Research Article

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Selection for yield and stability over seasons in *Hevea brasiliensis*

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Abstract

Twelve clones of rubber (*Hevea brasiliensis*) viz. PB 217, PB 235, PB 255, PB 260, PB 280, PB 310, PB 311, PB 312, PB 314, KRS 25, KRS 128 and KRS 163 introduced from Malaysia and Thailand were evaluated in a large scale trial along with the control clone RRII 105 for high yield and stability. The data on annual yield, peak season yield and combined yield during the peak and dry seasons for a period of four years were subjected to Additive main effects and multiplicative interaction (AMMI) analysis. Analysis revealed that the chosen clones, environments and their interactions were significant. Clones viz., PB 314, PB 255, PB 280 and PB 260 showed non-sensitive relationship with interactive forces hence preferable for their yield and stability. Clones PB 312 and KRS 163 may be considered for further improvement since they have high potential with specific suitability for favourable environments. This study carried out with emphasis on performance stability during selection helped in identifying high yielding stable clones.

Key words: Dry rubber yield, G x E interaction, *Hevea*, stability, Additive Main effects and Multiplicative Interaction (AMMI).

Introduction

In *Hevea* the crop productivity can be maximized by planting high yielding clones, which have been selected effectively for the target production system. But the effectiveness of selection is complicated by the failure of clones to perform uniformly across environments ie., genotype x environment interaction. To study the effect of genotype (clone) – environment (G x E) interaction and to make selection of clones more effective, both yield id stability of performance should be considered simultaneously in the evaluation of clones. Yield in *Hevea* consists of latex which is extracted by tapping round the year. Latex yield is influenced by physiological factors, which are effected by seasonal changes. Selection of high yielding clones that perform consistently from year to year and across seasons would benefit growers. A better understanding of the genetic basis of G x E interaction for rubber yield can enhance breeding efficiency and / or better agronomic management and lead to higher productivity. With this objective thirteen clones were evaluated over four years for their yield predictability and dependability from year to year over seasons at the central rubber growing region of Kerala.

Materials and Methods

The material for the study comprised of 12 introduced clones from Malaysia and Thailand viz.,PB 217,PB 235, PB 255,PB 260, PB 280, PB 310, PB 311, PB 312, PB 314, KRS 25, KRS 128 and KRS 163 along with the control clone RRII 105.The details of the clones are presented in Table 1. These clones were planted employing Randamised Block Design with five replications and seven trees per plot at the experiment station of the Rubber Research Institute of India, Kottayam during 1989. The trees were opened for tapping during 1996. Yield recording was carried out every month by cup coagulation at fortnightly intervals. The annual mean dry rubber yield, the mean dry rubber yield during the stress period, ie, from February to May and the mean dry rubber yield during the peak period from October to January and the combined yield during the stress and peak period over four years from 1997 to 2000 were computed and statistically analysed. In order to understand the G x E interaction encountered and to simultaneously select for yield and stability over different seasons at a single location, the data was subjected to stability analysis following AMMI analysis as proposed

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by Zobel *et al.*, 1988 which combine yield and stability into a single selection criterion.

Table 1. Details of clones evaluated

Clone	Parentage	Country of Origin
PB 217	PB5/51 x PB 6/9	Malaysia
PB 235	PB5/51 x PB S/78	- do -
PB 255	PB5/51 x PB 22/36	- do -
PB 260	PB5/51 x PB 49	- do -
PB 280	PBIG seedling	- do -
PB 310	PB5/51 x RRIM 600	-do-
PB 311	RRIM 600 x PB 235	-do-
PB 312	RRIM 600 x PB 235	-do-
PB 314	RRIM 600 x PB 235	- do -
KRS 25	Primary clone	Thailand
KRS 128	PB 5/63 x KRS 13	- do -
KRS 163	PB 5/ 63 x RRIM 501	- do -
RRII 105	Tjir 1 x Gl 1	India

The AMMI (Additive Main effects and Multiplicative Interaction) model is a hybrid statistical model incorporating ANOVA procedures to separate the additive variance from the multiplicative variance genotype by environment interaction and then use a multiplicative procedure – Principal Component Analysis (PCA) to extract a new set of coordinate axes which explains in more detail the pattern of interaction. The estimation is accomplished using least squares principle. The graphical representation of the components (Biplot analysis) often allows a straight forward interpretation of the underlying causes of the G x E interaction.

The AMMI model is:

$$Y_{ij} = \mu + g_i + e_j + S\, h_k\, a_{ik}\, t_{jk} + R_{ij}$$

where, Y_{ij} is the yield of i th genotype in the j th environment, g_i is the mean of the i th genotype as a deviation from the grand mean m; e_j is the mean of the j th environment minus the grand mean (m), h_k is the eigen value of the PCA axis k, a_{ik} and t_{jk} are principal component scores for PCA axis k of the i th genotype and the j th environment respectively and R_{ij} is the residual. The GE interaction sum of squares was subdivided into PCA axes, where axis k is regarded as having t + s – 1-2k degrees of freedom and t and s are the number of genotypes and environments respectively.

