Indian J. Genet., 73(1): 29-35 (2013)
DOI : 10.5958/j.0019-5200.73.1.004

Additive main effects and multiplicative interaction analysis for grain yield of short duration maize hybrids in North-Western Himalayas

S. K. Jha[1], N. K. Singh[1,6], R. Arun Kumar[1], P. K. Agrawal[1], J. C. Bhatt[1], S. K. Guleria[2], A. A. Lone[3], R. S. Sudan[4], K. P. Singh[5] and V. Mahajan[5*]

[1]Vivekanand Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand; [2]CSKHPKV, Bajaura, H.P.; [3]KD Research Station, SKUAS&T, Srinagar, J&K; [4]Maize Research Centre, SKUAS&T, Udhampur, J&K; [5]Directorate of Maize Research, Pusa, New Delhi; [6]Present address: Genetics & Plant Breeding, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand

(Received: November 2012; Revised: January 2013; Accepted: January 2013)

Abstract

An Additive main effect and multiplicative interaction (AMMI) model was used to analyze grain yield data of 21 single cross maize hybrids evaluated at four locations in north-western Himalayas. Variation among hybrids for grain yield was found to be significant in each location. AMMI analysis of variance indicated significant variance for locations, hybrids and hybrids×locations interaction (H×L). The location main effect had largest contribution (52.79 %) to the total sum of squares for grain yield followed by H×L interaction (28.16%) and hybrids (19.10%). The interaction component was further divided into interaction principal component axes (IPCA). Only first IPCA was found to be significant and accounted for 54.73% of the H×L variance. The second PCA was non-significant yet accounted for 26.16% variability of H×L interaction. The AMMI I analysis identified the nature and magnitude of interaction of each hybrids while AMMI II analysis identified the two hybrids namely, FH3594 and FH3609, which were moderately stable and promising across the north-western Himalayan environments.

Key words: AMMI analysis, maize, stability, IPCA

Introduction

Maize (*Zea mays* L.) improvement programme is heavily based on exploitation of heterosis for grain yield. *Per se* performance of the inbred lines, source population from where it derived and genetic diversity between the inbred lines are major factors determining success of single cross hybrid development programme [1]. The search for hybrid combinations with high grain yield adapted across the environments is one of the most important objectives for breeders. Allelic homeostasis seems to be essential for stability and adaptability of single cross hybrids across the environmental regimes. Multi-environment evaluation experiments are essential to evaluate grain yield and to quantify adaptability and stability of the hybrids since these are the complex traits and highly influenced by environments [2]. Changes in the relative behaviour of the genotype in different environments are usually noticed if experiments are conducted over the years and locations, and the phenomenon is generally referred to as genotype by environment interaction (G×E). The higher G×E interaction makes it difficult to select genotypes that produce high grain yield across the environments. Due to changing climate and inclement weather conditions throughout the year in general and during the cropping season in particular, the criteria for selection based on general as well as specific stability and adaptability parameters seem to be more relevant in improvement programme specifically in case of single cross hybrids, where only two parents are involved. Further, fragile ecosystem of north-western Himalayas, where maize is cultivated under rainfed conditions and influenced by macro as well as micro environmental conditions and altitudinal variation, necessitate identifying maize hybrids which can perform uniformly across the zone.

*Corresponding author's e-mail: vinmaha9@gmail.com
Published by Indian Society of Genetics & Plant Breeding, F2, First Floor, NASC Complex, PB#11312, IARI, New Delhi 110 012
Online management by indianjournals.com

The quantification of G×E is thus become extremely important, because it can be used to establish the breeding objectives, such as the choice of genitors, identification of the ideal test conditions and recommendations for regional adapted cultivars [3]. Among the statistical analyses proposed for the interpretation of the G×E based on the use of biplots, the AMMI model stands out due to the largest group of technical interpretations available. Additive main effects and multiplicative interaction (AMMI) analysis interprets the effect of the genotype (G) and environment (E) as additive effects plus the G×E as a multiplicative component and submits it to principal component analysis. G×E biplots of AMMI analysis combines the yield stability parameters [3]. The present investigation was therefore, aimed to determine the stability and adaptability of 21 single cross hybrids of maize evaluated at four locations in north-western Himalayas using AMMI analysis.

