). Performance of indigenous and exotic clones of rubber in India. *Journal of Plantation Crops*, **37**(2): 97-101.

John, A., Nazeer, M.A., Idicula, S.P., Thomas, V. and Varghese, Y.A. (2013). Potential new primary clones of *Hevea* evolved by ortet selection in India. *Journal of Rubber Research*, **16**(2): 134-146.

Kush, A., Goyvaerts, E., Chye, M.L. and Chua, N.H. (1990). Laticifer-specific gene expression in

Hevea brasiliensis (rubber tree). *Proceedings of the National Academy of Sciences of the United States of America*, **87**(5): 1787-1790.

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.

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

Marattukalam, J.G., Premakumari, D., George, P.J. and Chandrasekhar, T.R. (2005). Long-term performance of a few Indian and exotic clones of *Hevea brasiliensis* in large scale trials in India. *Natural Rubber Research*, **18**(2): 113-119.

Meenakumari, T., Nazeer, M.A., Mydin, K.K. and Nair, R.B. (2010). Long term performance of certain hybrid progenies of *Hevea brasiliensis* in a small-scale trial. *Proceedings of National Symposium on Plant Diversity Utilization and Management,* 27-29 May 2010, Department of Botany, University of Kerala, Thiruvananthapuram, India, pp. 48-54.

Meenakumari, T., John, A., Mercykutty, V.C., Mydin, K.K. and Varghese, Y.A. (2015). Long term yield performance of certain indigenous and exotic clones of *Hevea brasiliensis* under large scale evaluation in India. In: *Prospects in Forestry and Agriculture* (Eds. K.V. Mohanan, T.K. Hrideek, A.V. Raghu, M. Amruth, E.M. Muralidharan and V.V. Radhakrishnan). Kerala Forest Research Institute, Peechi, India, pp. 234-242.

Mercykutty, V.C., Meenakumari, T. and Mydin, K.K. (2013). Promising high yielding clones of *Hevea brasiliensis* evolved by ortet selection programme in Central Kerala. *Rubber Science*, **26**(1): 66-77.

Mydin, K.K. (2014). Genetic improvement of *Hevea brasiliensis*: Sixty years of breeding efforts in India. *Rubber Science*, **27**(2): 153-181.

Mydin, K.K. and Gireesh, T. (2016). Diversity and heterosis by recombination breeding of *Hevea brasiliensis* in India. *Rubber Science*, **29**(1): 20-35.

Mydin, K.K. and John, A. (2019). Success of recombination and polycross breeding approaches in *Hevea brasiliensis. Rubber Science*, **32**(2): 107-120.

Mydin, K.K. and Saraswathyamma, C.K. (2005). *A manual on breeding of Hevea brasiliensis.* Rubber Research Institute of India, Kottayam, India, pp.78-85.

Mydin, K.K., Nair, V.G., Sethuraj, M.R., Panikkar, A.O.N., Nazeer, M.A. and Saraswathy, P. (1996). Prepotency in rubber. 2. Seedling progeny analysis for yield and certain yield attributes. *Indian Journal of Natural Rubber Research*, **9**(1): 63-66.

Mydin, K.K., Sankariammal, L., Thomas, V. and Saraswathyamma, C.K. (2002). Prepotency in rubber: Half sib progeny evaluation. In: *Proceedings of the 15th Plantation Crops Symposium, PLACROSYM XV* (Eds. K. Sreedharan, P.K. Vinod Kumar, Jayarama and Basavaraja M. Chaluki). Central Coffee Research Institute, Karnataka, India, pp. 47-52.

Mydin, K.K., John, A., Nazeer, M.A., Prem, E.E., Thomas, V. and Saraswathyamma, C.K. (2005). Promising *Hevea brasiliensis* clones evolved by ortet selection with emphasis on latex-timber traits and response to stimulation. *Journal of Plantation Crops*, **33**(1): 18-28.

Mydin, K.K., John, A. and Meenakumari, T. (2016). Clones evolved by ortet selection from polycross populations of rubber in Central India. *Rubber Science*, **29**(3): 246-255.

Mydin, K.K., Meenakumari, T., Narayanan, C., Antony P.D., Lakshmanan, R., Abraham, T. and Jacob, J. (2019). New exotic *Hevea* clones for planting recommendation in the traditional rubber growing areas in India. *Rubber Science*, **32**(3): 240-250.

Premakumari, D., Panikkar, A.O.N., Sethuraj, M.R. and Marattukalam, J.G. (1991). Growth, yield and flow characters and their correlations with brown bast incidence in ten *Hevea* clones. *Indian Journal of Natural Rubber Research*, **4**(2): 107-113.

Reju, M.J. and Mydin, K.K. (2019). Clonal variability and seasonal contribution to yield of *Hevea* clones in the traditional rubber growing region of India. *Rubber Science,* **32**(3): 262-271.

Reju, M.J., Mydin, K.K. and Abraham, T. (2014). Utilization of wild *Hevea* germplasm in India: Long-term yield and growth of certain W x A hybrids. *Rubber Science*, **27**(2): 215-224.

Reju, M.J., John, A. and Mydin, K.K. (2019). Genetic improvement of *Hevea* clones for economic traits through hybridization. *Rubber Science*, **32**(2): 181-198.

Sankariammal, L., Mydin, K.K., Thomas, V. and Varghese, Y.A. (2011). Heterosis for yield and growth in Wickham x Amazonian hybrids of *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg. *Natural Rubber Research*, **24**(2): 187-196.

Sebastian, T. and Saraswathyamma, C.K. (2005). Seedling progeny analysis for estimation of prepotency in exotic *Hevea* clones. *Indian Journal of Botanical Research*, **1**(2): 279-287.

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

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.