Results and Discussion

The AMMI analysis of variance for annual mean dry rubber yield, mean dry rubber yield during peak period ,mean dry rubber yield during dry period and mean dry rubber yield during the combined peak and dry period over four years indicating except for yield during the dry months, all others indicated the chosen clones, environment and their combination were highly variable and interactive. The ANOVA model partitions the treatment d.f and SS into three sources. (1) Additive genotype effects, (2) additive environmental effects and (3) genotype – environment interaction (ie.non additive residual from the additive ANOVA model).

The ANOVA for annual mean dry rubber yield of the AMMI analysis is presented in Table 2. The genotype (clone), environment (years) and G x E interaction explained 76.84, 14.50 and 8 percentage of the total treatment variation respectively. Since ANOVA provided no insight into the particular pattern of genotypes or environments that gave rise to interaction, the ANOVA model was combined with PCA model to further analyse the residuals of the ANOVA model, which infact contains G x E interaction.The G x E interaction was partitioned into interaction PCA axis (IPCA) which was found to be highly significant and explained 5% of the total variation which is 59.54% of the G x E interaction.

Table 2. ANOVA for mean dry rubber yield

Sources of variation	Annual df	Annual SS	Annual %	Peak df	Peak SS	Peak %
Treatment combination	51	11463.65***	100	51	16353.17***	100
Genotypes	12	8809.77***	76.84	12	13163.01***	80.49
Environments	3	1661.87***	14.50	3	1369.87***	8
G X E interactions	36	992.00*	8	36	885.05*	11
IPCA 1	14	590.63**	5	14	802.23*	5
IPCA 2	-	-	-	12	133.01*	4.9
Residual	22	401.37		10	6220.58	
Error	208	3797.98		208	22573.75	

* P>0.05, ** P>0.01, *** P>0.001

The mean annual yield ranged from 34 to 79. 08g/ t/t. The bi-plot, a graphical representation from AMMI analysis, is useful in understanding more comprehensively the specific patterns of main effects and G x E interaction of both the genotype and environments simultaneously. (Kempton, 1984, Zobel *et al.*, 1988 and Crossa *et al.*, 1991). The bi-plot of main effects against IPCA 1 (fig. 1) thus explained 96.34% (ie. 76.84 + 14.5 + 5) of the total treatment variation. In figure 1 the displacement along the abscissa (horizontal axis) reflects differences in main effects, whereas displacement along the ordinate (vertical axis) exhibits differences in interaction effects. When a genotype and an environment fall in the upper or lower portion from the line indicating IPCA 1= 0 in the biplot, their interaction is positive. However, the genotypes and the environments of opposite portions from the IPCA 1=0 line show negative interaction. According to the AMMI model, the genotypes which are characterized by means greater than the grand mean and the IPCA scores nearly zero are considered as generally adaptable to all environments. However, the genotypes with high mean performance and with large value of IPCA scores are considered as having specific adaptability to environments. Prediction of stability of genotypes on the basis of mean performance and the magnitude of IPCA 1 scores from AMMI analysis has already been reported in other crops (Zobel *et al.*, 1988; Crossa *et al.*, 1990; Crossa *et al.*, 1991; Zavala- Garcial, *et al.*, 1992 and Romagossa *et al.*, 1993).