Materials and methods

The materials for the present investigation comprised of 19 new single crosses along with 2 released single cross hybrids of maize of early maturity group. Of these, 12 single crosses (FH hybrids) and two check hybrids [Vivek Maize Hybrid 9 (VMH9) and Vivek Maize Hybrid 33 (VMH33)] were developed at Vivekanand Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora (Uttarakhand) whereas 5 single crosses (EHL hybrids) and 2 single crosses (KDM crosses) were developed at Chaudhary Shravn Kumar Himachal Pradesh Krishi Vishvavidyalaya (CSKHPKV), Bajaura (Himachal Pradesh) and KD Research Station, Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAS&T), Srinagar (J&K), respectively. All the 21 single crosses were evaluated in randomized complete block design (RCBD) with three replications during *kharif* 2011 at four locations namely, Almora (Uttarakhand), Bajaura (Himachal Pradesh), Srinagar and Maize Research Centre, SKUAS&T, Udhampur (Jammu & Kashmir) located at different altitudes in north western Himalayas (Table 1). Performance evaluation experiments were conducted in plot size of 3.6 m^2 at Almora (L1) and Bajaura (L2), and in plot size of 4.8 m^2 at Srinagar (L3) and Udhampur (L4) under rainfed conditions at Almora and Udhampur, whereas 3 supplementary irrigations at Bajaura and 2 at Srinagar were provided during no rain period. All the recommended cultural practices were followed to raise the normal crop.

Fresh cobs were harvested at physiological maturity and grains shelled from freshly harvested cobs were used to determine the moisture percentage of grain. Shelling coefficient was calculated by dividing grain weight/plot by cob weight after drying. Grain yield (kg/ha) at 15% moisture content was calculated using following formula:

$$\text{Grain yield (kg/ha)} = \frac{\text{FCY/plot (kg)} \times (100\text{-MC}) \times 10000\ (m^2) \times \text{SC}}{85 \times \text{Plot area } (m^2) \times \text{ha}}$$

Where:

FCY = Fresh cob yield/plot

MC = Moisture content (%) in grains at harvest

SC = Shelling coefficient

The grain yield (kg/ha) of each treatment replication wise thus obtained was used to single site analysis and the G×E interaction was analyzed using AMMI model [4]. The data were analysed using IRISTAT 4.3 software [5].

Table 1. Locations used for evaluation of maize hybrids

Parameters	Almora	Bajaura	Srinagar	Udhampur
Altitude	1250.00 m	1090.00m	1652.00 m	634.00m
Latitude	29.36^{0}N	32.20^{0}N	34.06^{0}N	32.54^0 N
Longitude	79.40^{0}E	77.00^{0}E	74.51^{0}E	75.09^{0}E
Total Rainfall (mm)	816.00	624.30	178.00	681.90
Average Temp ^{0}C (Max)	28.80	30.10	29.70	32.60
Average Temp ^{0}C (Min)	19.60	19.80	15.40	22.00

Note: Data for maize crop season *kharif* 2011

Result and discussion

The location wise analysis of 21 hybrids indicated significant differences for grain yield in all the four test locations (Table 2). The mean grain yield across the four locations was found to be highest for cross combination FH 3594 (8345 kg/ha). The other hybrids found high yielding in order of rank were FH 3605, FH 3609, EHL 111, FH 3583, EHL 411, EHL 211 and VMH 9 where grain yield was found to be higher than the overall mean (7079 kg/ha) and varied from 8306 kg/ha to 7414 kg/ha. However, only three hybrids namely, FH3594, FH3605 and FH3609 exhibited significantly higher grain yield over the best check hybrid VMH 9 (7414 kg/ha). Thirteen hybrids possessed grain yield lower than the overall mean. Analysis of location mean over all the hybrids indicated that Bajaura (L2) had more conducive environment as it gave highest location mean of 9180 kg/ha whereas Srinagar (L3) had the lowest mean may be because of the prevailing un-favourable environmental conditions not conducive for proper growth and development of maize. It is evident from the data over the locations that the rank of hybrids did not remain the same and changed from one location to another location. The differential response of the hybrids over the locations indicates the existence of G×E interaction for grain yield in single cross maize hybrids evaluated at four locations in north-west Himalayas.

