



Research Article

Grain yield stability of single cross maize (*Zea mays* L.) hybrids over three different environments

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Abstract

An investigation was conducted to determine the grain yield performance of seventy two single cross maize hybrids, their nine parents and one commercial check across three seasons (Summer, Kharif and Rabi) of the year 2006 at the Department of Millets, Tamil Nadu Agricultural University, Coimbatore. The design lay out was a randomized blocks design with three replications. The additive main effects and multiplicative interactions (AMMI) analysis indicated that the grain yield performance of maize genotypes were mainly due to genotypes and environmental interaction. The first two principal component axis (IPCA I and IPCA II) were significant ($p < 0.01$) and cumulatively contributed to entire degrees of freedom available for interaction component. The biplot 1 and 2 were constructed using genotype and environmental mean and scores. Among parents, UMI 432 was found to be higher yielder and stable across environments. The single crosses namely UMI 79 x UMI 176, UMI 79 x UMI 57, UMI 79 x UMI 936 (w), UMI 79 x UMI 285, UMI 176 x UMI 102, UMI 176 x UMI 936 (w), UMI 432 x UMI 176, UMI 467 x UMI 57 and UMI 57 x UMI 102 were identified as stable yielder across environments in addition to higher yield. These hybrids can be recommended for all the three seasons for cultivation.

Key words

AMMI model, genotype environment interaction, PCA, single cross maize hybrids

Introduction

Maize or Indian corn (*Zea mays* L.) is an important cereal crop of the world after wheat and rice. It probably originated in Mexico and evolved from teosinte (*Zea mexicana*) (de Wet and Harlan (1972). Being a C4 plant, it is physiologically more efficient and has higher grain yield and wider adaptation over a range of environmental conditions (Dowswell et al., 1996). Maize has a wider range of uses than any other cereals as animal feed, human food and for hundreds of industrial purposes (Dhillon, 1988). In India, maize is grown in an area of 7.4 million hectares and the annual production is about 14.5 million tonnes with a productivity of 1.96 tonnes per hectare (Singh, 2006). In Tamil Nadu, maize occupies 1.90 lakh hectares with an average production and productivity of 2.95 lakh tonnes and 1552 kg per hectare respectively (Annon., 2005). It is expected to increase in future to meet the growing demands of poultry and other animals feed industry, industrial utilization and human consumption. The demand for maize is increasing every year.

Agricultural yield is strongly influenced by

environmental conditions that generally lead to wide variations in yield, both among years in a location and among locations in a single year or, even further, between locations and years. Improving yield stability of an agricultural crop throughout a production region is an important objective of any breeding programmes. Unfortunately, it is not uncommon to have situations where selection based on yield stability causes lower mean yields (Finalay and Wilkinson, 1963; Helms, 1993) and, conversely, where selection for higher means results in less stability (Simmonds, 1991). However, Holland and his co-workers (Holland et al., 2002) reported that a selection for wide adaptation to various environments in oat resulted in a significant increase in mean grain yield in the population.

Multi-environment trials play an important role in selecting the best cultivars to be used in future years at different locations and in assessing a cultivar's stability across environments before its commercial release. When the performance of cultivars is compared across environments, several cultivar attributes are considered, of which grain yield is one of the most important (Vargas et al., 1999).

Many methods of analysis for stability have been proposed for predicting cultivar responses in multi

environment trials. Of which, the additive main effects and multiplicative interactions (AMMI) model combines standard analysis of variance with principal component analysis (Zobel et al., 1988). The AMMI model has been extensively applied in the statistical analysis of multi environment cultivar trials (Kempton, 1984; Gauch, 1988; GAuch and Zobel, 1989, Crossa et al., 1999; Gauch and Zobel, 1997). The results of AMMI analysis can be presented graphically in the form of biplots (Gabriel, 1991) for easy interpretation of genotype and environment interaction.

Materials and methods

The research work was carried out to study the grain yield stability of single cross maize hybrids over three seasons (Summer, Kharif and Rabi) of the year 2006 at the Department of Millets, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore. The materials selected as parents for the present study consisted of nine maize inbred lines maintained by sib mating in Maize unit, Department of Millets, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore. The source and details of the parent materials are given in Table 1.

