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RESEARCH ARTICLE

# GGE biplot analysis and selection indices for yield and stability assessment of maize (*Zea mays* L.) genotypes under drought and irrigated conditions

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## Abstract

Maize is mainly a rainfed crop prone to drought stress, suffering yield losses. The present study evaluated eleven early and nine late maturity hybrids to identify widely adapted genotypes under drought stress and irrigated conditions at the flowering stage. Genotypes showed 25.2% yield reduction under drought over irrigated conditions. GGE biplot analysis demonstrated major effect of environment (72–85%) on grain yield followed by genotype × environment (8–18%), identifying two different mega-environments under drought stress. Suitable selection indices identified DRMH 1417, DKC 7074 in the early and CMH12-686 in late maturity group as high-yielding and drought-tolerant hybrids.

**Keywords:** Drought stress, GGE biplot, stress tolerance, mega-environments, selection indices

## Introduction

The ever-growing human population puts a formidable challenge before scientists to meet the global food demand, more so under the existing challenges of deteriorating soil conditions, depleting moisture level and increasingly unreliable weather patterns due to climate change. Abiotic stresses are the major yield constraints that present far serious concerns for productivity in different crops (Bailey-Serres et al. 2012). Drought continues to be a major constraint on the productivity of cereal crops and the future projections on climate change indicate that water deficit may increase most in arid and semi-arid regions (Wassmann et al. 2009). Maize productivity is adversely affected by different stresses including drought, heat and waterlogging (Kumar et al. 2016).

In India, *kharif* maize is primarily grown as a rainfed crop and is highly susceptible to drought, resulting in wide fluctuations in maize yields over the years (Kumar et al. 2022). Grain yield under water-deficit conditions is often used to quantify a genotype's level of drought tolerance, as detailed information on the genetic mechanism of drought tolerance is lacking (Farshadfar and Sutka 2002). Various selection indices facilitate the breeders to judge the inherent potential of genotypes under drought and irrigated conditions. Several selection methods and stability indices for quantifying drought tolerance have

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been devised to identify tolerant genotypes (Clarke et al. 1992; Pour-Aboughadareh et al. 2019). Among these indices, stress susceptibility index (Fischer and Maurer 1978), stress tolerance index (Fernandez 1992), geometric mean productivity (Ramirez-Vallejo and Kelly1998) and harmonic mean (Kumar et al. 2016) suitable selection indices were applied to find out the stable genotypes. However, Additive Main Effects and Multiplicative Interactions (AMMI) and the genotype, genotype × environment interaction (GGE) biplot models are characterized as a powerful tool for successful analysis and interpretation of multi-environment data structure (Samonte et al. 2005) and nowadays they are the most widely used approaches for the identification of better cultivars with broad and or environment-specific adaptivity under multi-environment trials (Gauch 1988; Choudhary et al. 2019; Kumar et al. 2020; Patel et al. 2023; Singh et al. 2024). Developing drought-tolerant maize varieties is the most significant challenge for maize breeders. However, drought tolerance in crops including maize is a complex trait to understand. The present study was, therefore, undertaken to evaluate the response of short and long-duration maize hybrids under drought and irrigated conditions, perform stress selection indices and GGE biplot analysis to identify better performing stable hybrids for yield.

## Materials and methods

### *Experimental material and the design*

Two sets of genotypes of different maturity, *viz.,* early and late comprising 11 and 9 maize hybrids, respectively, were evaluated under 10 environments (Env.), five each under irrigated and drought stress for both maturity groups separately at Bhiloda, Devisour, Karimnagar, Vagarai and Udaipur (Supplementary Table S1). Experiments were laid out in randomized block design (RBD) with three replications (sown in July last week). Each genotype was planted in 3 rows of 3 meters length with row-to-row and plant-to-plant spacing at 75 cm and 20 cm. Drought stress was imposed at 10 days before initiation of flowering for 20 days and optimally irrigated in a normal set. Observations were recorded for days to flowering, cobs weight (Kg) and, shelling and moisture in percent at harvest to estimate grain yield per plot which was converted into yield per hectare and then final grain yield per hectare for each genotype. Calculated at 15% moisture as per Kumar et al. (2016) where grain yield (kg/ha) at 15% moisture = (cob yield per hectare × shelling% × dry matter)/0.85, where dry matter was calculated by 1-moisture % at harvest.