The commonly used method for G×E interaction study is linear regression model of Eberhart and Russell [6]. This model states that a stable genotype should have non-significant deviation from regression. Considering this criterion, a high yielding genotype often gets rejected due to high deviation from

Table 2. Means and rank of maize hybrids tested over four locations

Hybrids	Almora (L1)		Bajaura (L2)		Srinagar (L3)		Udhampur (L4)		Mean	
	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank
FH 3583	8704	1	9718	8	5936	14	7607	6	7991	5
FH 3585	5738	12	9605	10	6057	10	6875	13	7069	9
FH 3586	5093	17	8200	15	6082	8	7535	8	6728	14
FH 3587	6095	9	8228	14	5931	15	6168	16	6606	16
FH 3592	4575	20	7836	18	5771	19	7301	9	6371	18
FH 3594	7887	4	10720	5	6069	9	8703	3	8345	1
FH 3599	5590	14	8563	13	5950	12	8165	5	7067	10
FH 3605	8170	2	11770	3	5712	20	7574	7	8306	2
FH 3606	6104	8	7889	16	5941	13	5911	17	6461	17
FH 3609	7949	3	9733	7	6083	7	9127	1	8223	3
FH 3610	5350	16	9326	11	5854	17	7210	12	6935	12
EHL 111	5496	15	11860	2	5828	18	8785	2	7993	4
EHL 211	5954	10	12170	1	6016	11	5678	18	7453	7
EHL 311	4906	18	6418	20	6237	3	6538	14	6025	19
KDM 957 x KDM 1159	4602	19	6415	21	6298	2	6494	15	5952	20
KDM 1095 x KDM 115	4026	21	7055	19	6106	5	5485	19	5668	21
EHL 411	5680	13	9955	6	5919	16	8690	4	7561	6
EHL 511	6150	7	11020	4	5710	21	5357	20	7059	11
FH 3612	5788	11	7860	17	6086	6	7283	10	6754	13
VMH 9	7337	5	8722	12	6369	1	7228	11	7414	8
VMH 33	6552	6	9711	9	6193	4	4265	21	6680	15
Site mean	6083		9180		6007		7047		7079	
CD (5%)	1206		1046		314		624		798	

regression over the range of environments. It is likely that high deviation from regression may occur when a genotype showing high positive interaction in some environments and negative interaction in others and therefore, the genotype is classified as unstable. However, data analysis with AMMI model [4, 7, 8] provides estimate of total G x E interaction effect of each genotype and also further partitions it into interaction effects due to individual environments. Low G x E interaction of a genotype indicates its stability over the range of environments. A genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment and is therefore best suited to that environment. AMMI analysis also permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes best suited for specific environmental conditions.

AMMI analysis of variance for grain yield data of the 21 maize hybrids evaluated across the four environmental conditions showed significant variance due to hybrids (H), locations (L) and the H x L interaction (Table 3). This pointed out that all sources of variance are important in analysis. However, locations main effect (L) was emerged as the most important source of variance due to its largest contribution (52.79 %) to the total sum of squares (TSS) for grain yield in maize. The contribution of H x L interaction to the TSS was observed to be 28.16% which was larger than those contributed by hybrids (19.10%). This indicated that differences among hybrids mean and rank across environments was largely due to interaction effects [9].

The H x L interaction was further divided into Interaction Principal Component Axes (IPCA). In the present AMMI analysis, three IPCA axes were found to be necessary to explain the whole variance of H x L interaction. The first axis which consisted of 54.73% variance of H x L interaction was noted to be significant. The second and third IPCA accounted for 26.16% and 19.10% of the interaction sum of squares (SS), respectively, were found to be non-significant. The IPCA 1 and IPCA 2 together with had a total of 80.89% variance of the H x L interaction.

Table 3. AMMI ANOVA of maize hybrids for grain yield

Source of variation	DF	SS	MS
Hybrids	20	49830700	24915400*
Locations	3	137636000	45878700*
Hybrid × Location	60	73472300	12245400*
IPCA 1	22	40215200	18279600*
IPCA 2	20	19219600	960982
IPCA 3	18	14037500	779860
Pooled error	160	22603600	141273
Total	83	26093900	

DF: Degree of Freedom, SS: Sum of Squares, MS: Mean Squares, *: Significant at 5% level of probability

