

Graphic Analysis of Genotype by Environment Interaction for Maize Hybrid Yield using Site Regression Stability Model

Saeed Safari Dolatabad, Rajab Choukan

Abstract—Selection of maize (*Zea mays*) hybrids with wide adaptability across diverse farming environments is important, prior to recommending them to achieve a high rate of hybrid adoption. Grain yield of 14 maize hybrids, tested in a randomized complete-block design with four replicates across 22 environments in Iran, was analyzed using site regression (SREG) stability model. The biplot technique facilitates a visual evaluation of superior genotypes, which is useful for cultivar recommendation and mega-environment identification. The objectives of this study were (i) identification of suitable hybrids with both high mean performance and high stability (ii) to determine mega-environments for maize production in Iran. Biplot analysis identifies two mega-environments in this study. The first mega-environments included KRM, KSH, MGN, DZF A, KRJ, DRB, DZF B, SHZ B, and KHM, where G10 hybrid was the best performing hybrid. The second mega-environment included ESF B, ESF A, and SHZ A, where G4 hybrid was the best hybrid. According to the ideal-hybrid biplot, G10 hybrid was better than all other hybrids, followed by the G1 and G3 hybrids. These hybrids were identified as best hybrids that have high grain yield and high yield stability. GGE biplot analysis provided a framework for identifying the target testing locations that discriminates genotypes that are high yielding and stable.

Keywords—*Zea mays* L, GGE biplot, Multi-environment trials, Yield stability.

I. INTRODUCTION

NEW genotypes generally need to be tested at many locations and for several years before being recommended for production for a given area. To achieve this goal, multi-environmental trials (MET) are conducted annually for all major crops throughout the world with the purpose of identifying superior genotypes for the target locations [2]. The measured grain yield for each cultivar in each test environment is in fact a measure of the environment main effect (E), the genotype main effect (G), and the genotype \times environment (GE) interaction [12]. The GE interaction results from the differential responses of genotypes across a range of environments [1]-[5]-[6].

Reference [9] developed a GGE biplot methodology for graphical analysis of multi-environment trial data. GGE refers to genotype main effect (G) plus genotype by environment interactions (GE), which are the two sources of variation that are relevant to genotype evaluation. A biplot is a plot that simultaneously displays the effects of genotypes and the environment [3]. The GGE biplot is a biplot that displays the GGE of multi-environment trial data. It is constructed by plotting the first two principal components (PC1 and PC2) derived from singular value decomposition of the environment-centered data.

Models that decompose the environment-centered data are commonly referred to as sites regression models [10]. The objectives of this study were (i) identification of suitable hybrids with both high mean performance and high stability (ii) to determine mega-environments for maize production in Iran.

II. MATERIALS AND METHODS

A. Experimental Locations and Plant Material

Data used in this study were obtained from the national maize multi-environment yield trials. These trials were conducted in two years (2006 and 2007) by the Seed and Plant Improvement Institute, Iran. Each year, 14 maize hybrids (Table I) were grown and tested in 9 field stations in different regions in Iran.

These stations were the Moghan (MGN) field station in the northwestern, Karaj (KRJ) field station in the northern, Esfahan (ESF) field station in the center, Shiraz (two sowing dates, SHZ A and SHZ B) field station, Darab (DRB) field station, and Kerman (KRM) field station in the southern, Khoramabad (KHM), and Kermanshah (KSH) field stations in the western, and Dezfol (two sowing dates, DZF A and DZF B) field station in the southwestern part of the country. In each location a randomized complete block design with four replicates were used.

Plots, consisting of two rows (9 m² with row spacing at 75 cm and plant spacing at 35 cm) were hand planted and harvested. Plots were initially over-planted and later thinned to two plants per hill. Plant density is 76000 plants ha⁻¹ in all environments. Grain yield (t/ha) adjusted to 14% moisture was harvested from the two rows of each plot in each year and location.

TABLE I
 NAMES, CODES, AND ORIGIN OF 14 MAIZE HYBRIDS

Name of hybrids	Hybrids code	FAO group	Origin of hybrids
ZP 677	G1	600	Serbia
ZP 434	G2	400	Serbia
ZP 684	G3	600	Serbia
BC 572	G4	500	Croatia
BC 678	G5	670	Croatia
BC 666	G6	660	Croatia
BC 582	G7	580	Croatia
BC 5982	G8	510	Croatia
BC 682	G9	680	Croatia
OSSK 602	G10	600	Croatia
G-3261	G11	500	Greece
ZP 599	G12	500	Serbia
KSC 700	G13	700	Iran
KSC 704	G14	700	Iran

B. Statistical Analysis

Analysis of variance was performed using MSTAT-C to determine the effect of the environment (consisting of year (Y), location (L), and Y \times L interaction), genotype, and all possible interactions among these sources of variation.