### *Calculation of drought tolerance selection indices*

Stress tolerance (TOL) (Rosielle and Hamblin 1981), stress susceptibility index (SSI) (Fischer and Maurer 1978), stress tolerance index (STI) (Fernandez 1992), geometric mean productivity (GMP) (Ramirez-Vallejo and Kelly1998) and harmonic mean (HM) (Kumar et al. 2016), yield index (YI), yield stability index (YSI) and relative stress index (RSI) were calculated using following mathematical equations:

$$TOL = Yp - Ys \quad \text{Eq. 1}$$

$$MP=(Yp+Ys)/2 \quad \text{Eq. 2}$$

$$GMP=\sqrt{Ys \times Yp} \quad \text{Eq. 3}$$

$$HM=2(Ys \times Yp)/ Ys +Yp \quad \text{Eq. 4}$$

$$SSI=(1-( Ys / Yp))/(1-(\bar{Y}s/\bar{Y}p)) \quad \text{Eq. 5}$$

$$STI=(Ys \times Yp)/(\bar{Y}p2) \quad \text{Eq. 6}$$

$$YI=(Ys)/(\bar{Y}s) \quad \text{Eq. 7}$$

$$YSI=Ys/Yp \quad \text{Eq. 8}$$

$$RSI= (YS/YP)/(\bar{Y}s/\bar{Y}p) (\bar{YS}/\bar{YP}) \quad \text{Eq. 9}$$

where Ys and Yp are the individual yield of genotype 'i' and $\bar{Y}s$ *and* $\bar{Y}p$ *are the overall*

## Statistical analyses

Agricolae R package was used to test the significance of genotypic performance for grain yield using analysis of variance (ANOVA) and stability analysis using AMMI function. GGE biplot graphs are plotted with the help of GGEBiplot R package. Various selection indices were calculated using iPASTIC online software (Pour-Aboughadareh et al. 2019).

## Results

The AMMI-based ANOVA (Table 1) for the early and late maturity hybrids showed the significance of genotype (G), environment (E) and genotype-environment interaction (G×E) for grain yield under both drought and irrigated conditions. For early maturity hybrids, mean yield under irrigated condition (Yp) was 4.75 t/ha and ranged from 3.90 t/ha (KDMH-103) to5.40 t/ha (PMH5), whereas yield under stress conditions (Ys) ranged from 2 (KDMH-103) to 4.2 t/ha (DKC 7074) with a mean of 3.57 t/ha. The mean yield in case of late-maturity varieties under irrigated and drought stress were 6.1 and 4.54 t/ha, respectively. The yield ranged from 5.0 (GH-1514) to 6.7 t/ha (PMH1) under irrigated conditions, while it ranged from 3.5 (GH-1514) to 5.5 t/ha (BIO 9682) under drought stress. The grain yields of early maturity groups were significantly affected by E, which accounted for 75% of total sum of squares (TSS), whereas G and G×E captured 9% and 16% of TSS, respectively, under irrigated conditions. In drought stress, there was 73%, 14% and 13% contribution of E, G and G×E, respectively. For late maturity group, corresponding figures were 85, 7 and 8%, respectively in drought, whereas 10% genotypic, 72% environment and 18% GE effects were observed in irrigated conditions. The large G×E effect relative to G, suggested the possible existence of different mega-environments. It was noted that

**Table 1.** AMMI- based analysis of variance for grain yield under stress and normal conditions for early and late maturity groups maize hybrids

| Source of variation | df | Sum of square | Mean square | F | Significance (on basis of p-value) | SS (%) |
|---|---|---|---|---|---|---|
| **Early maturity** | | | | | | |
| Grain yield (stress) | | | | | | |
| Genotype (G) | 10 | 51865823 | 5186582 | 10.15 | *** | 13.66 |
| Environment (E) | 4 | 278102105 | 69525526 | 89.40 | *** | 73.23 |
| Interaction (G×E) | 40 | 49812382 | 1245310 | 2.44 | *** | 13.12 |
| Grain yield (normal) | | | | | | |
| G | 10 | 36699210 | 3669921 | 7.1299 | *** | 9.04 |
| E | 4 | 303170108 | 75792527 | 88.0987 | *** | 74.74 |
| G × E | 40 | 65734658 | 1643366 | 3.1927 | *** | 16.20 |
| **Late maturity** | | | | | | |
| Grain yield (stress) | | | | | | |
| G | 8 | 35496958 | 4437120 | 5.28 | *** | 6.83 |
| E | 4 | 440794176 | 110198544 | 59.68 | *** | 84.89 |
| G×E | 32 | 42985829 | 1343307 | 1.60 | * | 8.28 |
| Grain yield (normal) | | | | | | |
| G | 8 | 35058369 | 1889314 | 2.4911 | *** | 10.36 |
| E | 4 | 242979926 | 60744981 | 52.3782 | *** | 71.78 |
| G × E | 32 | 60458033 | 1889314 | 5.7782 | *** | 17.86 |

