Research Article
AMMI analysis of grain yield in rice genotypes across environments

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Abstract
The identification of the highest yielding cultivar for a specific environment on the basis of both genotype (G) and genotype x environment (GE) interaction would be useful to breeders and producers since yield estimates based only on G and environment (E) effects are insufficient. The objective of this study was to demonstrate the usefulness of additive main effects and multiplicative interactions (AMMI) model analysis. Replicated grain yield data of rice (*Oryza sativa* L.) genotypes at three locations in Coimbatore (E1), Bhavanisagar (E2) and Aliyar Nagar (E3) were obtained and used for this purpose. Through AMMI model analysis, the magnitude and significance of the effects of GE interaction and its interaction principal components relative to the effects of G and E were estimated. Among the three, E3 environment was far away from the origin. The environments E2 and E3 condition were exhibiting high interaction effect, whereas the environment E1 had moderate interaction effect with the other two environments. The parent TP 1021 R and the hybrids *viz.,* IR 80559 A X RR 286 R, APMS 6 A X IR 62037 R, IR 75601 A X IR 72865 R, IR 75601 A X RR 347 R, IR 75596 A X MDU 5 R, IR 75596 A X ASD 06-8 R, CRMS 32 A X IR 62037 R, CRMS 32 A X TP 1021 R and IR 75608 A X ASD 06-8 R showed IPCA 1 score close to zero with high main effects indicating that these varieties were less influenced by environments. Hence, the above said hybrids were stable and had general adaptability for all the environments. Since, the environments E3 had positive IPCA 1 score and high mean, it had positive interaction with these genotypes and this environment was considered as the stable environment for these hybrids.

Key words
Rice, AMMI, Biplot analysis, G x E interaction

Introduction
Genotype x Environment Interaction is commonly observed by crop producers and breeders as the differential ranking of cultivar yields among locations or years. Plant breeders conduct multiple-environment trials (MET) primarily to identify the superior cultivar for a target region and secondarily to determine if the target region can be subdivided into different mega-environments. Several statistical methods have been developed for the analysis of Genotype by Environment Interactions (GEI) and phenotypic stability. Regression technique has been widely used (Eberhart and Russell, 1966; Perkins and Jinks, 1968) due to its simplicity and the fact that its information on adaptive response is easily applicable to locations. The PCA is a multiplicative model that contains no sources of variation for additive G or E main effects and does not analyze the interactions effectively. The linear regression method uses E means, which are frequently a poor estimate of environments, such that the fitted lines in most cases account for a small fraction of the total GE (Zobel *et al.,* 1988). The AMMI model analysis combines the ANOVA (with additive parameters) and PCA (with multiplicative parameters) into a single analysis. The AMMI model analysis is useful in making cultivar recommendations, specifically by mega-environment analysis, in which the best performing cultivar for each subregion of the crop's growing region is identified. Biplot graphs, which show markers of both genotypes and environments, are used to present AMMI analysis results (Ebdon and Gauch, 2002). Crop breeding programs should take GE interaction into consideration and have an estimate of its magnitude, relative to the magnitude of G and E effects, which affect grain yield. Furthermore, the identification of the cultivar that yields best at a specific growing environment would be useful to breeders and producers. AMMI analysis has been reported to have significantly improved the probability of successful selection and has been used to analyse GxE interaction with greater precision in many crops. The model combines the conventional analysis of variance for genotype and environment main effects with principal components analysis to decompose the GEI into several Interaction Principal Component Axes (IPCA). With the biplot facility from AMMI analysis, both genotypes and environments are plotted together on the same scatter plot and inferences about their interaction can be made. The present study demonstrated the utility of AMMI model analysis in evaluating the significance and magnitude of the GE interaction effect on grain

yield and in determining the best performing cultivar for each environment.

Materials and Methods

The experimental material for the present investigation consisted of 100 genotypes including 18 parents *viz.,* IR 80559 A, APMS 6 A, IR 72081 A, IR 75601 A, IR 75596 A, IR 80154 A, CRMS 32 A, IR 75608 A, IR 62037 R, IR 72865 R, IR 68427 R, MDU 5 R, ACK 99017 R, TP 1021 R, RR 363 R, RR 347 R, RR 286 R, ASD 06-8 R and their 80 hybrids along with 2 checks. Crosses were effected between eight female and ten male parents in Line x Tester fashion and a total of 80 cross combinations were obtained and they were evaluated in randomized block design with two replications at Coimbatore (E1), Bhavanisagar (E2) and Aliyar Nagar (E3). The hybrids along with their parents were sown in raised beds and 25 days old seedlings were transplanted in main field under puddled condition. For each genotype, single seedling per hill was planted at 20 x 20 cm spacing in two rows of 2.0 m length. Recommended fertilizer dose and cultural practices were adopted. Observations were recorded for four yield contributing traits *viz.,* plant height, number of productive tillers, per plant, number of grains per panicle and grain yield per plant. Statistical constants of mean for all the characters were estimated by AMMI model.