The biplot analysis is the most impressive and objective tool in analysis of G x E interaction in AMMI model. The biplots permit easy visualization of differences in interaction effects. In AMMI I biplot, the IPCA1 scores of genotypes and environments are plotted against their respective means whereas in AMMI II biplot, the IPCA1 and IPCA2 scores of genotype and environments are plotted against each other. In the biplot display, genotypes or environments that occupy horizontal line of the AMMI 1 graph had similar mean grain yields and those that fall almost on a perpendicular line had similar interaction [10]. AMMI I biplot analysis for grain yield of the 21 hybrids tested at four locations in the present investigation showed that the relative variability due to hybrids was less than the variability due to locations as indicated by the distribution as well position occupied by the 21 hybrids and 4 environments on biplot display (Fig. 1). Hybrids or locations on the upper half of the horizontal lines have higher grain yield than those on the lower half. Thus, seven out of 21 hybrids namely, FH3594, FH3605, FH3609, FH3583, EHL111, EHL211, EHL411 and VMH 9 were identified to be high yielding with FH3594 being the overall best with grain yield potential of 8345 kg/ha. In contrast, the remaining of the hybrids except FH3585, FH3599 and EHL511 located quite close to horizontal line, were observed to low yielding as they occupied place below the main effect mid line on the biplot. Among the testing locations, Bajaura (L2) was the only location occupied position on the upper half of the midpoint of the main effect axis and seems to be the most favourable environment whereas Almora (L1) and Srinagar (L3) were identified to have relatively unfavorable environments as they occupied positions at lower half of the AMMI 1 biplot. The Udhampur (L4) location exhibited grain yield close to average grain yield and therefore said to be average environment.

Hybrids or locations with large negative or positive IPCA1 scores have high interactions, while those with IPCA1 scores near zero (close to the vertical line) have little interaction across environments [10]. The only hybrid FH3610 fell almost on the vertical line indicating uniform performance across the locations but its grain yield potential is less than the average grain yield. However, it is to mention that five hybrids namely FH3594, FH3609, FH3583, EHL411 and VMH 9 were quite close to IPCA1 axis and also above the midpoint axis of main effect and therefore considered to be stable against the environmental changes with minor positive or negative interactions. The three more hybrids namely FH3605, EHL211 and EHL111 had grain yield above the horizontal main effect line but large negative scores on IPCA 1 and therefore expected to perform better under Bajaura environment but variable performance across the different locations of north-western Himalaya.

The first two IPCA of the AMMI model explained 80.89% of the data variability was used for AMMI II biplot analysis as suggested by Gauch and Zobel [11]. A biplot was generated using hybrids and locations scores of the first two IPCA [12-13] and presented as Fig. 2 to demonstrate the relative magnitude of the H x L for specific hybrids and locations. Purchase and co-workers [8] pointed out that the closer the genotypes score to the center of the biplot, the genotypes are more stable than the score of the genotypes away from the centre. The angles between the genotype and environment vectors determine the nature of the interaction as it is positive for acute angles, negligible for right angles, and negative for obtuse angles. At the same time, the angle formed by the vectors of two environments provided an estimate of their correlation. Perusal of the Fig 2 indicated that the locations Bajaura (L2), Srinagar (L3) and Udhampur (L4) had large interaction as indicated by large scores on both IPCA 1 and IPCA 2 whereas Almora (L1) was quite close to IPCA 1 but large score on IPCA 2. Thus, the distribution of locations on AMMI II biplot exhibited specificity of each environment and large effect on hybrids performance.

Orthogonal projections of the genotypes on the environmental vector showed that hybrids, FH3612, KDM957 x KDM1119, EHL311, KDM1095 x KDM115, FH3587, VMH 9 and FH3606 were adapted to poor yielding environment at Srinagar (L3). Of these, VMH 9 recorded grain yield higher than the other hybrids

