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*Adaptability Analysis of Rubber (*Hevea Brasiliensis *Muell.-Arg.) Clones* via *GGE Biplot*

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*Yield of rubber (*Hevea brasiliensis *Muell.- Arg.) in Tripura, a sub-optimal area, has low and high yielding regimes. Data on overall means, low and high yielding periods for 11 years (1990 to 2001) were separately analysed* via *GGE biplot to judge specific adaptation of clones. Stability estimates* viz.*, ecovalence, stability variance, s^2, Huehn's non-parametric statistics and Lin and Binn's superiority measure were also calculated. These estimates were comparable except for Huehn's non-parametric statistics. GGE biplot analysis was conducted under symmetrical, entry-focused and tester-focused procedures. While entry-focused scaling for overall means kept years towards a single cluster presuming that all clones were performing comparably over the years, under tester-focused scaling, the years were well spread, indicating the climates of all the years were not same. Overall genotype means were high for PB 235, RRII 203, RRIM 600, RRII 118 and RRIM 703. The symmetrical scaling of data of regime II showed 1999 and 2000 exhibiting higher principal component analysis (PCA) 1 values. Clones RRII 105, RRII 118, RRIM 703 and PB 235 were high yielders under this regime. The performance of clones was different when mean values were plotted against PCA values. While RRII 105, RRIM 703, RRIM 600 and RRII 118 were most stable under regime I, RRIM 605 had a higher stability under regime II. Under both circumstances, PB 235 and RRII 203 were high yielders. When overall means were plotted, RRII 105, RRIM 703, RRII 118 and PB 235 were noted to be most stable over 11 years. Under all these years, PB 235, RRII 203 and RRIM 600 were high yielding.*

Key words: clone; GGE Biplot; GE interactions; *Hevea* rubber; stability; selection; specific adaptation; sub-optimal environments; symmetrical scaling; entry-focused scaling; tester-focused-scaling

Tripura state of Northeast India (22-24°N latitude and 91-92°E longitude) has a non-traditional climate with a predominant cold period and has sub-optimal conditions for rubber cultivation. Here, the clones of *H. brasiliensis* give different yields as compared with traditional rubber-growing areas because of specific adaptation[1]. Two yield regimes are

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prevalent in Tripura: low yielding regime occurring from May to September and high yielding regime from October to January[2]. This significant difference in yield is attributed to the range of latitude and longitude covered by the state that resulted in areas that are sub-optimal for rubber production. Hence, selecting rubber clones that have specific adaptation is vital since the exceptional climate of Tripura (in terms of temperature and wind) offers low- and high-yielding environments. According to Ceccarelli[3], genotypes exhibiting high yield potential in otherwise low-yielding environments should be preferred when selecting for specific adaptation.

The primary goal of a plant breeder is to identify/develop superior cultivars/clones for a target environment. An understanding of the causes of genotype-by-environment (GE) interactions is essential to establish breeding objectives and to formulate recommendations for new areas[4]. The methodology used to understand the cause(s) falls under two categories: one involves factorial regression analysis of the GE matrix (*i.e.*, the yield matrix after the environment and genotype main effects are removed) against environmental factors, genotypic traits or a combination; and the other involves correlations or regression analysis that relates the genotypic and environmental scores derived from principal component analysis (PCA) of the GE interaction matrix to genotypic and environmental covariates[5]. The latter category is associated with the Additive Main effects and Multiplication Interaction model (AMMI) that partitions the GE interaction matrix into individual genotypic and environmental scores[6]. The GE interaction becomes a prominent issue when genotypic (G) and environmental (E) main effects cannot explain persistent yield variation. Both G and GE must be considered simultaneously to evaluate genotypes because both are relevant to cultivar evaluation[7,8]. A combination of G and GE (or GGE) and repartitioning these effects into crossover and non-crossover interaction is possible through GGE biplot analysis[8,9]. A GGE biplot is a versatile graphic approach. A biplot is a graphical display of entries (e.g., clones) and testers (e.g., environments), *i.e.*, a two-way data structure. By subjecting the data to singular value decomposition, three matrices are obtained: the singular value matrix, the entry eigenvector matrix and the tester eigenvector matrix. The singular value matrix is a diagonal matrix and can be partitioned into entry and tester eigenvector matrices. After singular values are partitioned, the positions of entries in the biplot are defined by the entry eigenvector matrix and those of the testers by the tester eigenvector matrix. Such biplots enable visualisation of interrelationship among the entries (clones) and testers (environments) and the interaction between them.