E and G×E played a significant role in optimal expression of early and late maturity genotypes under stress and irrigated conditions. The presence of significant GEI necessitated the evaluation of G×E patterns for the identification of most stable hybrids or location-specific hybrids

### *Polygon view of GGE biplot*

Which-won-where biplots for yield under irrigated and stress condition of early maturity groups are presented in Fig.1 A and B, respectively. Polygon view explained 83% and 93% of the GGE (genotype and genotype × environment) variation for the grain yield under irrigated and stress treatment, respectively. The polygon view of biplots for yield confirmed the existence of crossover G×E and mega-environments. Under control treatment, environments fall into three sectors with different wining genotypes (Fig. 1A). It indicated E4 (KDMH-103), E5 (DMRH1417) and E8 (PMH5) as vertex genotypes. Among them, E4 was highest yielder in environment 3 (Env3: Karimnagar), whereas E5 was in environment 1 (Env1: Bhiloda) and environment 5 (Env5: Udaipur). Similarly, E8 was found at vertex in environment 2 (Env2: Devisour) and environment 4 (Env4: Vagarai). Under stress conditions, environments fall only under two sectors, with E5 (DMRH 1417) and E10 (DKC 7074) as the vertex genotypes and, hence indicating presence of two mega-environments (Fig. 1B). The first mega-environment consisted of Karimnagar, Vagarai and Udaipur with E5 as highest yielder, whereas second consisted of Bhiloda and Devisour with E10 as the wining genotype. Conclusively, genotype E5 was found the best grain yielder among the early maturity hybrids at Udaipur under irrigated as well as drought stress.

In late maturity group, GGE effect for grain yield under irrigated and drought stress condition was nearly equal with 84 and 88%, respectively (Fig. 1C-D). The winning genotypes under irrigated conditions were L1 (CMH 12-686), L2 (GH 1514), L5 (PMH1) and L7 (BIO 9682) with all locations falling under three sectors. Fig. 1C indicates that genotype L1 was the highest yielder in the mega environments consisting of Bhiloda (Env. 1) and Udaipur (Env. 5), L2 for Karimnagar (Env 3) and L5 and L7 for Devisour (Env. 2) and Vagarai (Env. 4). Under drought stress, L1 and L7 hybrids were the winning genotypes in the mega-environment 1(Env. 4: Vagarai, 5: Udaipur and 1: Bhiloda) and mega-environment 2 (Env. 2: Devisour and 3: Karimnagar), respectively (Fig. 1D). L1 and L2 were the superior genotypes in Env. 5 (Udaipur) and Env. 2 (Devisour) under both irrigated and drought stress conditions, respectively.

### *Mean vs. stability of the genotypes*

Based on the "mean vs stability" view of early maturity group, the hybrid E8 (PMH5) was found to be the highest yielder followed by E10 (DKC 7074), E5 (DMRH1417), E9

(BIO605), and E7 (Vivek Hybrid 45) whereas the E4 (KDMH-103), E2 (WH-2093) and E3 (GEMH-15115) were the poorest yielders under irrigated condition (Fig. 2A). However, the hybrids E8, E10, E5, E9 and E7 (with high mean performance) were found to be least stable, whereas among E4, E2 and E3 (with low mean yield), E3 was nearly stable. Therefore, under irrigated conditions none of the genotype was found to be a combination of high mean yield and better stability. This indicates that the genotypes under study are location-specific performers. Under drought stress, genotypes E5 and E10 were found to be the highest grain yielders but least stable, whereas E4, E2 and E1 (WH-2104) were the poor yielders, with E4 nearly stable (Fig. 2B). Therefore, the E5 (DMRH1417) and E10 (DKC7074) were relatively higher mean yielder but with less stability under both irrigated and drought stress conditions, hence, exhibit location specific adaptation.

For late maturity genotypes under irrigated treatment, the "mean vs. stability" indicated that the genotype L5 (PMH1) was the highest mean yielder followed by L1 (CMH 12-686) and L3 (GK 3206), whereas poor yielders such as L2 (GH-1514), L8 (CMH 08-287) and L4 (RCRMH-4), were relatively more stable (Fig. 2C). Similarly, under stress treatment the genotypes *viz.,* L1 and L7 (BIO 9682) exhibited high yields while L2, L4 and L9 (CMH 08-282) were poor yielders (Fig. 2D). Therefore, the genotype L1 (CMH12-686) was found to be the best genotype under both drought as well as normal treatment. Based on GGE biplot and "mean vs. stability", early maturity hybrid- E5 (DRMH 1417) and late maturity hybrid-L1 (CMH12-686) were found to be the highest yielder under both stress and irrigated conditions.