Additive Main effects and Multiplicative Interaction (AMMI) model (Zobel *et al.,* 1988) was performed by IRRI Stat. The AMMI statistical model is a hybrid model. It makes use of standard ANOVA procedures to separate the additive variance from the multiplicative variance (genotype x environment interaction) and then uses a multiplicative procedure (Principal Component Analysis-PCA) to extract the pattern from the G x E portion of the ANOVA analysis. The result is the least square analysis, which, with further graphical representation of the numerical results (Biplot analysis), often allows a straightforward interpretation of the underlying causes of G x E.

Results and Discussion

The AMMI analysis of variance clearly indicated that genotypes, environments and G X E interaction components were significant for the four traits studied (Table 1). The per cent contribution of individual components to total sum of squares was worked out for yield. The genotypes, environments, GEI components accounted for 85.39, 0.001 and 0.12 per cent of the percentage sum of square respectively. The significant GEI which was further partitioned into two IPCA axes (Interactive principal component axes). The two

terms (IPCA 1 and IPCA 2) were found significant with 100.00 per cent of G x E sum of squares, getting partitioned into first IPCA1 axis with 81.10 per cent and the remaining 18.91 per cent into second IPCA2 axis without leaving any residual effect which suggested that the first interaction axis accounted at least as much variance as the additive terms. Similar findings was reported by Kayode A. Sanni *et al.* (2009) and suggesting that a wide range of genotypic diversity and environmental variation.

Biplot analysis is possibly the most powerful interpretive tool for AMMI models. Biplots are graphs where aspects of both genotypes and environments are plotted on the same axes so that inter relationships can be visualized. There are two basic AMMI biplots, the AMMI 1 biplot where the main effects (genotype mean and environment mean) and IPCA1 scores for both genotypes and environments are plotted against each other and the AMMI 2 biplot where scores for IPCA 1 and IPCA 2 are plotted. AMMI 2 biplots do not show genotype or environment main effects and hence do not show adaptation.

For number of grains per panicle, the IPCA1 value varied from -4.90 (CRMS 32 A X ASD 06-8 R) to 4.05 (IR 68427 R) and IPCA 2 values varied from -2.85 (IR 80154 A X ACK 99017 R) to 4.85 (IR 75596 A X RR 363 R). The three environments recorded the values such as 120.30 (E1), 121.70 (E2) and 121.00 (E3) as means and 6.57 (E1), 4.89 (E2) and -11.46 (E3) as IPCA 1 scores. IPCA 2 scores varied from -7.51 (E2) to 6.81 (E1). Environment 1 recorded the mean 29.98g, -4.03 (IPCA 1) and -2.91 (IPCA 2), whereas, the mean, IPCA1 and IPCA2 found in E2 were 29.59g, -1.61 and 3.87 respectively and in E3 were 30.22g, 5.63 and -0.98 respectively for single plant yield. The IPCA 1 score of genotypes varied from -3.18 (IR 75596 A X TP 1021 R) to 2.16 (IR 80154 A X MDU 5 R), while IPCA 2 score was found to differ from -1.64 (IR 75596 A) to 1.83 (RR 347 R) (Table 2). The AMMI 1 biplot for single plant yield clearly indicated that the three environments had differed in both main and interaction effects (Figure 1). Among the three, E3 environment was far away from the origin. The environments E2 and E3 condition were exhibiting high interaction effect, whereas the environment E1 had moderate interaction effect with the other two environments. However, these three environments showed little variation in main effect with each other. Similar findings were reported by Shanmuganathan (2005).

The parent TP 1021 R and the hybrids *viz.,* IR 80559 A X RR 286 R, APMS 6 A X IR 62037 R,

IR 75601 A X IR 72865 R, IR 75601 A X RR 347 R, IR 75596 A X MDU 5 R, IR 75596 A X ASD 06-8 R, CRMS 32 A X IR 62037 R, CRMS 32 A X TP 1021 R and IR 75608 A X ASD 06-8 R showed IPCA 1 score close to zero with high main effects indicating that these varieties were less influenced by environments (Table 2). Hence, the above said hybrids are stable and had general adaptability for all the environments. Since, the environments E3 had positive IPCA 1 score and high mean, it had positive interaction with these genotypes and this environment was considered as the stable environment for these hybrids. Similar results were observed by Mahalingam *et al.* (2006). Among the parents, APMS 6 A and IR 72081 A and the hybrids *viz.,* IR 80559 A X MDU 5 R, IR 80559 A X ACK 99017 R, APMS 6 A X ACK 99017 R, APMS 6 A X TP1021 R, IR 72081 A X IR 68427 R, IR 72081 A X RR 347 R and CRMS 32 A X RR 363 R exhibited high main effect with positive IPCA 1 score. Hence, they were identified as specifically adapted to favourable locations.

