Assessment of $G \times E$ Interactions in Maize ($Zea mays$ L.) Hybrids for Yield using AMMI and GGE Models

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Abstract

Background: In the wake of unpredictable climate change, it is imperative for the breeders to identify hybrids with better adaptation to meet the growing food demand. The present study was carried out to identify stable maize hybrids across various environments.

Methods: Twenty one maize hybrids along with two commercial checks viz., CP-818 and Bioseed-TX369 were tested over three locations viz., Viluppuram, Trivandrum and Nagercoil. The experiments were laid out in randomized block design with three replications.

Result: AMMI and GGE analysis of variance revealed that the first two principal axes explained the majority of $G \times E$ interaction. According to AMMI analysis, the hybrid AUK 6240 was relatively stable with high mean whereas, GGE biplots-genotype view identified AUMH 1277 as stable with better yield per plant. GGE biplot-environment view identified Nagercoil as the ideal test location. What-won-where biplots identified three hybrids viz., AU-101, AU-110 and CP-818 suited to Viluppuram and Nagercoil. Though, hybrids with specific adaptability and ideal test location were efficiently identified, study must be extended to more number of environments and hybrids.

Key words: AMMI stability value, GGE biplots, Principal components, Stability, Yield stability index.

Introduction

Maize is a highly flexible crop which is grown over a multitude of agro-climatic conditions. Maize, being a widely grown crop across the globe and staple crop for most of the African counties holds a key role in ensuring food security (Legesse et al., 2018). As a multipurpose crop, maize is used as food, feed and fodder. The genetic potential of maize to produce high yield under wide range of environment is what makes this cereal crop “queen of cereals” (Arunkumar et al., 2020). Maize contributes a major share into the global food bowl and more than 150 Mha of maize is cultivated, accounting for nearly 36% of the total food grain production (Sah et al., 2020). The adoption of high yielding maize hybrids instead of traditionally used open pollinated varieties (OPV) has contributed vastly towards a quantum jump in production (Arunkumar et al., 2020).

Maize hybrids have increased the production over the years however, the yield of any hybrids across various environments are inconsistent. In maize along with production and productivity, adaptation of hybrids is also a priority (Ararsa et al., 2016). Any hybrid performance is a product of genotype and its growing environment. The differential response of genotype in different environment or the change in rank of genotypes is due to the interaction between genotype and environment (Yan and Tinker, 2006). A non-significant GEI is a direct indication of genetic potential of a genotype in expression of a trait, whereas a significant GEI masks the genotypic contribution in trait expression (Mafouasson et al., 2018). A hybrid should perform in an uniform manner across environments, if it is to remain commercially viable (Legesse et al., 2018). Thus, high yielding hybrids must be evaluated for stability in suitable test locations before their release (Ndhllela, 2012). A test location must be a representative location of a particular region where the hybrid is intended to be released.

Assessment of $G \times E$ interaction can be carried out using both univariate and multivariate analysis. Most commonly employed univariate methods are Finlay and Wilkinson model (1963) and Eberhart and Russell model (1966). The major drawback with this approach is that, it does not recognize major proportion of GEI effect as the regression analysis is mainly based on linearity among variables, whereas GEI is multivariate in nature (Akpan and Udoh, 2017). The most reliable approach for stability analysis is the multivariate model of AMMI and GGE (Badu-Apraku et al., 2012). AMMI combines both additive type of ANOVA and principal component analysis which is highly efficient in explaining majority of $G \times E$ interaction (Ebdon and Gau, 2002). The biplots helps to visualize the winning genotype and their relationship with environment in a single vector.
technique (Gauch, 2006). A modification from AMMI is GGE biplots which has been used to distinguish the environments on a much better sense (Yan et al., 2000). GGE biplots can identify representative location and location specific genotypes (Yan and Holland, 2010). Considering these, the present investigation was carried out to identify stable maize hybrids for yield and their interaction with various environments using AMMI and GGE model.

MATERIALS AND METHODS
The present investigation on G × E interaction was conducted using twenty one hybrids obtained from Faculty of Agriculture, Annamalai University and two commercial hybrids were used as checks. The particulars of these hybrids are given in Table 1. The experiment was carried out in three different locations viz., Viluppuram (E1), Trivandrum (E2) and Nagercoil (E3), India during Kharif season (June-July), 2017. The maize hybrids were laid out in a randomized block design with three replications with a standard spacing of 60 cm inter and 30 cm intra rows. All management practices such as, sowing, nutrient application, irrigation and weeding were carried out as per the recommendations of each environments.