### *Evaluation of drought selection indices*

The details of nine drought selection indices calculated for grain yield under stress (Ys) and irrigated conditions (Yp) in 11 early and nine late maturity maize genotypes are presented in Tables 2 and 3, respectively. Hybrids DMRH 1417, Vivek Hybrid 45, PMH5, BIO605 andDKC 7074 had high MP, GMP, HM, STI, YI, YSI and RSI except YSI of Vivek Hybrid 45 (< mean value). These entire genotypes also had high average grain yield under drought-stress (>3.7 t/ha) as well as irrigated (>5.0 t/ha) conditions. TOL was high (>1.3) for the hybrids, *viz.*, WH-2093, KDMH-103, Vivek Hybrid 45 and PMH5. SSI was less (<1.01) for the hybrids DMRH1417, Vivek Hybrid 51, PMH5, BIO605 and DKC 7074. Therefore, the genotypes DMRH1417, PMH5 and DKC 7074 were found to be relatively more drought-tolerant genotypes.

Late maturity hybrids namely CMH 12-686, GK 3206, PMH1, PMH3, BIO 9682 and CMH 08-282 had high MP (>5.4), GMP (>5.3), HM (>5.3) and STI (>0.8). TOL was high for the hybrids such as GK 3206, RCRMH-4, PMH1 and CMH 08-282. YI was highest for BIO 9682 followed by CMH 12-686. The hybrids CMH 12-686, BIO 9682 and CMH 08-287 showed high YSI, with BIO 9682 and CMH 08-287 having high RSI (>1.1) as well. SSI was least for CMH 12-686, BIO 9682 and CMH08-287. Therefore, the genotypes CMH 12-686 and BIO 9682 were found to be relatively more drought tolerant genotypes.

## Discussion

The significant effects of genotype, environment and G×E interaction for both early and late maturity genotypes signify the ample variation among genotypes and test environments. It indicates the immense opportunities for selection of genotypes with broad or environment-specific adaptation (Kumar et al. 2016; Choudhary et al. 2019; Kumar et al. 2020; Patel et al. 2023; Singh et al. 2024). Further, the highest contribution of environmental effect on cultivars yield performance indicates changeable behavior in the

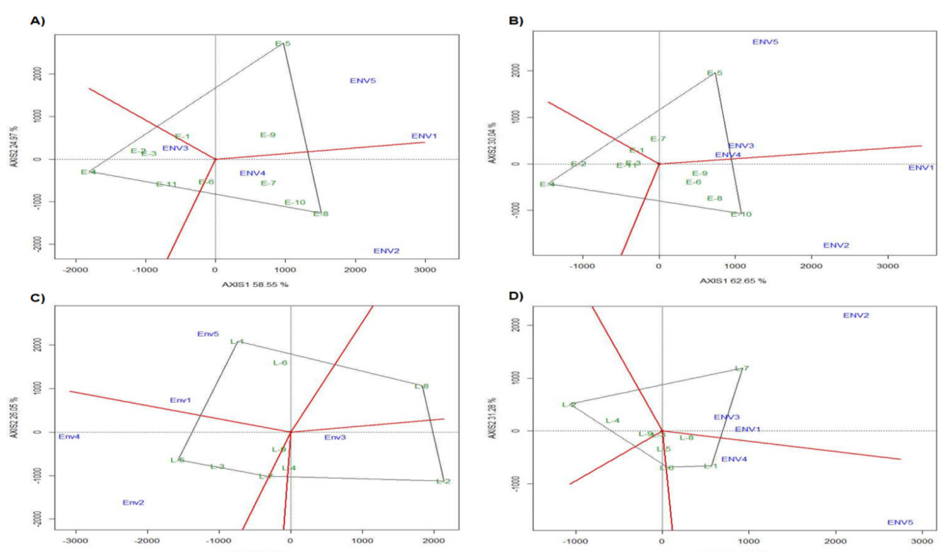


**Fig. 1.** GGE biplot (A to D) for grain yield under irrigated (A, C) and drought stress (B, D) treatment for early (A, B) and late maturity (C, D) genotypes

