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Short Communication

GGE biplot analysis for grain yield of single cross maize hybrids under stress and non-stress conditions

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Abstract

In AMMI analysis environment main effect and genotype × location interaction were found significant. Significant differences in maize hybrids were observed for grain yield among the locations over the years both under stress and non-stress conditions. Among the four interaction principal component axes (IPCA) of GGE biplot, first two IPCA were significant explaining 75.89 % variation. Hybrid, KDMI-15 × NEI-9202-B was found superior among all the hybrids over checks over all the locations. Other hybrids *viz*., CM-111 × HYD SEL-15 and CI-4 × NEI-9202-B exhibited almost no interaction with the environments convincing the reliability of their performance. The hybrids *viz*., KDMI-15 × NEI-9208-B, CM-111 × HYD SEL-17, 900M, CML-446 × HYD SEL-4, CI-4 × HYD SEL-17, HYD SEL-7 × KDMI-15 and HYD SEL-15 × HYD SEL-17 were most responsive.

Key words: G × E interactions, biplot, multi-environment trial, AMMI analysis

Maize (*Zea mays* L.) is the third most important cereal crop in India after wheat and rice. The demand for maize has considerably increased due to the expansion in the poultry and livestock industries (Edmeades 2013). Drought has major implications on grain yield due to gradual climate change and the variation in climatic extremes in the short period (Edmeades 2013). Increased temperatures are also an important concern because the major maize producing areas may become warmer, drier and subjected to an evolving array of diseases and pests that are new to those areas (Betran et al. 2003). Genotype × environment interactions are a challenge to plant breeders because they cause difficulties in selecting genotypes evaluated in diverse environments. When G×E interaction is significant, its cause, nature, and implications must be carefully considered (Kang and Gorman 1989). The G×E interaction reduces the correlation between phenotypic and genotypic values, and has been shown to reduce progress from selection (Comstock and Moll 1963). The GEI in multi-location trials complicates the identification of superior genotypes for a single location, because magnitudes of genotype by location interaction are often greater than genotype by year interaction (Badu et al. 2003). Grain yield is quantitative in nature and routinely exhibit GEI. This necessitates genotype evaluation in multi-environments trials (MET) in the advanced stages of selection (Annicchiarico 2002).

Several stability statistics used to partition genotype × environment interaction include regression analysis (Gauch 1988), multivariate analysis (Westcoff 1987) and cluster analysis (Crossa et al. 1991) etc. In recent years, additive main effect and multiplicative interaction (AMMI) model is also being used (Gauch 1992). However, the GGE-biplot is a powerful technique that allows visual examination of the GE interaction pattern of MET data. The GGE-biplot

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methodology applied in maize has revealed some useful results for evaluating the maize genotypes and hybrids (Betran 2003; Jha et al. 2013). Therefore, a study was undertaken to study the efficacy of the test sites using the GGE-biplot technique and to investigate the stability performance of different maize hybrids under stress and non stress conditions.

The material comprised of 23 single cross maize hybrids selected from 66 hybrids synthesized by using 12 inbred lines that varied for drought tolerance (Kuchanur et al. 2013). These 23 hybrids were evaluated along with check hybrids during 2008 and 2009 at Bhemarayanagudi under managed stress, and non-stress in 2008 and 2009, Hagari under managed stress in 2009 and Arabhavi during *kharif* 2009 under normal conditions. The hybrids under non-stress conditions received recommended cultural practices besides regular furrow irrigation at an interval of 10-12 days to avoid water-stress. The same genotypes under stress condition received recommended cultural practices but irrigation up to 40 days after sowing and no irrigation there after till harvest so that they experienced moisture stress during flowering and grain filling period. The experiments were laid out in a Randomized Complete Block Design with two replicates. Data on yield was recorded and used for statistical analysis.

Data was analysed using analysis of variance to determine the contribution of genotypes, location and their interaction. Statistical analysis for ANOVA and AMMI model was done using Windowstat 8.0. The AMMI statistical model is a hybrid model which makes use of standard ANOVA procedure to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then uses a multiplicative procedure - Principal Component Analysis (PCA) to extract the pattern from the G x E portion of ANOVA analysis. The resulting statistical model is a hybrid of the two models and results in a least squares analysis with graphical representation of the numerical results (Biplot analysis), which often allows interpretation of the underlying causes of G x E interaction (Zobel et al. 1988; Gauch 1993).