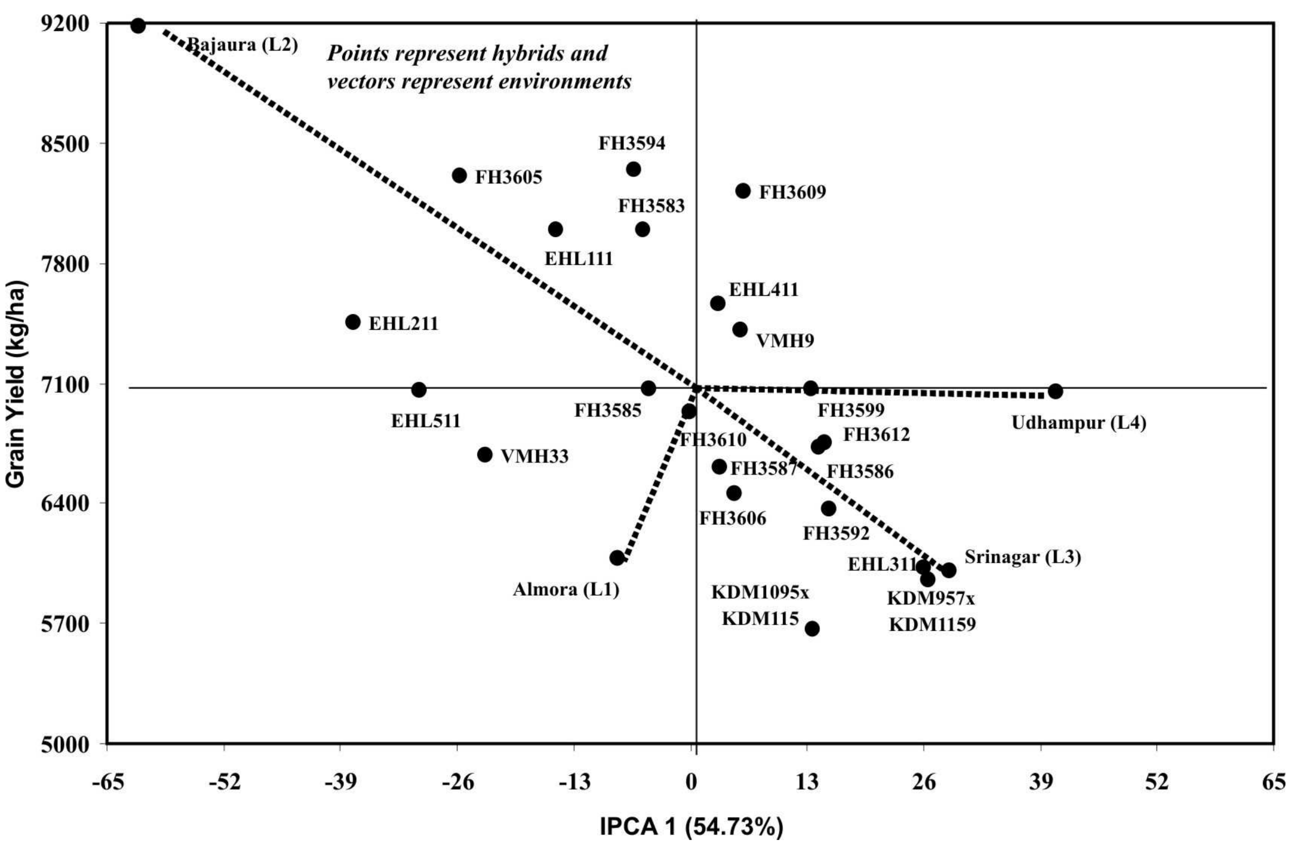

Fig. 1. AMMI I biplot of main effects and G×E interaction of 21 single cross maize hybrids in four environments