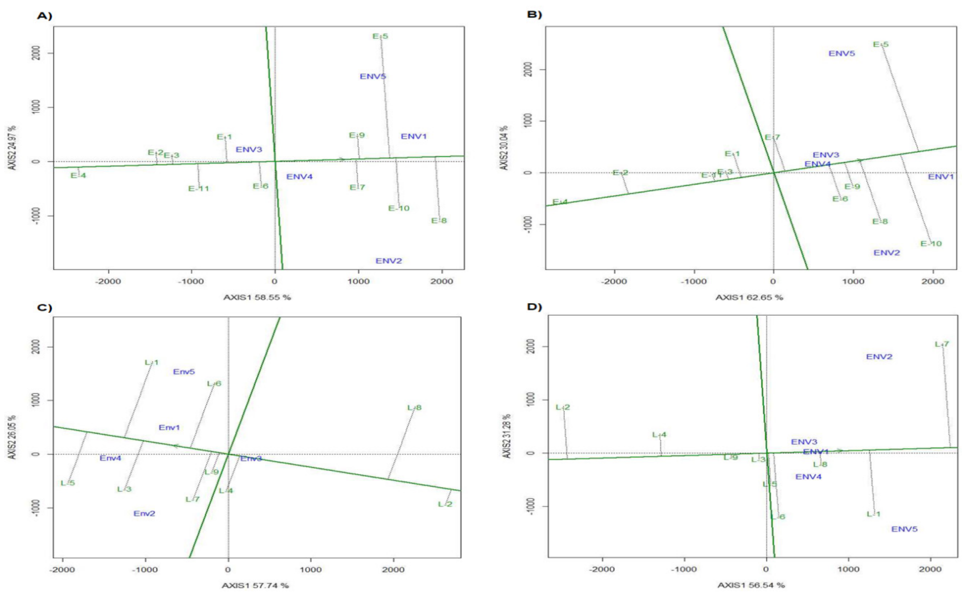

**Fig. 2.** Mean vs. stability graph (A to D) for grain yield under irrigated (A, C) and drought stress (B, D) treatment for early (A, B) and late maturity (C, D) genotypes

**Table 2.** Yield performance of 11 early maturity maize genotypes in irrigated (Yp) and drought stress (Ys) conditions and their values for various selection indices calculated using the Yp and Ys

| Hybrid | Yp | Ys | TOL | MP | GMP | HM | SSI | STI | YI | YSI | RSI | ASR | ASV | IPCAg1 | IPCAg2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WH-2104 | 4.5 | 3.4 | 1.1 | 3.9 | 3.9 | 3.8 | 1.0 | 0.7 | 0.9 | 0.8 | 1.0 | 7.0 | 23.2 | 8.3 | 1.9 |
| WH-2093 | 4.5 | 2.8 | 1.7 | 3.7 | 3.6 | 3.5 | 1.6 | 0.6 | 0.8 | 0.6 | 0.8 | 10.1 | 29.7 | 9.2 | -14.6 |
| GEMH-15115 | 4.4 | 3.3 | 1.1 | 3.8 | 3.8 | 3.8 | 1.0 | 0.6 | 0.9 | 0.7 | 1.0 | 8.2 | 8.0 | 2.8 | 0.9 |
| KDMH-103 | 3.9 | 2.5 | 1.4 | 3.2 | 3.1 | 3.0 | 1.5 | 0.4 | 0.7 | 0.6 | 0.8 | 10.5 | 26.1 | 3.6 | -24.1 |
| DMRH1417 | 5.2 | 4.3 | 0.9 | 4.7 | 4.7 | 4.7 | 0.7 | 1.0 | 1.2 | 0.8 | 1.1 | 1.6 | 100.6 | 34.6 | 27.4 |
| Vivek Hybrid 51 | 4.6 | 3.9 | 0.7 | 4.2 | 4.2 | 4.2 | 0.6 | 0.8 | 1.1 | 0.9 | 1.1 | 4 | 32.3 | -11.5 | -1.0 |
| Vivek Hybrid 45 | 5.2 | 3.7 | 1.4 | 4.4 | 4.4 | 4.3 | 1.1 | 0.9 | 1.0 | 0.7 | 1.0 | 6.5 | 36.9 | 12.9 | -8.0 |
| PMH5 | 5.4 | 4.0 | 1.3 | 4.7 | 4.6 | 4.6 | 1.0 | 1.0 | 1.1 | 0.8 | 1.0 | 4.1 | 60.8 | -21.7 | 4.9 |
| BIO605 | 5.0 | 3.9 | 1.0 | 4.4 | 4.4 | 4.4 | 0.8 | 0.9 | 1.1 | 0.8 | 1.0 | 3.9 | 26.6 | -9.1 | 7.8 |
| DKC 7074 | 5.3 | 4.2 | 1.1 | 4.7 | 4.7 | 4.7 | 0.9 | 1.0 | 1.2 | 0.8 | 1.0 | 2.7 | 92.0 | -32.5 | 13.7 |
| Prakash | 4.2 | 3.3 | 0.9 | 3.7 | 3.7 | 3.7 | 0.9 | 0.6 | 0.9 | 0.8 | 1.0 | 7.3 | 13.2 | 3.4 | -9.1 |
| Mean | 4.75 | 3.57 | 1.15 | 4.13 | 4.10 | 4.06 | 1.01 | 0.77 | 0.99 | 0.75 | 0.98 | 5.99 | 40.85 | 0.00 | -0.02 |
| S.D. | 0.50 | 0.57 | 0.28 | 0.50 | 0.52 | 0.55 | 0.30 | 0.21 | 0.16 | 0.09 | 0.10 | 2.95 | 30.62 | 18.14 | 14.03 |

