



ISSN Print: 2664-844X
 ISSN Online: 2664-8458
 NAAS Rating (2026): 4.97
 IJAFS 2026; 8(3): 496-503
www.agriculturaljournals.com
 Received: 19-01-2026
 Accepted: 22-02-2026

Praveenkumar B
 Scientist (Pigeonpea
 Breeding), AICRP on
 Pigeonpea, Zonal Agricultural
 Research Station, Kalaburagi,
 Karnataka, India

Shivakumar K
 Professor (Ground nut
 Breeding), MARS, Raichur,
 Karnataka, India

Ravi Pujari
 Assistant Professor and Head,
 Horticulture, College of
 Agriculture,
 Bheemarayanagudi,
 Karnataka, India

Sridevi O
 Ex-Dean (UG), UAS,
 Dharwad, Karnataka, India

Dr. Ramesh Methre
 Assistant Professor, Plant
 Biotechnology, Department of
 Genetics and Plant Breeding,
 College of Agriculture,
 Bheemarayanagudi, University
 of Agricultural Sciences,
 Raichur, Karnataka, India

Corresponding Author:
Praveenkumar B
 Scientist (Pigeonpea
 Breeding), AICRP on
 Pigeonpea, Zonal Agricultural
 Research Station, Kalaburagi,
 Karnataka, India

Stability analysis in maize (*Zea mays* L.) under stress and non-stress situation

Praveenkumar B, Shivakumar K, Ravi Pujari, Sridevi O and Ramesh Methre

DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i3f.1746>

Abstract

The present investigation was conducted during the kharif, rabi, and summer seasons of 2011-12, 2012-13, and 2013-14 at the Main Agricultural Research Station, Dharwad, Karnataka, India, to assess the stability of maize (*Zea mays* L.) single-cross hybrids under contrasting moisture regimes. Eight experimental single-cross hybrids, along with five commercial checks (900M Gold, NK6240, Arjun, Bio-9681, and All Rounder), were evaluated under both drought stress and non-stress conditions using a randomized complete block design (RCBD) with three replications. Combined analysis of variance across environments revealed significant genotypic differences for nine agronomic and yield-related traits. Environmental effects were significant for most of the studied characters, whereas genotype $\times$ environment ($G \times E$) interactions were non-significant for the majority of traits under both moisture regimes. The environmental linear component contributed significantly to variation in most traits, while the $G \times E$ (linear) interaction remained non-significant for most characters under stress and non-stress conditions. The pooled deviation, representing the nonlinear component of $G \times E$ interaction, was non-significant for all traits under non-stress conditions, whereas under drought stress it was significant only for days to 50% anthesis, chlorophyll content at 90 days, and cob length. Stability analysis identified seven hybrids—CM-111 $\times$ NEI-9202B, HS-4 $\times$ NEI-9202B, 900M, CI-4 $\times$ HS-4, HS-2 $\times$ NEI-9202B, HS-15 $\times$ HS-17, and KDMI-15 $\times$ NEI-9202B—as stable across environments under drought stress. Under non-stress conditions, eight hybrids, namely Arjun, NEI-9208B $\times$ HS-15, NK6240, 900M, CI-4 $\times$ HS-4, KDMI-15 $\times$ NEI-9202B, HS-4 $\times$ NEI-9202B, and HS-2 $\times$ NEI-9202B, exhibited stable performance across seasons. These findings demonstrate the potential of selected maize hybrids for consistent productivity under contrasting moisture environments and provide valuable genetic resources for developing climate-resilient maize cultivars.

Keywords: *Zea mays*, drought stress, genotype $\times$ environment interaction, stability analysis, single-cross hybrids, maize breeding

Introduction

Maize (*Zea mays* L.) is one of the world's most important cereal crops owing to its high productivity, remarkable genetic diversity, and broad adaptability to diverse agro-climatic conditions. It belongs to the family Poaceae, tribe Maydeae, and is believed to have originated in Central and South America approximately 8,000 years ago. The species is diploid ($2n = 20$), monoecious, and predominantly cross-pollinated. Its closest wild relatives include *Tripsacum* (gama grass) and *Teosinte* (*Zea* spp.), which have played a significant role in understanding maize evolution and genetic improvement.