MATERIAL AND METHODS

The experiment was conducted at the Research Farm of the Regional Station of the Rubber Research Institute of India at Taranagar in Tripura State, Northeast India (23° 53′ N latitude; 91° 15′ E longitude and 30 m above sea level). The trial included 15 clones from different geographic origins (*Table 1*) that had been planted during 1979 in a completely randomised design using 5 m × 5 m spacing between plants. Forty trees per clone, which were multiplied by bud grafting, were planted. Latex was collected from each tree of each clone once a month, coagulated, squeezed through rollers to remove excess water, dried in a smoke house, weighed and mean dry rubber yield in grams per tree per tapping (g tree^{-1} tapping^{-1}) was calculated.

Yield data of 11 years (1990-91 to 2000-2001) were subjected to GGE biplot analysis[9].

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TABLE 1. DETAILS OF THE CLONES INVESTIGATED

Country/Clone	Parentage
India	
RRII 5	Primary
RRII 105	Tjir 1 × Gl 1
RRII 118	Mil 3/2 × Hil 28
RRII 203	PB 86 × Mil 3/2
Malaysia	
G1 1	Primary
PB 5/51	PB 56 × PB 24
PB 86	Primary
PB 235	PB 5/51 × PB S/ 78
RRIM 600	Tjir 1 × PB 86
RRIM 605	PB 49 × Tjir 1
RRIM 703	RRIM 600 × RRIM 500
Indonesia	
GT 1	Primary
Sri Lanka	
RRIC 52	Primary
RRIC 105	Tjir 1 × RRIC 52
Liberia	
Harbel 1	Primary

Since two yielding regimes are prevalent in Tripura, the following sets of data were analysed: a) overall mean of 11 years; b) yield data of regime I (June to September) and c) yield data of regime II (October to January). GGE analyses options, such as symmetrical scaling, entry-focused scaling and tester-focused scaling, were used[8]. Stability measures like ecovalence, stability variance, S^2, Huehn's non-parametric statistics and Lin and Binn's superiority measure were also calculated[10-14].

RESULTS AND DISCUSSION

Analysis of variance was conducted using data of overall means, data for regime I and regime II (*Table 2*). Variations observed between clones and months were highly significant, indicating the need for systematic and sustained selection procedures to be adopted to study adaptability under the environment of Tripura.

Stability Measures

Stability estimates calculated through various means are shown in *Tables 3 and 4*. Irrespective of the method used, these values are comparable, except for Huehn's non-parametric statistic[10]. Under regime I, PB 235, RRII 203, RRII 118, and RRIM 600 showed higher genotype means, but they are also less stable with higher values (*Table 3*). PB 235,

TABLE 2. ANALYSIS OF VARIANCE FOR OVERALL MEANS (ALL MONTHS)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
CLONES	14051.7	14	1003.6	24.7	4.58E-26	1.79
MONTHS	16216.4	7	2316.6	57.0	8.5E-32	2.10
Error	3976.3	98	40.5			
Total	34244.5	119				

TABLE 3. STABILITY MEASURES FOR REGIME I (JUNE TO SEPTEMBER)

Clones	Genotype Mean (g/ tree/tap)	Ecovalence @	Stability variance#	s^2	S13	S16	PI
RRII 5	25.2	1069.4	112.4	90.7	10.3	3.3	12.7
RRII 105	24.3	903.0	93.3	105.4	12.2	3.4	12.1
RRII 118	33.0	2837.5	316.4	356.9	3.3	1.5	55.3
RRII 203	42.4	4596.0	519.3	69.7	0.35	0.4	182.5
RRIM 600	32.1	996.3	103.9	100.3	0.85	0.6	28.6
RRIM 605	18.8	760.8	76.8	48.5	7.56	3.5	36.2
RRIM 703	28.8	932.1	96.6	83.5	5.2	1.9	13.9
PB 5/51	19.8	903.4	93.3	54.1	14.5	4.5	31.2
PB 86	23.8	883.3	90.9	90.2	7.2	5.6	13.0
PB 235	46.9	1725.0	188.1	133.0	0.3	0.4	233.6
RRIC 52	23.4	715.4	71.6	75.6	10.0	3.3	12.3
RRIC 105	23.0	308.8	24.6	24.9	7.6	2.5	8.8
GT 1	24.1	413.3	36.7	43.8	9.1	3.3	6.9
Gl 1	12.3	1816.6	198.6	25.4	9.5	5.6	117.8
Harbel	15.6	1085.4	114.3	51.5	3.3	3.5	68.9