The combined analysis of variance for the grain yield of the hybrids evaluated over two years across the three locations showed highly significant differences for environment, genotype × environment interaction indicating major contributions of environment and genotype × environment interaction to the total variance. However, the environmental conditions prevailed during experimental period had the highest contribution (87.67%) compared to GE interaction (9.67%) and hybrids (2.34%) towards total variation. The percentage contribution of environment to the total variation is an indication that climatic condition is one of the major factors that influences yield performance of these hybrids as also observed earlier (Grand and Ciulca 2013). A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing most of the variation in maize yield.

Further, the results of AMMI analysis showed that GE interaction component was divided into four IPCA axes. Among the four IPCA first and IPCA second were significant, which explained about 49.13 and 26.76 per cent variance, respectively and together explained 75.89 per cent variation. By plotting the hybrids and years on the same graph the associations between the hybrids and years can be seen clearly. The IPCA score of a genotype in the AMMI analysis is an indication of the stability or adaptation of genotype over environments. The greater the IPCA scores, either negative or positive, the more specific adapted is a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotype is over all the environments sampled. Genotypes that are close to each other tend to have similar performance and those that are close to one year indicate their better adaptation to that particular climate conditions.

In AMMI biplot, the IPCA1 score of hybrids and environment are plotted against their respective means. The AMMI graph showed that relative variability explained by hybrids were less compared to environments (Fig.1). Majority of the hybrids occupied similar position in graphs, whereas, environments were highly scattered as indicated by biplot display. In biplots, the hybrids *viz*., CM-111 × HYD SEL-15, NEI-9208-B × HYD SEL-15, CI-4 × NEI-9202-B, CM-111 × CI-4 and check 900M showed low IPCA score and mean yield was above the average except 900M indicating less GE and their stability. Some of the hybrids had higher mean yield compared to average yield but their IPCA scores were higher indicating highly interactive nature. Among all the hybrids, KDMI-15 × NEI-9202-B with higher IPCA1value ranked first was specifically adapted to conditions at Bhemarayanagudi in 2008 under non-stress.

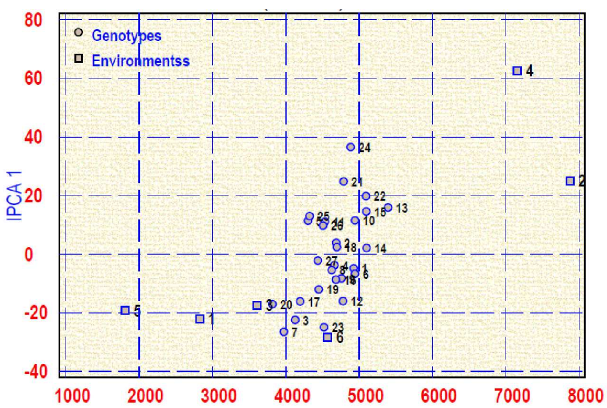

Fig. 1. AMMI I biplot for mean yield and IPCA1 of maize hybrids

In mega-environment analysis, all the testing environments occupied different positions in the biplot analysis. The testing environments at Bhemarayanagudi under non-stress non-stress conditions during 2008 and 2009 occupied the position above the average grain yield values signifying favorable environments for high yield. Whereas environments under managed stress at Bhemarayanagudi in 2009 and at Hagari in 2009 occupied the position below the average grain yield indicating low yielding and unfavorable environments. The environment Arabhavi 2009 *kharif* normal presented very near mid value and therefore, said to be an average environment (in Arabhavi 2009 *kharif* normal low yield was mainly due to heavy rain fall during grain filling stage leading to water logged conditions for few days). The differences in environments were mainly due to the crop grown both under stress and non-stress conditions.