Seeds of nine inbred lines were sown in crossing block during Rabi, 2005 for effecting crosses. All agronomic practices recommended in crop production guide [TNAU, 1999] were followed in crossing block. Tassel bag method (Jugenheimer, 1976) was adopted for making hand pollinations in maize to effect crosses. For making crosses, pollen was collected from desired male parent and dusted on the silks of desired female parent, where as in the case of selfing, pollen was collected from the tassel and dusted on the silks of the same plant to obtain a self fertilized ear. Nine maize inbred lines were crossed during Rabi, 2005 in all possible combinations including reciprocals in diallel fashion to synthesize seventy two F_1 hybrids.

Totally, seventy two hybrids along with their nine parents and a check (COH(M)5, a recently released public commercial hybrid from TNAU, Coimbatore) were raised in Randomized Blocks Design replicated thrice during three seasons (Summer, Kharif and Rabi) of the year 2006 at Department of Millets, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore. They were sown with inter and intra row spacing of 60 cm and 25 cm respectively. Each entry per replication was represented by a single row of 4 m length which can accommodate 16 plants per row. All agronomic practices recommended in Crop production manua (TNAU, 1999) were followed to grow a successful crop. Grain yield per plant was recorded in each

entry, in each replication and in each season on five randomly selected competitive plants excluding border plants and their mean values were computed for statistical analysis.

The AMMI statistical model (Zobel et al., 1988) is a hybrid model. It makes use of standard analysis of variance (ANOVA) procedures to separate the additive variance from the multiplicative variance ($G \times E$ interaction) and then uses a multiplicative procedure. Principal components Analysis (PCA) is to extract the pattern from the $G \times E$ portion of the ANOVA analysis. The results of least square analysis, which with further graphical representation of the numerical results (Biplot analysis) often allows a straight forward interpretation of the underlying causes of $G \times E$ interaction. The AMMI biplot is developed by placing both genotype and environment means on the x-axis and the respective PCA axis eigen vectors on the y-axis (Vargas and Crossa, 2000)

Results and discussion

Plant breeders invariably encounter genotype \times environment interactions when testing cultivars across a number of environments. Depending upon the magnitude of the interactions or the differential genotypic responses to environments, the varietal rankings can differ greatly across environments. A combined analysis of variance can quantify the interactions and describe the main effects. However, analysis of variance is uninformative for exploiting genotype \times environment interaction. Other statistical model for describing genotype \times environment interaction such as the additive main effects and multiplicative interaction (AMMI) model are useful for understanding genotype \times environment interaction.

The AMMI model is a hybrid analysis that incorporates both the additive and multiplicative components of the two-way data structure. AMMI biplot analysis is considered to be an effective tool to diagnose genotype \times environment interaction patterns graphically. In AMMI, the additive portion is separated from interaction by analysis of variance. The biplot display of principal component analysis scores plotted against each other provides visual inspection and interpretation of the genotype \times environment interaction components.

Present study was carried out to determine the grain yield performance of eighty-two maize genotypes across three seasons (Summer, Kharif and Rabi) of the year 2006. These eighty-two genotypes includes nine parents, seventy-two single cross hybrids and one commercial check (COH(M)5).

Data of the analysis of variance showed that grain yield was influenced by the environments of testing, genotypes and their interactions (Table 2). The later factor was of particular significance, since the presence of a reliable genotype x environment interactions ($p < 0.01$) allows further analysis.

The AMMI analysis of variance of grain yield per plant of the eight-two genotypes tested in three environments showed that 80.28 per cent of the total sum of squares was attributable to genotypic effects, 8.09 per cent to environmental effects and 11.64 per cent to genotype x environment interaction effects (Table 2). The estimates of stability parameters of eighty-two genotypes and three environments for grain yield are presented in Table 3.

The first principal component axis (IPCA I) of the interaction of AMMI analysis accounted for 62.29 per cent of the genotype x environment interaction sum of square, the second principal component axis (IPCA II) accounted for 37.71 per cent using eighty-two and eighty degrees of freedom respectively. These two principal component axis (IPCA I and IPCA II) accounted for 100 per cent of the genotype x environment interaction sum of squares and used entire degrees of freedom available in the interaction.

These results showed AMMI with two principal component axis (IPCA I and IPCA II) to be the best predictive model. This has presented a possibility of constructing the biplot and calculating the genotype and environment effects. A large sum of squares for genotypes indicated that the genotypes were diverse with large differences among genotypic means causing variation in grain yield. The magnitude of the genotype x environment interaction sum of squares was 1.44 times larger than that for environments indicating that there were substantial differences in environmental response towards genotypes.