On the other hand, the hybrids *viz.,* APMS 6 A X RR 347 R, APMS 6 A X ASD 06-8 R, IR 72081 A X IR 62037 R, IR 72081 A X MDU 5 R, IR 72081 A X TP 1021 R, IR 72081 A X ASD 06-8 R, IR 75601 A X IR 72865 R, IR 75601 A X MDU 5 R, IR 75601 A X ACK 99017 R, IR 75601 A X RR 286 R, IR 75596 A X MDU 5 R, IR 75596 A X TP 1021 R, IR 75596 A X RR 363 R, IR 80154 A X IR 62037 R and CRMS 32 A X IR 62037 R had negative IPCA 1 score with high main effect. The environment E1 and E2 had negative IPCA 1 score and these were considered as favourable environments for the above said hybrids.

Proximity of genotype points to environment points does not indicate a higher level of adaptation. The best adapted genotype can plot far from the environment. AMMI 1 predicted response for APMS 6 A in E3 was 40.14 g. The AMMI I predicted response for IR 80559 A X MDU 5 R in E3 was 49.85g The estimated yield showed that IR 80559 A X MDU 5 R was highly adapted to E3 than APMS 6A though it occupied closely to this environment demonstrating that proximity of genotypes to environment does not indicate a high level of adaptation.

In AMMI 2 biplot, the environment scores are joined to the origin by side lines. Sites with short spokes do not exert strong interactive forces. Those with long spokes exert strong interaction. The environment, E3 had long spokes and hence exerted strong interaction while the E1 and E2 had short spokes with the origin and they did not exert strong interactive forces (Fig 2).

The interaction of genotypes with sites can be read directly from the biplot by projecting genotype marks on the site lines. If the projection falls on to a site line then that genotype is positively adapted to that site. In the Fig. 3, the projection line of the genotype IR 80154 A X MDU 5 R fell on the site line of environment E3 and RR 347 R in E2 indicating that these had a positive interaction with E3 and E2 respectively. On the other hand, the site line must be extended back through the origin to meet the projection, and then the genotype has negative interaction with that site. The projection line of the genotype IR 75596 A X TP 1021 R fell on the extended portion of the site line E1. Hence, it had a negative interaction with that environment.

The genotypes occurring close together on the plot will tend to have similar yields in all environments, while genotypes apart may either differ in mean yield or showed pattern of response over the environments. The genotypes *viz.,* IR 80559 A X TP 1021 R, IR 72081 A X IR 68427 R, IR 75596 A X IR 72865 R, CRMS 32 A X RR 363 R A, IR 75608 A X IR 68427 R and CRMS 32 A X MDU 5 R were very close to the centre of the origin. Genotypes near the origin are non sensitive to environmental interactive forces and those distant from the origins are sensitive and have large interaction (Shinde *et al.,* 2002). Adaptation of different genotypes based on AMMI 1 biplot for single plant yield has been shown in table 3. The following hybrids *viz.,* IR 80559 A X ACK 99017 R, APMS 2 A X ACK 99017 R, IR 72081 A X IR 68427 R, IR 72081 A X RR 347 R and CRMS 32 A X RR 363 R found to have also high pooled per se performance, *sca*, heterosis and utilized for further breeding programme (Table 4).

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Table 1. ANOVA for stability (AMMI) for different quantitative characters

Source	df	PH	NPT	NG	SPY	Percentage sum of squares for yield
Genotypes	99	109.94**	71.88**	1530.00**	186.59**	85.39
Environment	2	1158.75**	77.98**	49.91**	10.13**	0.001
G x E interaction	198	30.98**	2.58**	252.45**	15.86**	0.12
IPCA 1	100	54.18**	3.68**	393.53**	25.47**	0.12
IPCA 2	98	7.30**	1.46**	108.87**	6.06**	0.03

** Significant at 1% level

Table 3. Adaptation of parents and hybrids for single plant yield based on AMMI 1model