Observations were recorded on the trait yield per plant from five randomly selected plants of each hybrid per replication. Data collected was analysed using PB tools vers. 1.3 to obtain combined ANOVA, AMMI and GGE biplots. AMMI stability value and yield stability index was estimated by using formulae described by Purchase (2000) and Kang (1993). ASV and YSi was calculated using R program 1.2.5.

RESULTS AND DISCUSSION
Combined analysis of variance revealed highly significant (p<0.001) mean sum of squares for environment, genotypes and genotype × environment interaction (Table 2). The significant main effect of genotypes indicated the possibility of selection of a stable hybrid from the lot, whereas the significance in main effect of environment indicated three distinct locations from each other. The significant G × E interaction meant that the environment had a definite effect on the growth and development of maize hybrids (Alberts, 2004). Hence, this set of experiment justified the use of AMMI and GGE for stability analysis.

Analysis of variance for AMMI model partitioned the genotype by environment interaction effects into interaction principal component analysis (IPCA) where the first two principal component axes explained the total variation due to G × E interaction (Table 4). Both IPCA1 and IPCA2 were highly significant, hence AMMI prediction model involving these two principal axes would be reliable (Ararsa et al., 2016). Analysis of variance for GGE model partitioned the main and interaction effects into three interaction principal component analysis (Table 3). All the three principal axes were highly significant. The first two principal components explained 89.6 per cent of total variation. Thus, GGE biplots were plotted based on IPCA1 and IPCA2.

AMMI biplots for yield per plant
In AMMI biplot 1, IPCA scores for both genotype and environment main effect were plotted against the mean value of yield per plant (Fig 1). This biplot provided the prevailing association between environment and genotype. The genotypes present in the farthest right of the biplots are high yielding, whereas those present in the farthest left are low yielding. Hybrid AU 101 (G9) recorded the highest mean value and the least mean value was recorded by the genotype A 9133 (G1). Genotypes with IPCA 1 score closer to zero are considered to be stable across environments, whereas genotypes with higher IPCA scores (either positive or negative) are suited to specific environment. The hybrid AUMH 8855 (G8) was very close to IPCA axis followed by AU 114 (G13), AUMH 1277 (G8) and AUK 6240 (G6), hence could be considered as stable hybrids. AU 114 is more preferable, as it had higher mean value for yield per plant. Hybrids such as, AU 110 (G12) and CP 818 (G22) were close to each other and had similar projection indicating their similarity in yield and interaction with environments. Out of

Table 1: List of maize hybrids used for stability analysis.

| Genotypes | Name             | Source                  |
|-----------|------------------|-------------------------|
| G1        | AUMH-1277        | Annamalai University    |
| G2        | AUMH-1247        | Annamalai University    |
| G3        | AUMH-007         | Annamalai University    |
| G4        | AUK-6240         | Annamalai University    |
| G5        | AUK-30           | Annamalai University    |
| G6        | A-3501           | Annamalai University    |
| G7        | A-3401           | Annamalai University    |
| G8        | AUC-751          | Annamalai University    |
| G9        | AUMH-8855        | Annamalai University    |
| G10       | AU-6668          | Annamalai University    |
| G11       | A-9133           | Annamalai University    |
| G12       | AU-101           | Annamalai University    |
| G13       | AU-102           | Annamalai University    |
| G14       | AU-104           | Annamalai University    |
| G15       | AU-107           | Annamalai University    |
| G16       | AU-108           | Annamalai University    |
| G17       | AU-110           | Annamalai University    |
| G18       | AU-111           | Annamalai University    |
| G19       | AU-113           | Annamalai University    |
| G20       | AU-114           | Annamalai University    |
| G21       | AU-105           | Annamalai University    |
| G22       | CP-818           | CP Seeds Pvt. Ltd.     |

Table 2: Combined analysis of variance for yield per plant.

| Source of variation | df  | SS       | MSS   |
|---------------------|-----|----------|-------|
| Environment         | 2   | 116469   | 58234*** |
| Replication (ENV)   | 6   | 11655    | 1943*** |
| Genotype            | 22  | 108773   | 4944*** |
| Environment:Genotype| 44  | 83552    | 1899*** |
| Residuals           | 132 | 50982    |       |