test environments which may be due to variations in land topography, regional weather patterns and soil type. Therefore, the performance ranking of maize genotypes can change depending on the environment (Oliveira et al. 2017). GGE biplot analysis helps to identify mega environments for selection and discriminating test environments (Yan 2001; Rad et al. 2013) as evident in wheat (Rad et al. 2013) and rice (Samonte et al. 2005; Poli et al. 2018) under drought stress environments. AMMI-based ANOVA revealed highest contribution of environment in the grain yield, signifying towards less contribution by genotypes and G×E interaction (Table 1). Similarly, Choudhary et al. (2019) reported upto 89.9% of variation due to environment in baby corn.

In this study, GE interactions were effectively analyzed through GGE biplot analysis (Yan and Tinker 2006), which revealed the presence of two rainfed mega-environments for both early and late maturity groups. High-yielding genotypes in each mega-environment are different, which

**Table 3.** Yield performance of 9 late maturity maize genotypes in irrigated (Yp) and drought stress (Ys) conditions and their values for various selection indices calculated using Yp and Ys

| Hybrid Code | Yp | Ys | TOL | MP | GMP | HM | SSI | STI | YI | YSI | RSI | ASR | ASV | IPCAg1 | IPCAg2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CMH 12-686 | 6.5 | 5.0 | 1.5 | 5.7 | 5.7 | 5.6 | 0.9 | 0.9 | 1.1 | 0.8 | 1.0 | 2.5 | 43.7 | 22.9 | -17.3 |
| GH-1514 | 5.0 | 3.5 | 1.5 | 4.3 | 4.2 | 4.2 | 1.2 | 0.5 | 0.8 | 0.7 | 0.9 | 8.0 | 38.5 | -19.2 | 18.9 |
| GK 3206 | 6.5 | 4.6 | 1.9 | 5.6 | 5.5 | 5.4 | 1.1 | 0.8 | 1.0 | 0.7 | 0.9 | 4.8 | 10.0 | 1.7 | 9.5 |
| RCRMH-4 | 5.9 | 4.0 | 1.8 | 5.0 | 4.9 | 4.8 | 1.2 | 0.6 | 0.9 | 0.7 | 0.9 | 7.7 | 18.2 | -8.2 | 11.1 |
| PMH1 | 6.7 | 4.5 | 2.2 | 5.6 | 5.5 | 5.4 | 1.3 | 0.8 | 1.0 | 0.7 | 0.9 | 5.6 | 19.5 | 10.9 | -4.3 |
| PMH3 | 6.3 | 4.7 | 1.6 | 5.5 | 5.4 | 5.4 | 1.0 | 0.8 | 1.0 | 0.7 | 1.0 | 4.4 | 39.8 | 21.9 | 10.8 |
| BIO 9682 | 6.2 | 5.5 | 0.7 | 5.8 | 5.8 | 5.8 | 0.5 | 0.9 | 1.2 | 0.9 | 1.2 | 1.5 | 65.9 | -35.7 | -21.1 |
| CMH 08-287 | 5.5 | 4.6 | 0.9 | 5.1 | 5.0 | 5.0 | 0.6 | 0.7 | 1.0 | 0.8 | 1.1 | 4.7 | 24.1 | 5.2 | -22.3 |
| CMH 08-282 | 6.3 | 4.5 | 1.8 | 5.4 | 5.3 | 5.3 | 1.1 | 0.8 | 1.0 | 0.7 | 1.0 | 5.8 | 14.8 | 0.5 | 14.7 |
| Mean | 6.10 | 4.54 | 1.54 | 5.33 | 5.26 | 5.21 | 0.99 | 0.76 | 1.00 | 0.74 | 0.99 | 5.00 | 30.50 | 0.00 | 0.00 |
| SD | 0.55 | 0.56 | 0.48 | 0.47 | 0.49 | 0.48 | 0.28 | 0.13 | 0.11 | 0.07 | 0.11 | 2.13 | 17.88 | 18.92 | 16.45 |

signifies the need to exploit such genotypes for their specific adaptation to appropriate environments. In multi-location trials, especially with diverse testing sites, the prevalence of a combination of crossover and non-crossover types of GEI is common (Choudhary et al. 2019; Kumar et al. 2020).