High mean and positive IPCA	High mean and negative IPCA	Low mean and positive IPCA	Low mean and negative IPCA
APMS 6 A	APMS 6 A X RR 347 R	IR 80154 A	IR 80559A
IR 72081 A	APMS 6 A X ASD 06-8 R	CRMS 32 A	IR 75601A
IR 80559 A X MDU 5 R	IR 72081 A X IR 62037 R	IR 75608 A	IR 75596A
IR 80559 A X ACK 99017 R	IR 72081 A X MDU 5 R	IR 72865 A	IR 62037 R
IR 80559 A X RR 286-1 R	IR 72081 A X TP 1021 R	RR 363 R	IR 68427 R
APMS 6 A X IR 62037 R	IR 72081 A X ASD 06-8 R	RR 347 R	MDU 5 R
APMS 6 A X ACK 99017 R	IR 75601 A X MDU 5 R	IR 80559 A X TP 1021 R	ACK 99017R
APMS 6 A X TP 1021 R	IR 7560 A X ACK 99017 R	IR 80559 A X RR 363 R	TP 1021R
IR 72081 A X IR 68427 R	IR 75601 A X RR 286 R	IR 80559 A X ASD 06-8 R	RR 286 R
IR 72081 A X RR 347-1 R	IR 75596 A X MDU 5 R	APMS 6 A X MDU 5 R	ASD 06-8 R
IR 75601 A X IR 72865 R	IR 75596 A X TP 1021 R	APMS 6 A X RR 363 R	IR 80559 A X IR 62037 R
IR 75601 A X RR 347 R	IR 75596 A X RR 363 R	IR 72081 A X RR 363 R	IR 80559 A X IR 72865 R
IR 75596 A X ASD 06-8 R	IR 80154 A X IR 62037 R	IR 72081 A X ACK 990 17 R	IR 80559 A X IR 68427 R
CRMS 32 A X RR 363 R	CRMS 32 A X IR 62037 R	IR 72081 A X RR 286 R	APMS 6 A X IR 72865 R
IR 75608 A X ASD 06-8 R		IR 75601 A X IR 62037 R	APMS 6 A X IR 68427 R
		IR 75601 A X IR 68427 R	APMS 6 A X RR 286 R
		IR 75601 A X ASD 06-8 R	IR 75601 A X TP 1021 R
		IR 75596 A X IR 72865 R	IR 75601 A X RR 363 R
		IR 75596 A X IR 68427 R	IR 75596 A X IR 62037 R
		IR 75596 X ACK 99017 R	IR 75596 A X RR 347 R
		IR 80154 A X IR 72865 R	IR 80154 A X TP 1021 R
		IR 80154 A X IR 68427 R	IR 80154 A X RR 286 R
		IR 80154 A X MDU 5 R	IR 80154 A X ASD 06-8 R
		IR 80154 A X ACK 99017 R	CRMS 32 A X IR 72865 R
		IR 80154 A X RR 363 R	CRMS 32 A X RR 347 R
		IR 80154 A X RR 347 R	CRMS 32 A X RR 286 R
		CRMS 32 A X IR 68427 R	CRMS 32 A X ASD 06-8 R
		CRMS 32 A X MDU 5 R	IR 75608 A X IR 62037 R
		CRMS 32 A X ACK 99017 R	IR 75608 A X ACK 99017 R
		IR 75608 A X IR 72865 R	IR 75608 A X RR 363 R
		IR 75608 A X IR 68427 R	IR 75608 A X RR 347 R
		IR 75608 A X MDU 5 R	
		IR 75608 A X TP 1021 R	
		IR 75608 A X RR 286 R	

Table 2. Estimates of stability parameters (AMMI) for quantitative traits

Sl. No	Genotypes	Plant height			Number of productive tillers/plant			Number of grains per panicle			Single plant yield		
		Mean	IPCA 1	IPCA 2	Mean	IPCA 1	IPCA 2	Mean	IPCA 1	IPCA 2	Mean	IPCA 1	IPCA 2
1	IR 80559 A	90.98	-0.26	-0.03	11.22	-0.11	-0.22	101.30	0.11	-0.33	26.00	-0.60	-0.25
2	APMS 6 A	87.21	-0.20	-0.42	9.83	0.21	-0.05	115.80	-0.15	-0.83	31.97	1.40	-0.19
3	IR 72081 A	79.26	0.40	0.95	10.15	-0.04	-0.24	133.30	0.41	0.54	32.95	1.04	-0.37
4	IR 75601 A	96.21	-0.30	-0.74	12.30	0.24	-0.10	119.00	0.01	0.10	27.29	-0.28	0.44
5	IR 75596 A	85.10	0.11	-0.14	9.05	0.01	0.04	142.70	0.64	0.86	24.02	-0.21	**-1.64**
6	IR 80154 A	83.35	0.08	1.35	10.88	0.06	-0.28	102.50	-0.32	-0.32	27.42	0.32	0.21
7	CRMS 32 A	85.09	-0.09	0.37	12.17	0.46	-0.19	112.00	-0.51	-0.44	29.57	0.47	0.67
8	IR 75608 A	70.19	-0.50	0.19	11.08	0.33	-0.17	121.30	-0.76	-0.09	27.65	0.42	-0.37
9	IR 62037 R	78.79	0.11	0.34	10.13	-0.01	-0.14	115.70	0.84	0.00	26.82	-0.62	0.48
10	IR 72865 R	79.70	-0.58	0.56	10.70	-0.16	-0.12	122.50	0.44	0.05	28.19	1.20	-0.06
11	IR 68427 R	95.67	-0.75	0.45	11.95	-0.20	0.11	182.70	**4.05**	-0.38	28.97	-0.32	0.45
12	MDU 5 R	87.42	-1.27	-0.49	10.43	-0.09	-0.14	193.00	2.00	-0.14	27.28	-0.20	0.86
13	ACK 99017 R	71.68	-0.87	-0.45	9.27	-0.20	-0.05	120.50	-0.95	0.21	26.76	-0.43	-0.05
14	TP 1021 R	65.16	-0.46	-0.21	10.30	0.06	-0.14	130.30	-0.40	0.15	29.99	-0.06	0.05
15	RR 363 R	94.98	-0.26	0.35	10.80	-0.15	-0.19	109.00	-0.51	0.16	29.43	0.25	-0.20
16	RR 347 R	67.55	-0.06	0.29	11.57	-0.01	-0.12	102.00	-0.69	0.18	23.82	0.22	**1.83**
17	RR 286 R	76.19	-0.35	-0.24	10.17	-0.04	-0.13	130.70	-1.15	0.23	24.75	-0.65	0.00
18	ASD 06-8 R	77.54	-0.07	0.36	13.13	0.12	0.24	120.70	-0.28	0.13	28.63	-0.11	-0.69
19	IR 80559 A X IR 62037 R	87.65	0.44	-0.29	12.45	-0.06	0.02	115.30	1.02	0.18	22.03	-0.11	-0.74
20	IR 80559 A X IR 72865 R	93.73	0.36	0.27	14.93	0.07	0.11	110.90	1.30	1.78	25.13	-0.29	-0.67
21	IR 80559 A X IR 68427 R	89.63	0.44	-1.87	18.33	0.09	0.27	132.60	2.78	-2.66	22.29	-0.21	-0.20
22	IR 80559 A X MDU 5 R	87.00	-0.70	0.13	17.58	-0.48	-1.10	133.80	-0.31	-0.54	45.39	0.74	0.45
23	IR 80559 A X ACK 99017 R	85.33	-0.24	-0.21	20.33	-0.37	-0.59	137.30	-0.26	-0.44	39.24	0.13	-0.31
24	IR 80559 A X TP 1021 R	87.28	0.71	-0.84	15.13	-0.04	0.33	141.20	-3.29	0.11	19.80	0.21	0.04
25	IR 80559 A X RR 363 R	82.77	0.70	-0.26	9.30	-0.19	0.11	103.50	1.96	-1.63	22.52	0.07	-0.21