Significant level; Pr<0.01: *, Pr<0.001: **, Pr<0.000: ***
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Table 3. Analysis of variance of AMMI and GGE model for yield per plant.

| Source of variation | df  | SS     | MSS      | % Explained | Cumulative % |
|---------------------|-----|--------|----------|-------------|--------------|
| IPCA1               | 23  | 33276.8| 1446.82***| 59.7        | 59.7         |
| IPCA2               | 21  | 22424.4| 1067.83***| 40.3        | 100          |
| IPCA3               | 19  | 0      | 0        | 0           | 100          |

Table 4. Quantification of AMMI biplots and ranking of maize hybrids.

| Hybrids    | Graph ID | Mean Yield (g) | Rank (Yield) | IPCA1 | IPCA2 | ASV | Rank (ASV) | YSI |
|------------|----------|----------------|--------------|-------|-------|-----|------------|-----|
| AUMH-1277  | G1       | 189.72         | 7            | 0.971 | -3.583| 3.862| 13          | 20  |
| AUMH-1247  | G2       | 191.98         | 6            | 2.435 | -3.809| 5.251| 19          | 25  |
| AUMH-007   | G3       | 171.93         | 11           | -2.815| -2.978| 5.130| 17          | 28  |
| AUK-6240   | G4       | 172.08         | 10           | 0.866 | 0.987 | 1.620| 2           | 12  |
| AUK-30     | G5       | 147.33         | 20           | 2.218 | 2.184 | 3.950| 14          | 34  |
| A-3501     | G6       | 140.72         | 22           | -0.805| 1.428 | 1.862| 3           | 25  |
| A-3401     | G7       | 182.42         | 8            | -2.508| 2.581 | 4.529| 16          | 24  |
| AUC-751    | G8       | 153.21         | 16           | 0.979 | 1.557 | 2.130| 4           | 20  |
| AUMH-8855  | G9       | 149.11         | 19           | -0.010| 1.553 | 1.553| 1           | 20  |
| AU-6668    | G10      | 156.55         | 14           | -1.791| 1.949 | 3.295| 9           | 23  |
| A-9133     | G11      | 136.19         | 23           | -2.150| 1.525 | 3.536| 11          | 34  |
| AU-101     | G12      | 215.81         | 1            | 2.688 | 2.049 | 4.484| 15          | 16  |
| AU-102     | G13      | 164.24         | 13           | 1.644 | 0.496 | 2.490| 5           | 18  |
| AU-104     | G14      | 149.28         | 18           | -1.881| -0.966| 2.954| 7           | 25  |
| AU-107     | G15      | 154.7          | 15           | -3.467| -0.694| 5.191| 18          | 33  |
| AU-108     | G16      | 196.73         | 4            | -3.760| -2.216| 6.003| 21          | 25  |
| AU-110     | G17      | 203.94         | 3            | 4.073 | -0.335| 6.053| 22          | 25  |
| AU-111     | G18      | 176.22         | 9            | -2.195| 0.650 | 3.321| 10          | 19  |
| AU-113     | G19      | 143.95         | 21           | -0.620| 3.559 | 3.676| 12          | 33  |
| AU-114     | G20      | 194.6          | 5            | -0.408| -2.892| 2.955| 8           | 13  |
| AU-105     | G21      | 170.28         | 12           | -1.165| -1.899| 2.568| 6           | 18  |
| CP-818     | G22      | 205.59         | 2            | 4.184 | -2.531| 6.705| 23          | 25  |
| BIOSEED-TX369 | G23    | 150.27         | 17           | 3.516 | 1.386 | 5.399| 20          | 37  |

IPC A - Interacting principal component axis, ASV - AMMI stability value, YSI - Yield stability index
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would be stable across environments and the hybrids with least yield stability index (YSi) would be the most stable with better response (Bose et al. 2013). Mean, IPCA scores, ranking of mean, ASV and YSi of twenty three hybrids are given in Table 4.