@ Wricke[13]; # Shukla[12]; S^2 = Francis and Kannenberg[11]; S13, S16 = Huehn's non-parametric statistics[10]; PI = Lin and Binns's superiority measure[14]

RRIM 600, and RRIM 703 exhibited higher genotype means under regime II (*Table 4*). Again, stability estimates were high for those clones. Overall genotype means were high for PB 235, RRII 203, RRIM 600, RRII 118 and RRIM 703. When only non-parametric stability statistics are considered, these high yielding clones were judged as stable for regime I, II and overall means. This is because while non-parametric analysis follows a ranking system, the other stability measures consider general mean as the central value for assessing stability. A covariance analysis done on the same clones earlier[2], judged RRII 5, RRIM 703, PB 5/51 and PB 235 as consistent yielders across two yielding regimes in Tripura. The overall genotypic means, seen in PB 235, RRII 203, RRIM 600, RRII 118 and RRIM 703 also endorse the findings of the earlier studies[15].

Symmetrical, Entry-focused and Tester-focused Scaling

An analysis of observations from symmetrical, entry-focused and tester-focused

TABLE 4. STABILITY MEASURES FOR REGIME II (OCTOBER TO JANUARY)

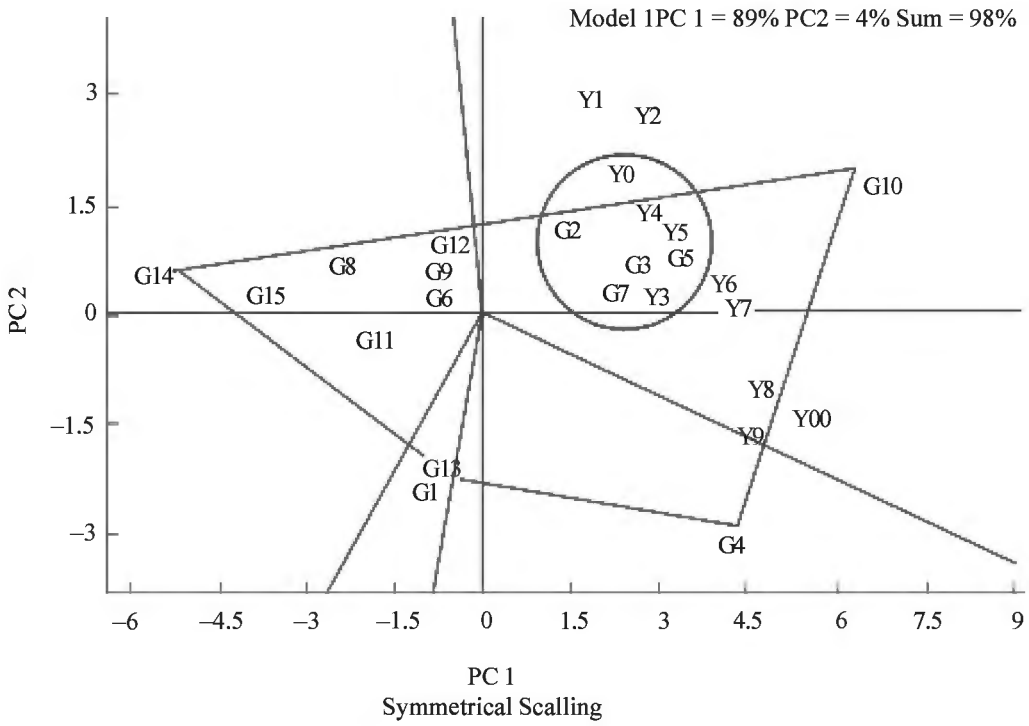
Clones	Genotype Mean (g/ tree/tap)	Ecovalence @	Stability variance#	s^2	S13	S16	PI
RRII 5	39.4	865.2	90.8	84.4	6.6	3.3	35.7
RRII 105	56.1	177.1	11.4	10.7	1.4	0.9	46.3
RRII 118	54.8	1286.0	139.3	158.1	3.2	1.4	48.5
RRII 203	57.1	1717.2	189.1	39.4	2.5	1.3	73.9
RRIM 600	62.1	1686.4	185.5	178.5	2.2	1.0	138.3
RRIM 605	48.0	804.1	83.7	96.8	1.9	1.3	10.1
RRIM 703	56.7	1094.4	117.2	78.1	1.7	0.9	63.6
PB 5/51	36.8	1321.3	143.4	55.8	2.9	2.3	63.0
PB 86	43.7	565.6	56.2	94.7	2.2	1.2	10.8
PB 235	68.3	1387.0	150.9	67.4	0.3	0.3	249.6
RRIC 52	36.2	597.7	59.9	64.6	2.7	2.3	61.3
RRIC 105	44.2	824.4	86.1	32.3	2.4	1.5	12.5
GT 1	41.5	635.4	64.3	71.7	3.9	2.3	20.4
Gl 1	24.0	2238.6	249.2	44.0	0.0	0.0	280.8
Harbel 1	30.6	1270.2	137.5	52.6	3.6	2.4	143.2