26	IR 80559 A X RR 347 R	86.33	0.22	-0.41	11.30	-0.59	0.42	150.60	0.52	1.98	25.56	-0.02	-0.27
27	IR 80559 A X RR 286 R	86.23	-0.36	-0.75	20.40	-0.22	0.23	156.30	3.01	-0.97	42.95	0.08	-0.04
28	IR 80559 A X ASD 06-8 R	89.27	1.81	-0.52	9.37	-0.14	0.17	76.02	-1.34	-1.31	23.43	0.12	-0.16
29	APMS 6 A X IR 62037 R	88.30	0.24	0.39	24.17	-0.43	0.31	124.50	2.45	-1.17	47.20	0.11	0.51
30	APMS 6 A X IR 72865 R	78.03	0.49	0.21	17.10	-0.01	-0.39	130.00	2.80	1.85	26.39	-0.45	-0.84
31	APMS 6 A X IR 68427 R	79.92	-1.27	-0.81	8.28	-0.26	-0.26	120.60	0.69	0.76	25.54	-0.06	-0.01
32	APMS 6 A X MDU 5 R	80.23	0.81	0.11	10.60	-0.21	-0.02	137.00	1.20	1.01	22.26	0.27	-0.15
33	APMS 6 A X ACK 99017 R	82.90	0.89	0.08	24.53	0.76	-0.54	162.40	0.01	0.07	40.61	0.42	0.34
34	APMS 6 A X TP 1021 R	82.70	1.04	-1.02	26.60	-0.19	0.11	170.10	0.31	0.71	44.34	0.43	0.84
35	APMS 6 A X RR 363 R	76.17	0.27	-0.79	14.80	0.13	0.07	83.93	-0.77	0.31	20.23	0.04	-0.08
36	APMS 6 A X RR 347 R	98.10	1.00	0.11	22.30	-0.05	0.37	126.10	0.36	-0.33	55.00	-0.90	-0.41
37	APMS 6 A X RR 286 R	86.02	1.07	-0.11	14.77	0.25	0.10	121.60	0.19	-0.03	29.24	-0.01	-0.03
38	APMS 6 A X ASD 06-8 R	78.20	0.25	0.03	15.57	0.19	0.08	106.20	-0.45	-0.04	31.01	-0.32	-0.42
39	IR 72081 A X IR 62037 R	83.60	1.37	0.24	25.00	-0.45	-0.12	126.50	0.25	-0.34	36.73	-0.94	0.32
40	IR 72081 A X IR 72865 R	79.90	0.87	0.17	14.20	-0.17	-0.31	121.80	-0.19	0.00	20.50	-0.19	0.21
41	IR 72081 A X IR 68427 R	85.28	0.24	0.13	28.10	-0.39	0.24	170.70	0.07	0.23	40.72	0.11	-0.18
42	IR 72081 A X MDU 5 R	87.70	-0.32	-0.38	23.57	-0.12	0.62	158.70	-0.14	-0.20	43.92	-0.33	-0.43
43	IR 72081 A X ACK 99017 R	94.37	-0.30	0.13	20.53	-0.28	0.08	91.12	1.08	-0.32	28.91	0.18	0.29
44	IR 72081 A X TP 1021 R	95.77	-1.29	-0.65	24.93	-0.04	0.14	182.00	-0.03	0.03	53.83	-0.70	0.22
45	IR 72081 A X RR 363 R	79.57	-0.42	-0.63	11.63	0.09	-0.40	113.30	0.68	-0.75	23.81	0.85	-0.67
46	IR 72081 A X RR 347 R	79.37	-0.90	-0.28	14.47	0.25	0.25	110.20	0.97	-0.31	31.42	0.29	-0.04
47	IR 72081 A X RR 286 R	86.05	-0.78	0.05	15.43	**0.00**	-0.25	110.30	0.69	-0.54	26.81	0.63	0.99
48	IR 72081 A X ASD 06-8	89.43	0.67	-1.30	17.57	0.28	0.07	128.10	2.23	-0.48	31.80	-0.46	0.01
49	IR 75601 A X IR 62037 R	87.57	0.06	-0.09	16.80	-0.03	0.16	119.10	1.62	-0.24	25.42	0.37	0.26
50	IR 75601 A X IR 72865 R	84.83	-0.18	-0.78	23.30	0.44	0.09	144.50	-0.56	-1.03	49.82	0.07	0.54
51	IR 75601 A X IR 68427 R	89.73	-1.51	-0.36	19.73	-0.13	-0.38	113.20	-0.23	-0.38	27.70	0.03	-0.21
52	IR 75601 A X MDU 5 R	85.30	-0.15	0.02	21.70	0.74	0.47	180.30	-0.79	-1.50	46.80	-0.11	0.71
53	IR 75601 A X ACK 99017 R	84.97	1.05	-0.41	16.30	-0.42	0.08	117.20	-0.55	0.03	31.81	-0.66	0.23
54	IR 75601 A X TP 1021 R	82.32	0.37	-0.64	19.73	0.54	-0.63	108.50	-0.18	0.57	27.73	-0.59	0.31