Since IPCA2 score also played significant contribution (26.67 %) in explaining GE interaction (Gauch and Zobel 1996), the IPCA1 scores were plotted against the IPCA2 scores to further explore the adaption. A biplot is generated using genotypic and environmental scores of the first two AMMI components (Vargas and Crossa 2000). Furthermore, It was pointed out that the closer the genotypes score to the center of the biplot, the more stable they are (Purchase et al. 2000). When IPCA1 was plotted against IPCA2 (Fig. 2), hybrids *viz*., CM-111 × HYD SEL-15, CI-4 × NEI-9202-B, HYD SEL-2 × KDMI-15, NEI-9208-B × HYD SEL-15, CM-111 × CI-4, CI-4 × HYD SEL-4, HYD SEL-7 × NEI-9202-B, HYD SEL-2 × HYD SEL-17 and HYD SEL-10 × NEI-9202-B were found closer or at proximity to the center of the biplot compared to other genotypes. Although hybrid KDMI-15 × NEI-9202-B achieved the highest and better mean yield compared others but it exhibited the highest interaction with the environments (IPCA 1 score), sinking the reliability of its performance. On the other hand hybrids CM-111 × HYD SEL-15 and CI-4 × NEI-9202-B exhibited almost no interaction with the environments (IPCA 1 score) convincing the reliability of its performance.

The biplot representing a polygon view (Fig. 2) having some vertex hybrids while the rest are inside the polygon. These vertex hybrids are supposed to be the most responsive since they have they are farthest from the biplot origin. Responsive hybrids are either best or the poorest at one or all locations (Yan and Rajcan 2002). Hybrids *viz*., Arjun, Allrounder, KDMI-15 × NEI-9208-B, CM-111 × HYD SEL-17, 900M, CML-446 × HYD SEL-4, CI-4 × HYD SEL-17, HYD SEL-7 × KDMI-15 and HYD SEL-15 × HYD SEL-17 present away from origins were unstable in performance and highly interacting with environments, as indicated in biplots. Based on the GGE biplot analysis, six environments fell into four different sectors with different high yielding hybrids (Fig. 2). The environments Bhemarayanagudi-2008-stress and Arabhavi-2009–*kharif* normal (heavy rains created water logged condition during grain filling stage) were part of similar clusters with marginal variation and Bhemarayanagudi-2009- managed stress and Hagari-2009- managed stress fell in similar cluster indicating the performance of hybrids in these locations not much different. Whereas environment Bhemarayanagudi-2008-non-stress and Bhemarayanagudi-2009-non-stress formed separate clusters.

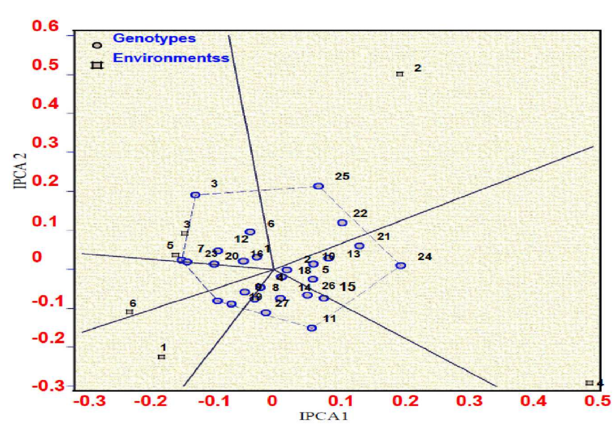

Fig. 2. AMMI II biplot genotype × environment interaction of maize hybrids

In summary, analysis of the 27 single cross maize hybrids using AMMI model showed that higher proportion of variation explained by environment compared to GEI and genotypes. The consistency in stabnility of a cultivar is affected by GEI, which determines superiority of individual genotypes across the range of encironments (Purchase et al. 2000; Jha et al. 2013). However, the GEI reduces the correlation between genotype and phenotype making difficult to judge the potential of a genotype (Sharma et al. 1987). The KDMI-15 × NEI-9202-B was found superior among all the hybrids over checks over all the locations. However, it was highly interactive with environment. On the other hand hybrids CM-111 × HYD SEL-15 and CI-4 × NEI-9202-B exhibited almost no interaction with the environments (IPCA 1 score) convincing the reliability of its performance. The hybrid, KDMI-15 × NEI-9202-B with higher IPCA1value ranked first was specifically adapted to Bhemarayanagudi-2008-non-stress.

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