In the biplot (Fig. 1) showing main effect means on the abscissa and IPCA I values as the ordinates, genotypes (or environments) that appear almost on a perpendicular line have similar means and those that fall almost on a horizontal line have similar interaction patterns. Genotypes (or environments) with large IPCA I scores (either positive or negative) have high interactions; where as genotypes (or environments) with IPCA I scores near zero have small interactions.

As pointed out by Zobel *et al.* (1988), the AMMI expected yield for any genotype and environment combination can be calculated from biplot 1. The genotype and environment with IPCA I scores of the same sign produce positive interaction effects, where as

combination of IPCA I scores of opposite signs have negative specific interactions. The positive main effects were recorded by the environments E2 (142.92g) and E3 (144.63g), on the other hand E1 (122.68g) had negative main effects.

All the nine parents showed a similar mean yield response (below the grand mean). Among the nine parents P8 and P9 had positive interaction effects where as P1, P2, P4, P6 and P7 had negative interaction effects. However parents P5 and P3 recorded PCA scores near to zero and they have differences only in main (additive) effects and they were found to be stable across environments and later one recorded higher mean value along with stable yield when compared to other parental lines. The parents P9, P6 and P7 and the parents P4 and P2 separately have similar mean values and have differences only in interaction effects.

The hybrids P1 x P2, P1 x P6, P1 x P8, P1 x P9, P2 x P7, P2 x P8, P3 x P2, P4 x P6 and P6 x P7 were found to be stable yielder across environments with high mean value for grain yield per plant. These hybrids are recommended for all environments for cultivation. The hybrids P3 x P4, P6 x P1, P6 x P3, P6 x P5, P7 x P6 and P8 x P1 posed in quadrant two and recorded high mean with positive interaction and shows that they have specific adaptation to favorable environments. Considering only the IPCA I scores it became clear that these hybrids were the more unstable genotypes, but they were well adapted to high yielding or more favorable environments. The hybrids P3 x P1, P4 x P7, P8 x P7, P9 x P2 and P9 x P4 had the higher magnitude of the genotype vectors reflects the amount of interaction for these hybrids. They have a specific adaptation and seem unstable and indicated less ability of these hybrids to respond to favorable environments.

A biplot 2 (Fig. 2) is generated using genotypic and environmental scores of the two AMMI components [20]. A biplot has four sections, depending upon signs of the genotypic and environmental scores.

The hybrids P6 x P1, P6 x P3, P3 x P4 and P7 x P6 were unstable and identified as best performing hybrids in E3 environment. Of these hybrids P6 x P1 had the highest grain yield in E3 environment. The crosses P8 x P2 and P9 x P4 were more suitable for cultivation in E1 environment. P4 x P7, P5 x P7 and P9 x P2 were the best performing hybrids in E2 environment.

With respect to environments E1 was most discriminating as indicated by the longest distance between its marker and the origin. However its large PCA II score, genotypic differences observed at E1



may not exactly reflect the genotypes in average yield over all environments. Environment E3 was not the most discriminating but genotypic differences at E3 should be highly consistent with those averaged yield over environments, because it had less PCA II scores compared to other two environments.