Selection indices have proved important for selecting the better tolerant genotypes for yields under drought-stress and irrigated environments in maize (Kumar et al. 2016). Based on MP, GMP, HM, STI and YI indices (with higher values), five early maturity genotypes such as DMRH1417, Vivek Hybrid 45, PMH5, BIO605 and DKC 7074 and four late maturity such as CMH 12-686, GK 3206, PMH1 and BIO 9682 were found have low SSI and TOL values and hence are relatively less drought sensitive. Selection based on high value of MP causes distinction between genotypes with higher mean yield under drought and irrigated conditions than other genotypes (Mehraban et al. 2018). Based on MP, DMRH1417, PMH5, DKC 7074, CMH 12-686 and BIO 9682 were found to be most stable and high yielders.

Understanding of genotype-environment interaction is crucial for the development of drought-tolerant genotypes. G, E, and G × E effects play significant roles, with environment (E) impacting genotype performance the most. GGE biplot analysis aids in identifying optimal genotypes. High correlation between yields under drought stress and irrigated conditions indicates the potential for drought tolerance. Selection indices like MP, HM, GMP, and STI suit both conditions, while YSI and RSI are better for drought stress. Integrating selection indices and biplot study helps select top-performing genotypes for specific conditions, aiding maize drought tolerance.

## Author's contribution

Conceptualization of research (BK, SR); Designing of the experiments (BK); Contribution of experimental materials (SD, NKV, GSK, RG, MV); Execution of field/lab experiments and data collection (MC, PK, BK, SK, BSJ, MCD); Analysis of data and interpretation (MC, PK, BK), Preparation of the manuscript (MS, PK, SK).

## References


Ashraf M. 2010. Inducing drought tolerance in plants: recent advances. Biotechnol. adv., **28**: 169-183.

Bailey-Serres J., Lee S.C. and Brinton E. 2012. Waterproofing crops: effective flooding survival strategies. Plant Physiol., **160**: 1698-1709.

Choudhary M., Kumar B., Kumar P., Guleria S.K., Singh N.K., Khulbe R., Kamboj M.C., Vyas M., Srivastava R.K., Puttaramanaik S.D and Mahajan V. 2019. GGE biplot analysis of genotype× environment interaction and identification of mega-environment for baby corn genotypes evaluation in India. Indian J. Genet. Plant Breed., **79**: 658-669. https://doi.org/10.31742/IJGPB.79.4.3

Clarke J. M., De-Pauw R. M. and Townley-Smith T. M. 1992. Evaluation of methods for quantification of drought tolerance in wheat. Crop Sci., **32**: 728-732.

Farshadfar E. and Sutka J. 2002. Screening drought tolerance criteria in maize. Acta Agronomica Hungarica., **50**: 411-416.

Fernandez C.G.J. 1992. Effective selection criteria for assessing plant stress tolerance., pp. 257–270. In Adoption of Food Crops to Temperature and Water Stress: Proceedings of an International Symposium, 13–18 August 1992 (edited by C. George Kuo). Asian Vegetable Research and Development Center (AVRDC), Taiwan.

Fischer R.A. and Maurer R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res., **29**: 892–912.

Gauch Jr. H. G. 1988. Model selection and validation for yield trials with interaction. Biometrics, 705-715. https://doi.org/10.2307/2531585

Kumar B., Guleria S.K., Khanorkar S.M., Dubey R.B., Patel J., Kumar V., Parihar C.M., Jat S.L., Singh V., Yatish K.R. and Das A. 2016. Selection indices to identify maize (*Zea mays* L.) genotypes adapted under drought-stress and drought-free conditions in a tropical climate. Crop Pasture Sci., **67**: 1087-1095.

Kumar P., Kumar S., Choudhary M., Chikappa G.K., Kumar B., Singh

N.K. and Sinha S.K. 2020. GGE biplot based stability analysis of experimental genotypes for baby corn purpose and green fodder. Range Manag. Agrofor., **41**: 60-66.

Kumar P., Longmei N., Jat B.S., Choudhary M., Yathish K.R., Bhushan B., Goyal M. and Rakshit S. 2022. Heterotic grouping of Indian baby corn lines based on combining ability. Indian J. Genet. Plant Breed., **82**(02):161-166. https://doi.org/10.31742/IJGPB.82.2.4

Mehraban A., Tobe A., Gholipouri A., Amiri E., Ghafari A. and Rostaii M. 2018. Evaluation of drought tolerance indices and yield stability of wheat cultivars to drought stress in different growth's stage. World j. environ. biosci., **7**: 8-14.