55	IR 75601 A X RR 363 R	83.43	0.11	-1.76	14.87	0.75	-1.04	141.50	3.71	0.84	22.50	-0.38	-0.83
56	IR 75601 A X RR 347 R	86.60	0.30	0.45	24.43	0.12	-0.05	146.60	-0.40	-0.71	36.85	0.03	-0.20
57	IR 75601 A X RR 286 R	89.50	0.11	-0.11	25.20	-0.09	-0.16	148.00	-0.38	-0.66	45.08	-0.71	-0.07
58	IR 75601 A X ASD 06-8 R	84.30	-0.18	-0.04	17.67	-0.29	0.29	107.30	-0.99	1.35	26.07	0.16	-0.24
59	IR 75596 A X IR 62037 R	81.93	-0.31	0.42	13.03	-0.48	-0.07	118.80	1.28	0.54	22.29	-0.09	-0.18
60	IR 75596 A X IR 72865 R	84.27	0.15	-0.41	12.63	-0.78	0.03	134.90	-2.77	0.35	23.00	0.52	-0.20
61	IR 75596 A X IR 68427 R	91.10	0.03	0.26	17.33	-1.49	-1.27	106.30	0.81	-0.06	24.43	0.99	0.09
62	IR 75596 A X MDU 5 R	81.03	-0.51	0.30	25.17	0.15	0.17	153.30	-0.70	-1.32	46.38	-0.21	0.79
63	IR 75596 X ACK 99017 R	87.98	-0.12	0.42	16.15	0.69	0.02	116.80	-1.62	0.78	24.97	0.90	-0.01
64	IR 75596 A X TP 1021 R	90.40	0.81	0.22	21.00	-0.23	0.53	115.20	-2.10	1.10	40.82	-3.18	-1.34
61	IR 75596 A X IR 68427 R	91.10	0.03	0.26	17.33	-1.49	-1.27	106.30	0.81	-0.06	24.43	0.99	0.09
62	IR 75596 A X MDU 5 R	81.03	-0.51	0.30	25.17	0.15	0.17	153.30	-0.70	-1.32	46.38	-0.21	0.79
63	IR 75596 X ACK 99017 R	87.98	-0.12	0.42	16.15	0.69	0.02	116.80	-1.62	0.78	24.97	0.90	-0.01
64	IR 75596 A X TP 1021 R	90.40	0.81	0.22	21.00	-0.23	0.53	115.20	-2.10	1.10	40.82	-3.18	-1.34
65	IR 75596 A X RR 363 R	88.53	-0.05	0.05	16.58	-0.72	0.51	127.50	1.47	4.85	35.45	-2.54	0.07
66	IR 75596 A X RR 347 R	88.70	1.44	0.20	15.70	0.52	0.05	101.90	-0.24	0.56	23.98	-0.52	0.29
67	IR 75596 A X RR 286 R	95.80	-1.70	0.30	13.92	0.01	-0.02	106.00	-1.08	-1.33	24.27	-0.29	0.08
68	IR 75596 A X ASD 06-8	82.43	-0.92	0.29	23.77	-0.07	-0.48	131.80	-0.18	-0.27	40.90	0.12	0.30
69	IR 80154 A X IR 62037 R	77.27	-0.05	0.36	21.32	0.27	0.20	135.20	-0.20	-0.31	35.76	-0.36	-0.40
70	IR 80154 A X IR 72865 R	82.40	-0.57	0.09	17.17	0.28	0.11	98.00	-2.16	0.35	20.96	0.31	-0.19
71	IR 80154 A X IR 68427 R	82.43	0.19	0.43	12.33	0.09	-0.06	105.90	-1.05	0.15	28.21	2.03	-0.39
72	IR 80154 A X MDU 5 R	78.45	-0.83	-0.13	11.50	0.36	-0.20	110.90	-0.69	-0.60	26.31	**2.16**	-0.68
73	IR 80154 A X ACK 99017 R	79.68	-1.85	0.26	13.33	0.50	0.29	127.60	-1.55	**-2.85**	24.67	0.16	0.29
74	IR 80154 A X TP 1021 R	74.18	-0.61	0.54	18.37	-0.34	-0.51	119.50	-1.00	-2.02	27.11	-0.43	0.30
75	IR 80154 A X RR 363 R	78.47	-2.58	0.40	13.00	**1.52**	-0.29	104.70	-1.37	-0.46	25.15	0.88	0.09
76	IR 80154 A X RR 347 R	85.23	0.54	0.84	16.43	0.58	-0.05	111.20	0.32	2.89	24.99	1.29	-0.20
77	IR 80154 A X RR 286 R	81.60	-0.86	-0.15	13.53	-0.31	0.44	91.87	0.14	-0.41	26.47	-1.58	0.76
78	IR 80154 A X ASD 06-8	84.80	0.58	-0.24	18.50	-1.29	-0.32	100.30	-0.06	-0.10	21.24	-0.01	0.11
79	CRMS 32 A X IR 62037 R	80.60	0.57	0.14	23.80	-0.32	-0.37	140.70	0.01	0.11	39.29	-0.01	0.12