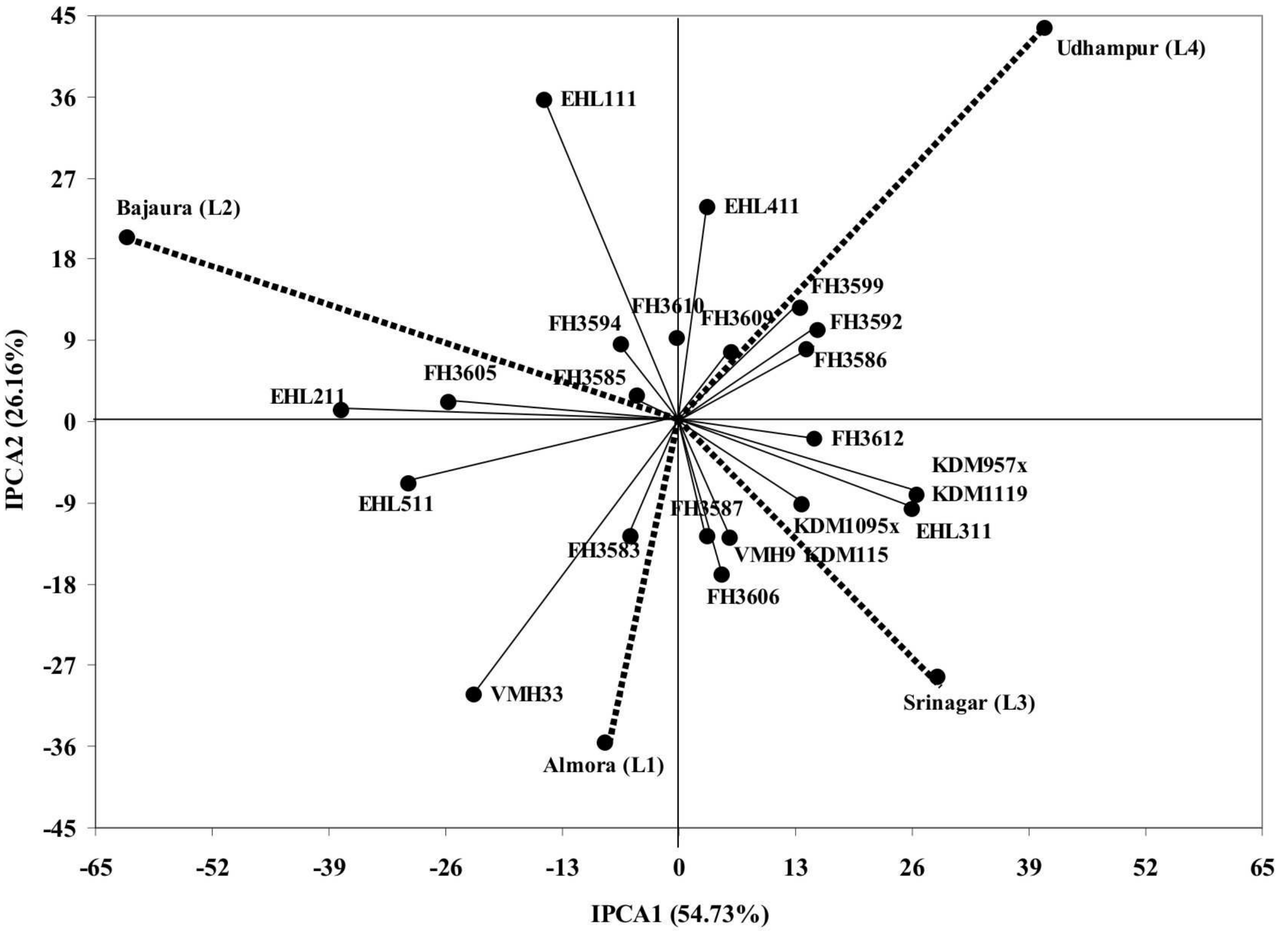

Fig. 2. AMMI II biplot of G×E interaction of 21 single cross maize hybrids in four environments

and thus identified as a potential hybrid for cultivation under the environment of Srinagar (L3). The hybrids FH3599, FH3592 and FH3586 had better adaptability to Udhampur (L4) environment as indicated by close acute angles between the location and hybrids. The hybrids EHL211 and FH3605 mainly associated with negative values of IPCA1 whereas EHL111 correlated with high positive value were found to be adapted to environmental condition of Bajaura (L2) location. All these hybrids had grain yield higher than the overall mean and therefore identified to be potential hybrids for environmental conditions of Bajaura (L2). VMH 33 followed by FH3583 and EHL511 were found to be adapted to Almora environment (L1) however FH3583 of the three hybrids had grain yield higher than the overall mean. The hybrids FH3585, FH3594, FH3609 and FH3610 were found to scattered relatively close to the origin point in the AMMI II biplot indicating minimal interactions of these hybrids with the environments. The grain yield potential of hybrids FH3585 and FH3610 was lower than the average grain yield and therefore did not qualify for stable hybrids. The other two hybrids namely FH3594 and FH3609 had high grain yield as well as low IPCA 1 and IPCA 2 scores and therefore assumed to be high grain yield performance across the locations in north-western Himalayas. The general adaptability of these two high yielding hybrids may be due to diversity of parents, allelic homeostasis and complementation of the grain yield related genes from the parents.