References

- Anonymous, 2005. 4:3. Area, production and productivity of principal crops, 2004-2005. Department of Economics and Statistics, Statistical Hand Book 2005. Chennai-600006.
- Crossa, J., Gauch, H.G. and Zobel, R.W. 1990. Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. *Crop Sci.*, 30: 493-500.
- de Wet, J.M.J. and Harlan, J.R. 1972. Origin of maize: The tripartite hypothesis. *Euphytica*, 21: 271-279.
- Dhillon, B.S. 1998. maize. In. Hybrid cultivar development. Ed. Banaga, S.S. and S.K. Banga. Naosa Publishing House. New Delhi, India.
- Dowswell, C.R., Paliwal, R.L. and Cantrell, R.P. 1996. Maize in the third world. Westview Press, Boulder, USA.
- Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaptation in a plant breeding programme. *Aust. J. Agric. Res.*, 14: 742-754.
- Gabriel, K.R. 1971. Biplot display of multivariate matrices with application to principal component analysis. *Biometrika*, 58: 453-467.
- Gauch, H.G. 1988. Model selection for yield trials with interaction. *Biometrics*, 44: 705-715.
- Gauch, H.G. and Zobel, R.W. 1989. Accuracy and selection success in yield trials. *Theor. Appl. Genet.*, 77: 473-481.
- Gauch, H.G. and Zobel, R.W. 1997. Identifying mega-environments and targeting genotypes. *Crop Sci.*, 37: 311-326.
- Helms, T.C. 1993. Selection for yield and stability among oat lines. *Crop Sci.*, 30: 423-426.
- Holland J.B., Bjonstad, A., Frey, K.J., Gullord, M. and Wesenberg, D.M. 2002. Recurrent selection for broad adaptation affects stability of oat. *Euphytica*, 126: 265-274.
- Jugenheimer, R.W. 1976. Corn: Improvement, seed production and uses. A Wiley Inter science Publications, USA. Pp: 124-129.
- Kempton, R.A. 1984. The use of biplots in interpreting variety by environment interactions. *J. agric. Sci.*, 103: 123-135.
- Simmonds, N.W. 1991. Selection for local adaptation in a plant breeding programme. *Theor. Appl. Genet.*, 82: 363-367.
- Singh, R.P. 2006. AICRP Maize Kharif Report, Directorate of Maize Research, New Delhi.
- TNAU, 1999. Crop production guide. Tamil Nadu Agricultural University, Coimbatore
- Vargas, M. and Crossa, J. 2000. The AMMI analysis and graphing the biplot. Biometrics and Statistics Unit, CIMMYT.
- Vargas, M., Crossa, J., van Eeuwijk, F.A., Ramirez, M.E., and Sayre, K. 1999. Using partial least squares regression, factorial regression, and AMMI models for interpreting genotype x environment interaction. *Crop Sci.*, 39: 955-967.
- Zobel, R.W., Wright, M.J. and Gauch, H.G. Jr. 1988. Statistical analysis of a yield trials. *Agron. J.*, 80: 388-393.

**Table 1. Details of the parent materials used in the study**

Code No.	Genotypes	Pedigree/Origin	Grain color	Reaction to SDM
P1.	UMI 79	Selection from Pioneer 102	Orange	Susceptible
P2.	UMI 176	Selection from V46	Yellow	Moderately Resistant
P3.	UMI 432	Derivative of UMI 25 x UMI 103	Yellow	Susceptible
P4.	UMI 467	Selection from K1	Yellow	Susceptible
P5.	UMI 13	Selection from CM 111	Yellow	Moderately Resistant
P6.	UMI 57	Selection from DMR pool – Taiwan-3	Yellow	Moderately Resistant
P7.	UMI 102	Selection from EH 431873	Yellow	Resistant
P8.	UMI 936 (w)	Selection from DMR pool – Taiwan 524	White	Resistant
P9.	UMI 285	Selection from Suwan 1 – Indonesia composite	Yellow	Resistant

Table 2. Additive Main effects and multiplicative Interaction (AMMI) analysis of variance for grain yield per plant (g) of eighty-two genotypes across three environments

Sources	df	S.S.	M.S.	Explained (%)
Genotypes	81	243244.0	3003.01**	80.28
Environments	2	24499.2	12249.60**	8.09
G x E interaction	162	35259.5	217.65**	11.64
AMMI component 1	82	21962.0	267.83**	62.29
AMMI component 2	80	13297.5	166.22**	37.71
Total	245	303002.0		