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Environment-centered matrix, containing the GGE data, was subjected to singular value decomposition (SVD); each element in the matrix was estimated using the following equation:

$$E(Y_{ij}) = \mu + \beta_j + \sum_{k=1}^K \lambda_k \gamma_{ik} \delta_{jk}$$

where $E(Y_{ij})$ is the expectation of genotype i in environment j ; μ is the general mean; β_j represents the environment main effect; K is the number of principal components (PC) needed to provide an adequate description of $G + GE$; λ_k is a proportionality constant or singular value for the k th PC (PC_k); and γ_{ik} and δ_{jk} are the i th genotype score and the j th environmental score, respectively, for PC_k . SVD was achieved by providing a scaling factor f to obtain alternative genotype ($n_{ik} = \lambda_k^f \gamma_{ik}$) and environment ($m_{jk} = \lambda_k^{f-1} \delta_{jk}$) scores.

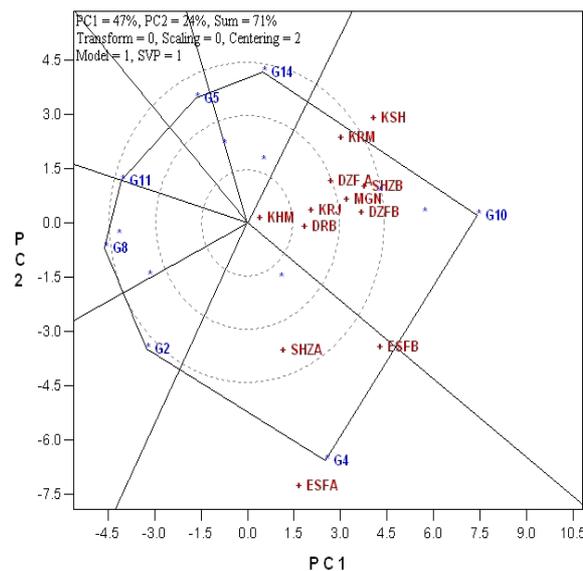
The SVD allowed $G \times E$ table of means to be displayed in a plot having n points for the genotypes plus m points for the environments. We chose the most straightforward scaling, i.e., symmetric scaling ($f = 0.5$) [11]. The statistical theory of this method has been described in detail by [12]. All biplots presented in this paper were generated using the software GGE biplot package that runs in a Windows environment [7].

III. RESULTS AND DISCUSSION

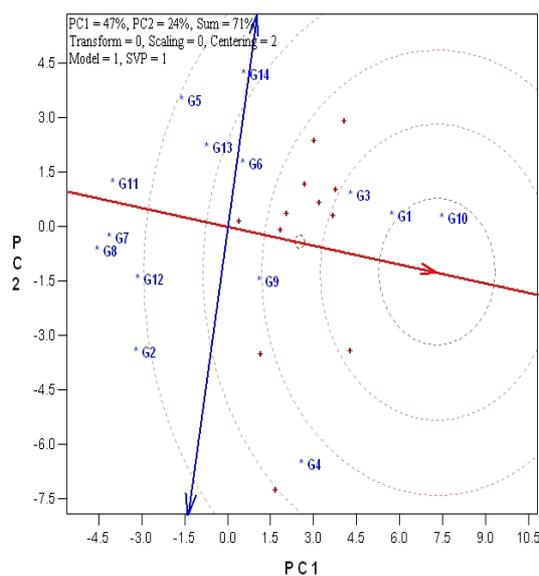
The magnitude of GE ($P < 0.01$) interactions for grain yield of 14 maize hybrids tested across nine locations in Iran were larger than that of G ($P < 0.01$) main effect, but smaller than that of E main effect. The relative contribution of G and the $G \times E$ interaction indicates that it would be very difficult to identify a common widely adapted maize hybrid across environments. The high magnitude of L (large variation), indicates that the Iran region is highly variable from location to location (results not shown). For plant breeding G concerns broad adaptations of benefit throughout a growing region, whereas GE concerns narrow adaptations that can be exploited only by subdivision into two or more mega environments. Because GE is often larger than G, understanding interactions and implementing mega environments can be strategic [4].