AMMI model has been used earlier to evaluate multi-environment experiments in maize [9-10, 14-17]. AMMI model has also been reported to be better than the site regression analysis because it allows distinguishing the effects of the genotype and the environment and then assessing the G x E interaction in a reduced dimensional space with minimum error [18]. Further, it was opined that use of AMMI model to evaluate multi-environment data are as effective as with the data recorded from two to five times more replications [19].

In summary, analysis of the 21 maize hybrids using AMMI statistical model has shown that the largest proportion of the total variation in grain yield was attributed to environments followed by interaction and hybrid components. The single cross maize hybrids, FH3594 and FH3609 were identified to be high yielding and moderately stable and, therefore, assume to perform well across a wide range of environments. The hybrids, FH3605, EHL211 and EHL111 were identified to be high yielding but specifically adapted to Bajaura location.

Acknowledgement

The authors are grateful to the Project Director (Maize) and the Zonal Coordinator (Zone 1) for providing the data and guidance.

References

1. **Koutsika-Sotiriou M. S. and Karagounis Ch. A**. 2005. Assessment of maize hybrids. Maydica, **50**: 63-70.
2. **Crossa J.** 1990. Statistical analyses of multilocation trials. Adv. Agron., **4**: 55-85.
3. **Yan W., Hunt L. A., Sheng Q. and Szlavnics Z.** 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Sci., **40**: 597-605.
4. **Zobel R. W., Wright M. J. and Gauch H. G.** 1988. Statistical analysis of a yield trial. Agron J., **80**: 388-393.
5. **IRRI.** 2002. IRRISTAT 4.3 for Windows. Tutorial manual. Biometrics units. International Rice Research Institute, Philippines, pp. 182.
6. **Eberhart S. A. and Russell W. A.** 1966. Stability parameters for comparing varieties. Crop Sci., **6**: 36-40.
7. **Gauch H. G. Jr.** 1992. Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Amsterdam, Elsevier, pp. 278p.
8. **Purchase J. L., Hatting H. and Van Deventer C. S.** 2000. Genotype × environment interaction of winter wheat in South Africa: II. Stability analysis of yield performance. South Afric. J. Plant Soil, **17**: 101-107.
9. **Admassu S., Nigussie M. and Zelleke H.** 2008. Genotype-environment interaction and stability analysis for grain yield of maize (*Zea mays* L.) in Ethiopia. Asian J. Plant Sci., **7**: 163-169.
10. **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.
11. **Gauch H. G. and Zobel R. W**. 1996. AMMI analyses of yield trials. *In*: Genotype by Environment Interaction. Kang M. S. and Gauch H. G. (eds.). CRC. Boca Raton, Florida, pp. 85-122.
12. **Vargas M. and Crossa J**. 2000. The AMMI analysis and graphing the biplot. Biometrics and Statistics Unit, CIMMYT.
13. **Gauch H. G. and Zobel R.W.** 1997. Identifying mega-environments and targeting genotypes. Crop Sci., **37**: 311-326.
14. **Betran F. J., Beck D., Banziger M. and Edmeades G. O.** 2003. Genetic analysis of inbred and hybrid grain yield under stress and non stress environments in tropical maize. Crop Sci., **43**: 807-817.
15. **Balestre M., Von Pinho R. G., Souza J. C. and Oliveira R. L.** 2009. Genotypic stability and adaptability in tropical maize based on AMMI and GGE biplot analysis. Genet. Mol. Res., **8**: 1311-1322.
16. **Babic V., Babic M., Ivanovic M., Kraljevic-Balalic M. and Dimitrijevic M**. 2010. Understanding and utilization of genotype-by-environment interaction in maize breeding. Genetica, **42**: 79-90.
17. **Kandus M., Almorza D., Ronceros R. B. and Salerno J. C**. 2010. Statistical models for evaluating the genotype-environment interaction in maize (*Zea mays* L.). Int. J. Exp. Bot., **79**: 39-46.
18. **Gauch H. G. Jr**. 2006. Statistical analysis of yield trials by AMMI and GGE. Crop Sci., **46**: 1488-1500.
19. **Gauch H. G. and Zobel R. W.** 1988. Predictive and postdictive success of statistical analyses of yield trials. Theor. Appl. Genet., **76**: 1-10.