AMMI stability value was lowest in hybrid AUMH 8855 (G9) followed by AUK 6240 (G4), A 3501 (G6) and AUC 751 (G8), indicating stable performance across the environments. However, only AUK 6240 recorded mean value higher than grand mean. Lowest values for yield stability index was recorded by three hybrids viz., AUK 6240 (G4), AU 114 (G20) and AU 101 (G12), indicating high yield with better stability. However, apart from AUK 6240 other two hybrids recorded higher ranks for AMMI stability value. From the findings of AMMI model, it is found that the hybrid AUK 6240 was relatively stable across environments with high mean. The hybrids AU 114 and AU 101 could be stable in specific environment for yield per plant.

**Genotype by Genotype-environment (GGE) biplots**

GGE biplot-environment view for yield per plant revealed the discriminating and representative environment among the three locations (Fig 3). Average environment axis represents both mean and stability parameters of the three locations. The arrow pointing is the direction of AEA and the small concentric circle indicates the ideal location. Any environment vector which makes a small angle with AEA is considered to be the representative location for every other location studied (Oyekunle et al., 2017). In this study, Nagercoil (E3) had the smallest angle with AEA and it was projected right inside the ideal environment region. Hence, Nagercoil can be considered as the representative location among the three environments. Length of environment vector depicts the standard deviation within an environment (discriminating power of that particular environment). The magnitude of vector length indicates the ability of any environment to differentiate between genotypes (Yan et al., 2010). The environment with higher vector length and small angle with AEA are suitable for genotype selection. The vector length was more in Nagercoil (E3) than others and also it had the smallest angle. Hence, this location is the ideal test location for maize hybrids.

GGE biplot-genotype view for yield gave insights on the yield stability of maize hybrids in comparison with the average environment axis (Fig 4). The AEA points towards the high yielding region and the genotypes falling under these concentric circles have higher mean values for yield across the three environments (Kumar et al., 2014). Double headed arrow in the middle separates the hybrids with above average yield and below average yield across environments. Stability of hybrids is determined by the length of projection of each hybrid on to the double headed arrow. Stable hybrids will have projection of smaller length, whereas unstable hybrids will have projection of greater length (Oyekunle et al., 2017). In this biplot, the hybrids AU 101 (G12) and CP 818 (G22) were falling under ideal genotype region but had...
projection of greater length indicating their poor stability. The hybrid AUMH 1277 (G₁) had the projection of smallest length indicating better stability and above average yield. What-won-where biplot clearly showed the hybrids suitable for specific environments (Fig 5). The hybrids present at the vertex of polygon in each sector will have high mean yield under the environment falling in the same sector (Yan et al., 2000). The sectors with no environment will have genotypes that are low yielders in either some locations or at all locations (Oyekunle et al., 2017). In this study, the hybrids AU 110 (G₁₁), AU 101 (G₁₂) and CP 818 (G₂₂) are the vertex hybrids and these hybrids are best suited for two environments viz., Viluppuram (E₁) and Nagercoil (E₃). Both Viluppuram and Nagercoil were placed under same sector forming a mega-environment. The hybrid AU 108 (G₁₆) is best suited to Trivandrum (E₂).

CONCLUSION

In view of both AMMI and GGE model, there is no clear winning hybrid which is both high yielding and stable. Though AMMI analysis revealed AUK 6240 could be relatively stable with mean value above grand mean, GGE analysis was not in agreement with the above result. Thus further studies are required to develop maize hybrids with stability over a wide range of environments. Out of the twenty three hybrids, AU 101 and AU 114 were identified as stable for yield in specific environments. Nagercoil was identified as the ideal test location for screening of maize hybrids.

REFERENCES

Akpan, E.A. and Udoh, V.S. (2017). Evaluation of cassava (Manihot esculenta crantz) genotype for yield and yield component, tuber bulking, early maturity in cross river basin flood plains. Canadian Journal of Agriculture and Crops. 2(2): 68-73.

Alberts, M.J.A. (2004). Comparison of statistical methods to describe genotype x environment interaction and yield stability in multi-location maize trials. M. Sc. Thesis, University of the Free State. pp. 96.

Ararsa, L., Zeleke, H., Nigusse, M. (2016). Genotype by environment interaction and yield stability of maize (Zea mays L.) hybrids in Ethiopia. Journal of Natural Sciences Research. 6(13): 93-101.

Arunkumar, B., Gangapp, E., Ramesh, S., Savithramma, D.L., Nagaraju, N., Lokesh, R. (2020). Stability analysis of maize hybrids for grain yield and its attributing traits using Eberhart and Russel model. Current Journal of Applied Science Technology. 39(1): 52-63.