Oliveira T.R.A., Carvalho H.W.L., Costa E.F.N. and Carvalho Filho J.L.S. 2017. Correlation among adaptability and stability assessment models in maize cultivars. Aust. J. Crop Sci., **11**: 516–521.

Patel R., Parmar D.J., Kumar S., Patel D. A., Memon J., Patel M.B. and Patel J.K. 2023. Dissection of genotype × environment interaction for green cob yield using AMMI and GGE biplot with MTSI for selection of elite genotype of sweet corn (*Zea mays* conva. Saccharata var. rugosa). Indian J. Genet. Plant Breed., **83**(1): 59-68. https://doi.org/10.31742/ISGPB.83.1.8

Poli Y., Balakrishnan D., Desiraju S., Panigrahy M., RaoVoleti S., Mangrauthia S.K. and Neelamraju S. 2018. Genotype × environment interactions of Nagina22 rice mutants for yield traits under low phosphorus, water limited and normal irrigated treatment. Scientific Reports., **8**: 15530.

Pour-Aboughadareh A., Yousefian M., Moradkhani H., Moghaddam V.M., Poczai P. and Siddique K.H.M. 2019. iPASTIC: An online toolkit to estimate plant abiotic stress indices. Appl. Plant Sci., **7**: e11278.

Rad M.R.N., Kadir M.A., Rafii M.Y., Jaafar H.Z.E., Naghavi M.R. and Ahmadi F. 2013. Genotype x environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum*) under normal and drought stress treatment. Aust. J. Crop Sci., **7**: 956–961.

Ramirez V.P. and Kelly J.D. 1998. Traits related to drought resistance in common bean. Euphytica., **99**: 127–136.

Rosielle A.A. and Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. Crop Science., **21**: 943–946.

Samonte S. O. P., Wilson L. T., McClung A. M. and Medley J. C. 2005. Targeting cultivars onto rice growing environments using AMMI and SREG GGE biplot analyses. Crop Sci., **45**(6): 2414-2424. https://doi.org/10.2135/cropsci2004.0627

Singh S.B., Kumar S., Kumar R., Kumar P., Yathish K.R., Jat B.S., Chikkappa G.K., Kumar B., Jat S.L., Dagla M.C., Kumar B., Kumar A., Kasana R.K. and Kumar S. 2024. Stability analysis of promising winter maize (*Zea mays* L.) hybrids tested across Bihar using GGE biplot and AMMI model approach. Indian J. Genet. Plant Breed., **84**(1): 73-80. https://doi.org/10.31742/ISGPB.84.1.6

Wassmann R., Jagadish S.V.K., Heuer S., Ismail A., Redona E., Serraj R. and Sumfleth K. 2009. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. Adv. Agron., **101**: 59-122.

Yan W. and Tinker N.A. 2006. Biplot analysis of multi-environment trial data: Principles and applications. Can. J. Plant Sci., **86:** 623–645.

Yan W. 2001. GGE Biplot-A Windows application for graphical analysis of multi-environment trial data and other types of two-way data. Agron. J., **93**: 1111–1118.

**Supplementary Table S1.** List of 20 maize genotypes evaluated at five locations viz., Env 1: Bhiloda, Env2: Devisour, Env3: Karimnagar, Env4: Vagarai and Env: 5 Udaipur, under irrigated and drought stress conditions

| Genotype code | Genotype name | Centre/Company |
|---|---|---|
| **Early maturity** | | |
| E1 | WH-2104 | Banswara |
| E2 | WH-2093 | Banswara |
| E3 | GEMH-15115 | Dharwad |
| E4 | KDMH-103 | SKUAST Kashmir |
| E5 | DMRH1417 | IIMR, New Delhi |
| E6 | Vivek Hybrid 51 | Almora |
| E7 | Vivek Hybrid 45 | Almora |
| E8 | PMH5 | PAU Ludhiana |
| E9 | BIO605 | Bioseed |
| E10 | DKC 7074 | Monsanto |
| E11 | Prakash | PAU Ludhiana |
| **Late maturity** | | |
| L1 | CMH 12-686 | TNAU Coimbatore |
| L2 | GH-1514 | Dharwad |
| L3 | GK 3206 | Ganga Kaveri Seeds |
| L4 | RCRMH-4 | USA Raichur |
| L5 | PMH1 | PAU, Ludhiana |
| L6 | PMH3 | PAU, Ludhiana |
| L7 | BIO 9682 | BIOSEED RESEARCH |
| L8 | CMH 08-287 | TNAU,Coimbatore |
| L9 | CMH 08-282 | TNAU,Coimbatore |