@ Wricke[13]; # Shukla[12]; S^2 = Francis and Kannenberg[11]; S13, S16 = Huehn's non-parametric statistics[10]; PI = Lin and Binns's superiority measure[14]

scaling gave unique results. When overall means were considered, the latter years (1998, 1999, 2000) were seen in a single cluster, indicating that the yield of latter years was nearly uniform (*Figure 1*). As per this scaling, RRII 105, RRII 118, RRIM 600, RRIM 703 and PB 235 were high yielders. While entry-focused scaling kept years towards a single cluster, presuming that the performance of clones were comparable over the years; under tester-focused scaling, the years were well spread, indicating that the yearly environments of all the years are not the same. When regime I was considered separately, symmetrical scaling gave no general feature, with clones and years exhibiting no definite pattern. The entry-focused scaling followed the same trend as that of the overall means. The tester-focused scaling showed 1997, 1998 and 2000 to be an entirely separate entity, indicating that these years offered a different climate for the clones to yield differently (*Figure 1*). RRII 5, RRIM 600, RRIM 703 and RRII 203 were high yielders under regime I. The symmetrical scaling of data of regime II showed 1999 and 2000 to exhibit higher PCA 1 values. Clones RRII 105, RRII 118, RRIM 703 and PB 235 were high yielders under this regime. When the same data were analysed as per entry-focused scaling, years showed no differences, indicating that the performance of clones were the same over the years. The tester-focused scaling of data from regime II kept 1999 and 2000 as unique with higher PCA 1 values. PCA values and yield data were depicted in order to assign clones with specific adaptation.

Depiction of Yield Against PCA Values

Mean yield was plotted against PCA 1 values. Yield under regime I indicated RRII 105, RRIM 703, RRIM 600 and RRII 118 to be the most stable clones even though PB 235



CLONES
1. RRII 5, 2. RRII 105, 3. RRII 118, 4. RRII 203, 5. RRIM 600, 6. RRIM 605, 7. RRIM 703, 8. PB 5/51, 9. PB 86, 10. PB 235, 11. RRIC 52, 12. RRIC 105, 13. GT 1, 14. GI 1, 15. HARBEL 1.

Figure 1. Biplot analysis of yield of 15 clones over eleven years.

and RRII 203 had the highest yield. Under regime II, RRIM 605 with higher stability gave an entirely different picture. Here too, the high yielding clones exhibited higher PCA scores (*Figure 2*). When overall means were plotted, RRII 105, RRIM 703 and RRII 118 were noted to be the most stable clones across 11 years (*Figure 2*). Under all these yearly climates, PB 235, RRII 203 and RRIM 600 were high yielding.