No	Cross												
80	CRMS 32 A X IR 72865 R	87.63	1.89	0.16	19.97	-0.32	0.24	113.90	0.62	1.68	27.30	-0.04	0.08
81	CRMS 32 A X IR 68427 R	78.67	0.01	0.20	12.63	0.15	0.26	116.80	-1.44	1.54	26.81	0.13	0.33
82	CRMS 32 A X MDU 5 R	92.50	1.76	0.29	20.27	0.03	-0.03	101.30	-0.97	-0.63	25.86	0.05	0.20
83	CRMS 32 A X ACK 99017 R	80.30	0.83	0.16	17.50	0.36	0.13	99.63	0.03	-0.23	26.58	0.18	0.40
84	CRMS 32 A X TP 1021 R	84.50	1.98	0.74	21.93	-0.18	0.20	97.30	0.83	0.22	30.76	-0.09	-0.01
85	CRMS 32 A X RR 363 R	77.83	1.32	0.14	25.07	-0.14	-0.21	115.50	0.40	0.88	40.40	0.56	0.12
86	CRMS 32 A X RR 347 R	81.33	2.16	0.35	20.47	0.36	0.03	97.17	-1.55	0.04	22.71	-0.53	0.64
87	CRMS 32 A X RR 286 R	78.77	-0.58	0.19	10.98	0.11	-0.11	94.45	-0.85	-0.27	26.95	-0.65	0.48
88	CRMS 32 A X ASD 06-8 R	86.93	1.33	0.43	20.65	0.49	0.39	97.37	**-4.90**	0.64	23.80	-0.65	0.60
89	IR 75608 A X IR 62037 R	80.17	-0.89	0.25	16.23	0.68	0.17	101.50	1.36	-0.65	27.49	-0.42	0.23
90	IR 75608 A X IR 72865 R	79.33	-0.21	0.14	15.45	0.37	0.19	106.10	0.61	-1.37	23.43	0.73	-0.63
91	IR 75608 A X IR 68427 R	81.33	-0.74	0.45	14.53	0.22	0.32	107.70	-0.47	-0.46	26.92	0.40	-0.37
92	IR 75608 A X MDU 5 R	81.30	-1.44	0.07	19.42	-0.18	0.58	114.30	-2.32	1.82	25.76	0.27	-0.20
93	IR 75608 A X ACK 99017 R	92.70	0.10	0.16	15.18	0.44	0.28	104.90	-2.28	-0.86	27.97	-0.18	0.28
94	IR 75608 A X TP 1021 R	80.13	0.18	0.22	17.33	-0.14	0.25	101.40	0.99	-0.13	25.10	0.84	-0.50
95	IR 75608 A X RR 363 R	79.52	0.24	0.70	15.37	-1.42	**0.83**	120.50	2.39	-0.18	27.38	-0.34	-1.12
96	IR 75608 A X RR 347 R	78.03	-0.82	0.65	16.63	-0.33	0.81	101.20	1.88	-0.12	28.25	-0.52	-0.07
97	IR 75608 A X RR 286 R	84.33	-1.56	0.62	12.93	0.44	0.15	104.00	-0.84	0.20	24.65	0.33	0.05
98	IR 75608 A X ASD 06-8 R	82.63	-0.15	0.33	15.53	0.83	0.09	99.13	-1.93	0.32	30.26	0.05	0.15
99	CORH 3	87.21	-0.47	-0.73	13.88	-0.23	-0.18	103.60	-0.29	0.13	29.36	0.05	-0.47
100	CO (R) 48	87.35	-0.22	0.17	11.57	-0.05	-0.17	91.20	-0.32	0.14	29.12	-0.05	0.13
	E1	**80.13**	**3.33**	**3.71**	**15.32**	**-2.40**	**-2.09**	**120.30**	**6.57**	**6.81**	**29.98**	**-4.03**	**-2.91**
	E2	**85.19**	**3.67**	**-3.59**	**16.40**	**-1.11**	**2.69**	**121.70**	**4.89**	**-7.51**	**29.59**	**-1.61**	**3.87**
	E3	**86.60**	**-7.00**	**-0.12**	**17.07**	**3.49**	**-0.59**	**121.00**	**-11.46**	**0.71**	**30.22**	**5.63**	**-0.98**
	Grand mean		**83.97**			**16.29**			**121.00**			**29.93**	