Badu-Apraku, B., Oyekunle, M., Obeng-Antwi, K., Osuman, A.S., Ado, S.G., Coulby, N., Yallou, C.G., Abdul, M., Baoyewa, G.A., Didjeira, A. (2012). Performance of extra-early maize cultivars based on GGE biplots and AMMI analysis. Journal Agricultural Sciences. 150: 473-483.

Bose, L.K., Jambhulkar, N.N., Pande, K., Singh, O.N. (2013). Use of AMMI and other stability statistics in the simultaneous selection selection of rice genotypes for yield and stability under direct seeded conditions. Chilean Journal of Agricultural Research. 74(1): 3-9.

Ebdon, J.S. and Gauch, H.G. (2002). Additive main effects and multiplicative interaction analysis of national turfgrass performance trials. Crop Science. 42: 497-506.

Eberhart, S.A. and Russell, W.A. (1966). Stability parameters for comparing varieties. Crop Science. 6: 36-40.

Finlay, K.W. and Wilkinson, G.N. (1963).The analysis of adaptation in a plant breeding programme. Australian Journal of Agricultural Research. 14: 742-754.

Gauch, H.G. (2006). Statistical analysis of yield trials by AMMI and GGE. Crop Science. 46: 1488-1500.

Gauch, H.G. and Zobel, R.W. (1996). Identifying mega-environments and targeting genotypes. Crop Science. 37: 311-326.

Kang, M.S. (1993). Simultaneous selection for yield and stability in...
crop performance trials: Consequences for growers. Agronomy Journal. 85: 754-757.
Kumar, R., Singode, A., Chikkappa, G.K., Mukri, G., Dubey, R.B., et al. (2014). Assessment of genotype × environment interactions for grain yield in maize hybrids in rainfed environments. SABRAO Journal of Breeding and Genetics. 46(2): 284-292.
Legesse, W., Keno, T., Tadesse, B., Bogale, G., Wold, A.T., Abebe, B. (2018). Mega-environment targeting of maize varieties using Ammi and GGE biplots analysis in Ethiopia. Ethiopian Journal of Agricultural Sciences. 28(2): 65-84.
Mafouasson, H.N.A., Gracen, V., Yeboah, M.A., Ntsefong, G.N., Tandzi, L.N., Mutengwa, C.S. (2018). Genotype by environment interaction and yield stability of maize single cross hybrids developed from tropical inbred lines. Agronomy. 62(8): 1-17.
Ndhlela, T. (2012). Improvement strategies for yield potential, disease resistance and drought tolerance of Zimbabwean maize inbred lines; Department of Plant Sciences (Plant Breeding), University of the Free State: Bloemfontein, South Africa, pp. 295.
Oyekunle, M., Haruna, A., Badu-Apraku, B., Usman, I.S., Mani, H., Ado, S.G., Olaoye, G., Obeng-Antwi, K., Abdulmalik, R.O., Ahmed, H.O. (2017). Assessment of early maturing maize hybrids and testing sites using GGE biplot analysis. Crop Science. 57: 2942-2950.
Purchase, J.L., Hatting, H., van Deventer, C.S. (2000). Genotype × environment interaction of winter wheat (Triticum aestivum L.) in South Africa: II. Stability analysis of yield performance. South African Journal of Plant and Soil. 17: 101-107.
Sah, R.P., Chakraborty, M., Prasad, K. et al. (2020). Impact of water deficit stress in maize: Phenology and yield components. Scientific Reports. 10: 2944.
Yan, W., Fregeau-Reid, J., Pageau, D., Martin, R., Mitchellfetch, J., Etienne, M., et al. (2010). Identifying essential test locations for oat breeding in Eastern Canada. Crop Science. 50: 504-515.
Yan, W. and Holland, K.J.B. (2010). A heritability-adjusted GGE bi-plot for test environment evaluation. Euphytica. 171: 355-369.
Yan, W., Hunt, L.A., Sheng, Q., Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on GGE biplots. Crop Science. 40: 597-605.
Yan, W. and Tinker, N.A. (2006). Biplot analysis of multienvironment trial data: Principles and applications. Canadian Journal of Plant Science. 86: 623-645.