**Table 3. Estimates of stability parameters (AMMI) for grain yield in maize**

Sl. No.	Genotype	Code used	Mean (g)	IPCA I	IPCA II	Sl. No.	Genotype	Code used	Mean (g)	IPCA I	IPCA II
1	UMI 79	P1	63.70	-1.19	-2.54	45	P5 x P4	36	137.12	-0.28	-2.25
2	UMI 176	P2	52.41	-1.51	0.71	46	P5 x P6	37	149.61	-0.59	0.16
3	UMI 432	P3	83.69	-0.17	-1.66	47	P5 x P7	38	147.86	-1.26	2.06
4	UMI 467	P4	53.28	-1.05	-0.89	48	P5 x P8	39	141.64	1.01	-0.17
5	UMI 13	P5	46.37	0.02	-1.21	49	P5 x P9	40	143.17	1.15	-0.14
6	UMI 57	P6	43.74	-0.47	-0.14	50	P6 x P1	41	163.77	1.92	2.03
7	UMI 102	P7	43.31	-1.25	-0.30	51	P6 x P2	42	149.27	-0.92	1.55
8	UMI 936(w)	P8	47.43	0.65	-1.61	52	P6 x P3	43	147.39	2.59	1.55
9	UMI 285	P9	44.64	0.64	-0.23	53	P6 x P4	44	123.64	-1.18	-1.42
10	P1 x P2	1	180.33	0.31	-0.47	54	P6 x P5	45	135.76	2.77	-0.16
11	P1 x P3	2	155.81	-0.50	-0.33	55	P6 x P7	46	156.53	-0.35	2.07
12	P1 x P4	3	132.27	0.30	-0.47	56	P6 x P8	47	142.06	1.18	-0.43
13	P1 x P5	4	163.07	-0.97	-1.46	57	P6 x P9	48	145.00	0.32	-0.22
14	P1 x P6	5	152.70	0.18	2.39	58	P7 x P1	49	141.26	1.33	1.01
15	P1 x P7	6	159.54	0.45	1.57	59	P7 x P2	50	142.68	-0.06	2.83
16	P1 x P8	7	158.81	0.09	1.24	60	P7 x P3	51	143.47	-0.97	-0.83
17	P1 x P9	8	159.04	0.14	2.07	61	P7 x P4	52	136.00	-0.04	-0.23
18	P2 x P1	9	172.41	0.76	-0.91	62	P7 x P5	53	139.49	-0.60	1.75
19	P2 x P3	10	151.91	-1.67	0.94	63	P7 x P6	54	146.21	4.16	-1.30
20	P2 x P4	11	129.41	-1.25	0.94	64	P7 x P8	55	137.74	1.26	-0.33
21	P2 x P5	12	170.09	-1.10	0.68	65	P7 x P9	56	138.43	1.30	-1.34
22	P2 x P6	13	136.88	-0.30	-2.19	66	P8 x P1	57	143.67	2.32	0.18
23	P2 x P7	14	157.39	0.23	1.32	67	P8 x P2	58	140.84	-1.68	-1.61
24	P2 x P8	15	153.00	-0.20	-0.76	68	P8 x P3	59	153.91	-1.35	0.61
25	P2 x P9	16	155.43	0.57	0.47	69	P8 x P4	60	140.59	-0.35	-2.21
26	P3 x P1	17	177.53	-2.03	0.68	70	P8 x P5	61	141.84	1.15	-0.82
27	P3 x P2	18	160.24	-0.23	-0.73	71	P8 x P6	62	142.42	-0.05	-1.01
28	P3 x P4	19	140.63	2.95	0.60	72	P8 x P7	63	141.28	-2.07	0.20
29	P3 x P5	20	149.74	1.32	0.51	73	P8 x P9	64	150.18	-0.47	0.13
30	P3 x P6	21	150.24	1.57	-0.65	74	P9 x P1	65	147.59	-0.78	-0.14
31	P3 x P7	22	155.42	0.67	-0.51	75	P9 x P2	66	152.00	-2.62	0.48
32	P3 x P8	23	141.82	1.63	1.30	76	P9 x P3	67	158.38	-0.62	0.73
33	P3 x P9	24	143.61	0.07	0.74	77	P9 x P4	68	135.18	-3.55	-0.17
34	P4 x P1	25	157.07	1.63	0.49	78	P9 x P5	69	150.49	-0.94	0.67
35	P4 x P2	26	129.57	2.77	-0.95	79	P9 x P6	70	146.56	-1.66	-0.46
36	P4 x P3	27	132.24	-0.79	-0.89	80	P9 x P7	71	124.16	1.88	-0.84
37	P4 x P5	28	142.04	-0.79	0.85	81	P9 x P8	72	146.09	-0.82	-2.32
38	P4 x P6	29	155.39	0.09	1.47	82	CoH(M)5	73	150.00	-0.29	0.35
39	P4 x P7	30	146.13	-2.04	1.63						
40	P4 x P8	31	138.09	0.85	0.12						
41	P4 x P9	32	142.43	-0.44	-0.85						
42	P5 x P1	33	141.24	-0.39	-0.62						
43	P5 x P2	34	141.49	-0.97	-1.03						
44	P5 x P3	35	141.11	0.29	1.09						
							Environments				
						1	Summer	E1	122.68	-0.38	-8.76
						2	Kharif	E2	142.92	-8.41	4.67
						3	Rabi	E3	144.63	8.79	4.09

Environmental mean = 136.90g

Fig. 1. AMMI I biplot for the grain yield mean and the first IPCA scores of eighty two maize genotypes and three environments