Table 4. Hybrids selected for *per se* performance, *sca* effects and standard heterosis in three environments

Characters	*per se* performance	*sca* effects	Heterosis per cent
Single plant yield	IR 80559 A X MDU 5 **IR 80559 A X ACK 99017** **IR 80559 A X RR 286-1** **APMS 2 A X ACK 99017** APMS 2 A X TP 1021 APMS 2 A X RR 347-1 IR 72081 A X IR 62037-93-1-3-1-1 **IR 72081 A X IR 68427-8-3-3-2** IR 72081 A X MDU 5 IR 72081 A X TP 1021 **IR 75601 A X IR 72865-94-3-3-2** IR 75601 A X MDU 5 IR 75601 A X RR 347-1 IR 75596 A X MDU 5 **IR 75601 A X RR 286-1** IR 75596 A X ASD 06-8 IR 80154 A X IR 62037-93-1-3-1-1 CRMS 32 A X IR 62037-93-1-3-1-1 CRMS 32 A X RR 363-1	**IR 80559 A X ACK 99017** **IR 80559 A X RR 286-1** APMS 2 A X IR 62037-93-1-3-1-1 **APMS 2 A X ACK 99017** APMS 2 A X RR 347-1 **IR 72081 A X IR 68427-8-3-3-2** IR 72081 A X TP 1021 **IR 75601 A X IR 72865-94-3-3-2** **IR 75601 A X RR 286-1** IR 75596 A X MDU 5 IR 80154 A X IR 62037-93-1-3-1-1 CRMS 32 A X IR 62037-93-1-3-1-1 CRMS 32 A X RR 363-1 IR 75608 A X ASD 06-8	IR 80559 A X MDU 5 **IR 80559 A X ACK 99017** **IR 80559 A X RR 286-1** APMS 2 A X IR 62037-93-1-3-1-1 **APMS 2 A X ACK 99017** APMS 2 A X TP 1021 **IR 72081 A X IR 68427-8-3-3-2** IR 72081 A X MDU 5 **IR 75601 A X IR 72865-94-3-3-2** IR 75601 A X MDU 5 IR 75601 A X RR 347-1 **IR 75601 A X RR 286-1** IR 75596 A X ASD 06-8

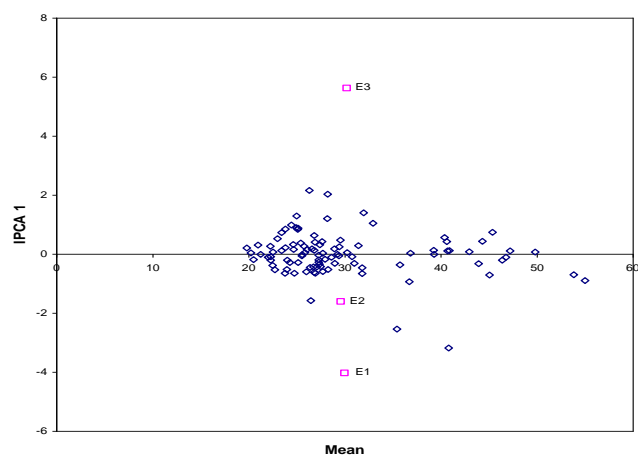Fig 1. AMMI 1 biplot for single plant yield
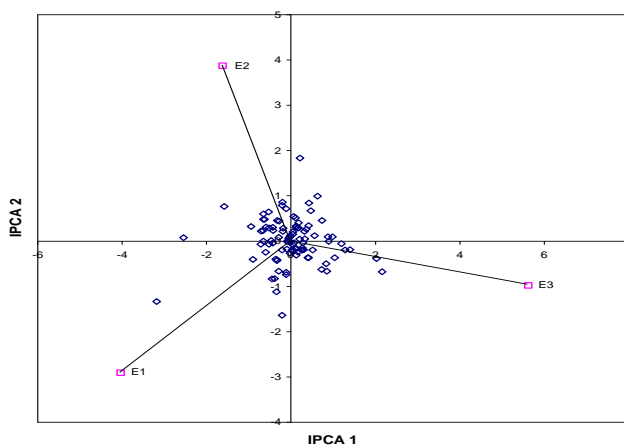

Fig 2. AMMI 2 Biplot for Single plant yield

Fig 3. Environmental indices for different characters in E1, E2 and E3 environments