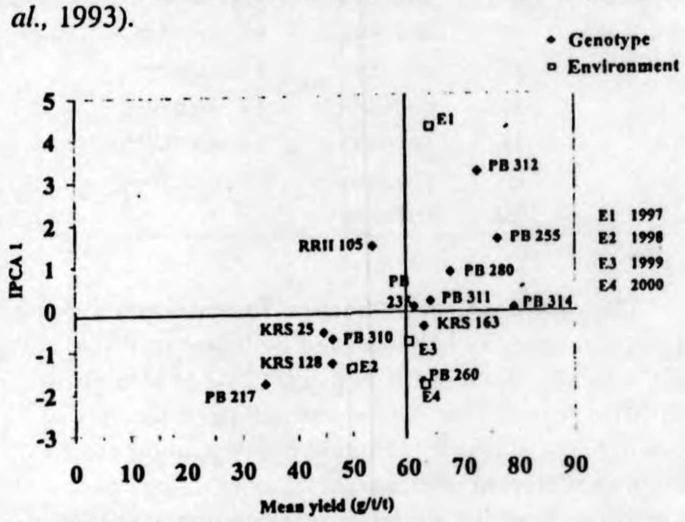

Fig. 1. AMMI biplot for annual yield

Among the genotypes (clones) eight clones viz., PB 314, PB 255, PB 312, PB 280, PB 311, PB 260, PB 235 and KRS 163 have shown high average yield (above the general mean). Of these clones, PB 314, PB 311 and PB 235 exhibited high mean yield and low interaction suggesting that they are highly suitable with general adaptability. In general, clones viz., PB 314, PB 311, PB 235 , KRS 163, PB 280 and PB 255 with high mean and small IPCA score were declared by the AMMI model as stable cultivars having general adaptability to all environments. Clone PB 312 with high mean yield and with large value of IPCA score was specifically suitable for the environment 1 (E1) while clone PB 260 was particularly suitable for the environment 4 (E4). The biplot (Fig.1) corresponding to environment means and first PCA revealed three grouping of the environments (years). The environments E1, E3 and E4 had similar main effects with above average yields but differed in their interaction with genotypes. The environment 3 (E3) showed high yield potential with IPCA score near zero suggesting little interaction with genotypes hence most suitable. The environment 4 (E4) had potential for above average yield level but exhibited interaction effect. In the environment 2 (E2), though had only less interaction, the yield potential was only below average. The environment 1 was the highest yielding among the environments studied but exhibited very high interaction effect, hence suitable only for the specifically adapted clones.

The ANOVA for yield during the peak period is presented in Table 2. The genotype (clone), environment (years) and G x E interaction contained 80.49, 8 and 11% of the treatment SS respectively. The environment and genotype additive effects and interaction effects are highly significant. IPCA1 and IPCA 2 capture 5 and 4.9% of the total SS. This accounts 48.62 and 44.07% of the G x E interaction SS. The resulting AMMI first axis bi-plot thus explained 98.39% of the total treatment variation (Fig. 2). From the biplot it is clear that clone PB 314 had high average yield and low IPCA score suggesting that this clone is highly suitable with general adaptability. In general clones viz., PB 314, PB 235, PB 255, PB 311 KRS 163 and PB 280 had high means as well as low IPCA score indicating that they are stable with general adaptation over environments. For peak yield clone PB 217, RRII 105, KRS 25, PB 310 were highly stable but with low main effects. Clone PB 311 and RRII 105 are suitable for E2 while clone KRS 163 is suitable for environment 3. In this case also clone PB 312 with high mean and large IPCA score was specifically adapted for the environment E4. In this biplot the means of four environments are displayed. E4 falls on the positive side of X axis origin while the remaining three environment means are on the negative side. The distance from the origin is highly interactive on the positive side. The other environments are also highly interactive but on the negative side.

Table 3. Mean and IPCA score for annual yield

Clone	Mean yield (g/t/t)	IPCA 1
PB 217	34.00	-1.80
PB 235	61.10	-0.04
PB 255	76.16	1.54
PB 260	62.75	-1.80
PB 280	67.67	0.77
PB 310	46.28	-0.77
PB 311	64.05	0.09
PB 312	72.57	3.14
PB 314	79.08	-0.08
KRS 25	44.61	-0.61
KRS 128	46.17	-1.34
KRS 163	62.82	-0.51
RRII 105	53.58	1.40
Envt. 1	64.04	4.22
Envt. 2	49.82	-1.47
Envt. 3	60.16	-0.87
Envt. 4	63.15	-1.88

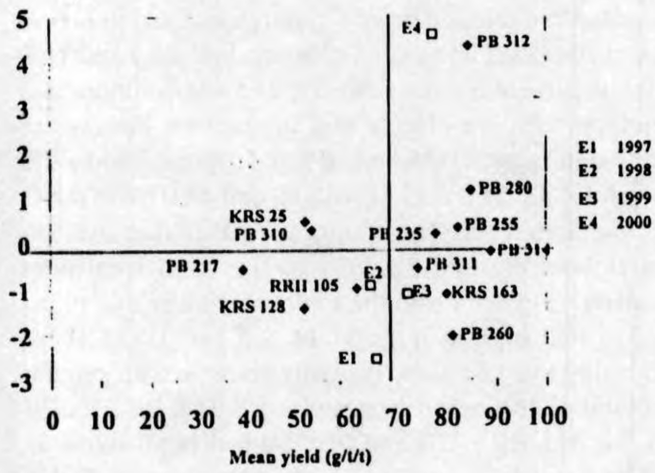

Fig. 2. AMMI biplot for peak yield

The ANOVA for yield during the stress period revealed significant variation for genotypes and environments but the variation for G x E interaction was non significant. The ANOVA for combined yield during peak and dry seasons over four years is given in Table 4. The seasons were taken as the environment and the complete AMMI model contained 98.57% of SS and the remaining percentage is residual, indicating that AMMI summarized these data very effectively. The IPCA 1 axes of the interaction captures 60.64% of the interaction SS in 9% of the interaction d.f. The MS for IPCA 1, IPCA 2 and IPCA 3 were highly significant. The remaining axes are pooled in the residual which is non significant. Clone RRII 105 had low PCA score indicating small interaction effect but differs in its main effect. Clones PB 314, PB 255, PB 312, PB 280 and PB 311 had low PCA score with high main effects. These clones are highly suitable for the combined environments. The clone PB 314 was particularly suitable for E1 and E4.