CONCLUSIONS

With regards to stability estimates *viz.*, ecovalence, stability variance, s^2, Huehn's non-parametric statistics and Lin and Binn's superiority measure were comparable except for Huehn's non-parametric statistics. In GGE biplot analysis, the entry- focused scaling for overall means kept years towards a single cluster presuming that all clones were performing comparably over the years. But under tester-focused scaling, the years were well spread, indicating that the yearly climates of all the years were not same. Overall genotype means were high for PB 235, RRII 203, RRIM 600, RRII 118 and RRIM 703. The symmetrical scaling of data of regime II showed 1999 and 2000 exhibiting higher PCA 1 values. Clones RRII 105, RRII 118, RRIM 703 and PB 235 were high yielders under this regime. The performance of clones was different when mean values were plotted

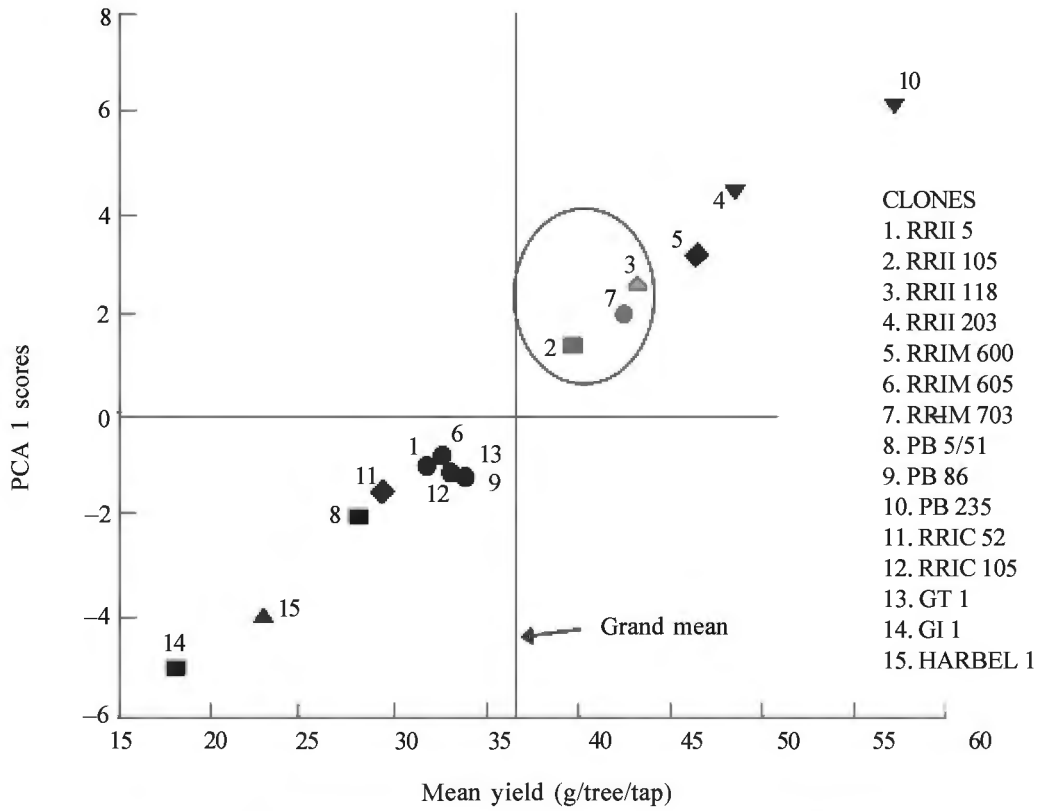


Figure 2. Depiction of mean yield against PCA 1 values.

against PCA values. While RRII 105, RRIM 703, RRIM 600 and RRII 118 were most the stable clones under regime I, RRIM 605 was with higher stability under regime II. Under both the circumstances, PB 235 and RRII 203 were high yielders. When overall means were plotted, RRII 105, RRIM 703, RRII 118 and PB 235 were noted to be the most stable over 11 years. Under all these yearly climates, PB 235, RRII 203 and RRIM 600 were high yielding.

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