The “which-won-where” pattern is important for studying the MET data for identification of different mega-environments [4]-[9]-[10]. The polygon view of a biplot is the best way for identifying the best genotype in each mega-environment.

Fig. 1 represents a polygon view, indicating that the vertex hybrids in this study were G10 (OSSK 602), G14 (KSC 704), G5 (BC 678), G11 (G-3261) G8 (BC 5982), G2 (ZP 434) and G4 (BC 572). The vertex hybrid for each sector is the one that gave the highest grain yield for the environments that fall within that sector. Fig. 1 also identifies two mega-environments in this study. The first mega-environments included KRM, KSH, MGN, DZF A, KRJ, DRB, DZF B, and, SHZ B, where hybrid OSSK 602 was the best performing hybrid. The second mega-environment included ESFA, ESF B and SHZ A, where BC 572 was the best hybrid. This result did not correspond with the traditional area division in Iran. In most cases, the suggested mega-environments based on the location grouping did not correspond with the traditional area divisions [10].



Which wins where or which is best for what
 Fig. 1 GGE Biplot based on the yield data for 14 maize hybrids in 9 locations and 2 years: identification of mega-environments. Moghan (MGN), Karaj (KRJ), Esfahan (two sowing dates, ESF A and ESF B), Shiraz (two sowing dates, SHZ A and SHZ B), Darab (DRB), Kerman (KRM), Khoramabad (KHM), Kermanshah (KSH) and Dezfol (two sowing dates, DZF A and DZF B)



Rankind entries based on both mean and stability
 Fig. 2 GGE Biplot based on the yield data for 14 maize hybrids in 9 locations and 2 years: best hybrids for both mean grain yield and yield stability

A best genotype is defined as one that is highest yielding with yield stability across environments [12]. Best hybrids are those that have large PC1 scores (high mean yield) and small (absolute) PC2 scores (high stability) [11]. In this study OSSK 602 hybrid (G10) was the closest to the concentric center of circles. Therefore, the OSSK 602 hybrid was the best among all hybrids, followed by the ZP 677 and ZP 684 hybrids (Fig. 2). These hybrids were identified as best hybrids that have high grain yield and high yield stability.

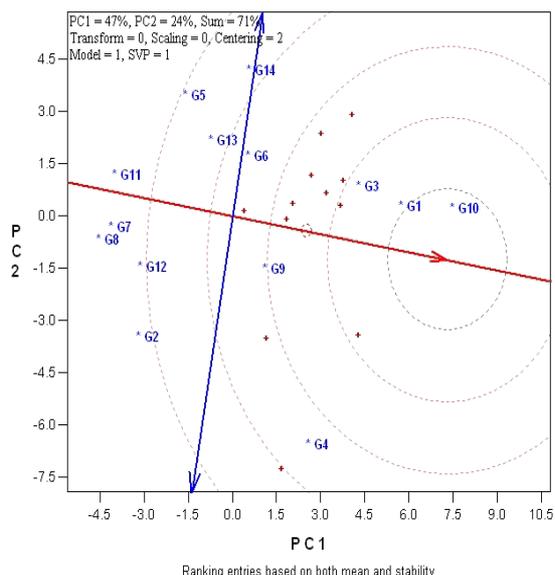


Fig. 2 GGE Biplot based on the yield data for 14 maize hybrids in 9 locations and 2 years: best hybrids for both mean grain yield and yield stability

The vector view of the GGE biplot shows the interrelationships between environments. The angle between the environmental vectors indicates the correlation coefficient between them [7].

The cosine of the angle between the vectors of environment indicates near-zero correlations between KSH and SHZ A, and ESF A as well as between KRM and SHZ A, and ESF A. When the angle between environments is less than 90° , the correlation coefficient between them is positive [9]. Therefore, it is expected that most of the environments are positively correlated, except KRM and ESF A (Fig. 3).

As in the present study, the G10, G1 and G3 are best hybrids based on grain yield; these hybrids would be useful for the improvement of maize traits in breeding programs. Consequently, the results obtained from this research may be used in planning future maize breeding programs.

Abbreviations

Genotype main effect and the Genotype \times Environment interaction (GGE), Moghan (MGN), Karaj (KRJ), Esfahan (two sowing dates, ESF A and ESF B), Shiraz (two sowing dates, SHZ A and SHZ B), Darab (DRB), Kerman (KRM), Khoramabad (KHM), Kermanshah (KSH) and Dezfol (two sowing dates, DZF A and DZF B)

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