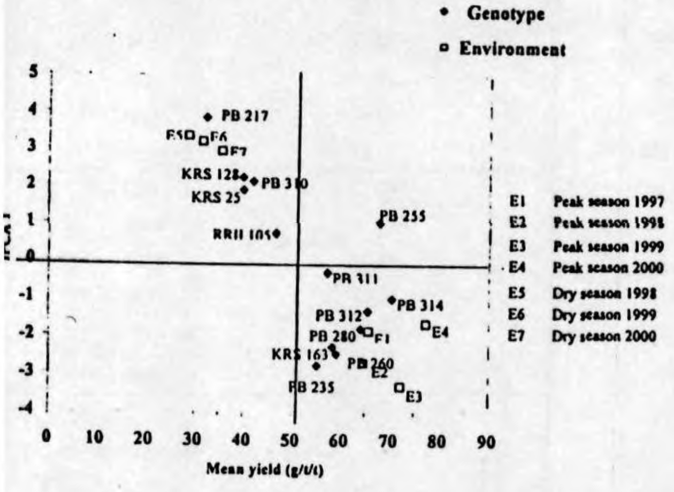

Fig. 3. AMMI biplot for combined yield during dry and peak seasons

Table 4. ANOVA for combined yield during dry and peak seasons

Sources of variation	df	SS	%	Probability
Treatment combinations	90	51844.12109	100	0.0000***
Genotypes	12	12792.2937	24.67	0.0000***
Environments	6	34115.5336	65.80	0.0000***
G X E interactions	72	4936.29378	9	0.0000***
IPCA 1	17	2993.37305	5	0.0000***
IPCA 2	15	893.28314	1.7	0.00016***
IPCA 3	13	746.50159	1.4	0.00053***
Residual	27	303.13600		0.96235
Error	364	7228.60386		

*** *P>0.001*

The magnitude of interaction for each genotype and environment can be visualized by biplot of IPCA 1 vs IPCA 2. The biplot of IPCA 1 vs IPCA 2 of combined yield from year to year over stress and peak seasons is shown in Fig. 4. Basically genotype points near the origin are non-sensitive to environmental interacting forces. Those distant from the origin are sensitive and have large interaction. The genotypes occurring close together on the plot will tend to have similar yields in all environments while genotypes far apart may either differ in mean yield or show a different pattern of response over environments. Thus environments E4, E1 and E5 exert strong interaction and clones PB 312 and PB 260 were most responsive genotypes. The clones PB 314, PB 311, RRII 105 and PB 255 were non-sensitive to the interacting forces.

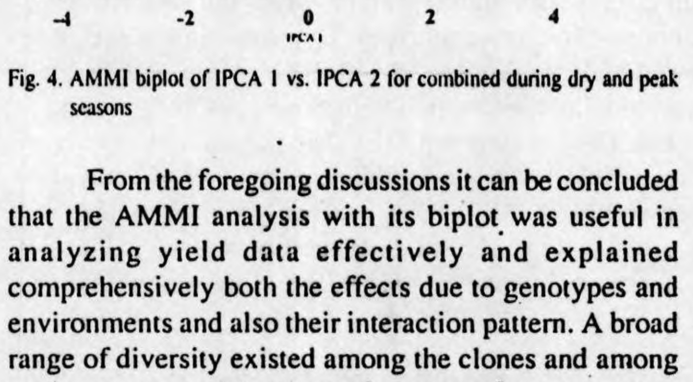

Fig. 4. AMMI biplot of IPCA 1 vs. IPCA 2 for combined during dry and peak seasons

From the foregoing discussions it can be concluded that the AMMI analysis with its biplot was useful in analyzing yield data effectively and explained comprehensively both the effects due to genotypes and environments and also their interaction pattern. A broad range of diversity existed among the clones and among environments, and that the performance of genotypes was different over environments. When the entire growing season was partitioned in to annual, peak and combined of both dry and peak season and their yield were subjected to analysis, they revealed that among the 13 clones, the clone PB 314 was highly superior for its yield performance and stability over different seasons followed by clones PB 311, PB 280 and PB 255. Clones, PB 312, PB 260 and KRS 163 exhibited high potential with specific suitability for favourable environments. The mean annual and peak yield over seasons were highly influenced by the factors, which had existed in environment 3. The study carried out with emphasis on performance stability during selection helped in identifying clones with high yield and stability.

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