Globally, maize has emerged as a strategic crop because of its extensive utilization in food, feed, fodder, and industrial sectors. Owing to its high yield potential and versatility, maize contributes substantially to global food security and agricultural economies. In addition to serving as a staple food in many regions, maize grain is widely used in livestock and poultry feed, starch production, bioethanol, pharmaceuticals, and numerous value-added food products. Specialty maize types such as quality protein maize (QPM), sweet corn, popcorn, baby corn, waxy corn, and high-oil maize have further expanded its commercial and nutritional significance (Yadav et al., 2014) [1].

According to recent agricultural statistics, maize is cultivated on approximately 199 million hectares worldwide, producing about 1,129.2 million tonnes of grain with an average productivity of 5,820 kg ha⁻¹ (Anon., 2024). In India, maize ranks third among cereal crops after rice and wheat, covering nearly 12.84 million hectares with a production of 46.15 million tonnes and an

average productivity of 3,595 kg ha⁻¹. Karnataka is one of the major maize-producing states, cultivating the crop over approximately 1.90 million hectares with an annual production of 6.35 million tonnes and an average productivity of 3,339 kg ha⁻¹ (Anon., 2025-26).

Despite continuous genetic improvement, maize productivity is frequently constrained by adverse environmental conditions. Among the various abiotic stresses affecting maize production, drought remains the most severe and widespread, particularly in tropical and subtropical regions where cultivation depends largely on seasonal rainfall. Water deficit during the reproductive phase, especially at flowering and grain filling, substantially reduces pollination efficiency, kernel set, grain development, and ultimately grain yield.

Consequently, drought is considered one of the principal factors limiting the realization of the genetic yield potential of maize (CIMMYT, 1999; Edmeades *et al.*, 2001)^[2].

The performance of maize hybrids under diverse environments is strongly influenced by genotype $\times$ environment (G $\times$ E) interaction, which often complicates the identification of consistently superior genotypes. A hybrid that performs exceptionally well under one environmental condition may not maintain similar performance under another. Therefore, evaluating hybrids across contrasting moisture regimes is essential for identifying genotypes with stable performance and broad adaptation. Stability analysis provides valuable information regarding the adaptability and predictability of genotype performance under varying environmental conditions, thereby assisting plant breeders in selecting hybrids suitable for both favourable and stress-prone environments.

The Eberhart and Russell stability model is one of the most widely adopted approaches for assessing genotype stability. This method simultaneously considers mean performance, regression coefficient, and deviation from regression to identify genotypes with consistent yield across multiple environments. Hybrids exhibiting high mean performance, a regression coefficient close to unity, and minimal deviation from regression are considered widely adapted and stable across environments.

Considering the increasing frequency of drought events associated with climate variability and the need for developing climate-resilient maize cultivars, the identification of stable and highyielding hybrids has become an important objective of maize breeding programmes.

Therefore, the present investigation was undertaken to evaluate the stability of experimental single-cross maize hybrids under both drought stress and non-stress conditions using stability analysis, with the objective of identifying superior hybrids possessing consistent performance across different environmental conditions.

Yield stability is governed by the ability of a genotype to maintain consistent performance across diverse environmental conditions, a characteristic largely determined by its genetic constitution (Borojevic, 1990)^[3]. Consequently, multi-environment evaluation has become an essential component of maize breeding programmes to identify hybrids with broad adaptability and minimal genotype $\times$ environment (G $\times$ E) interaction. Hybrids exhibiting stable performance under contrasting environmental conditions are preferred because they ensure reliable productivity across variable growing seasons and locations. Previous studies have shown that heterozygosity plays a critical role in enhancing yield stability in maize, making single-cross hybrids particularly valuable for commercial cultivation (Becker and Leon, 1988)^[4]. Likewise,

Eberhart and Russell (1969)^[5] reported that heterogeneous maize populations generally possess greater stability than homozygous populations and demonstrated that well-developed single-cross hybrids can perform as consistently as doublecross hybrids while achieving superior grain yield.

The development of drought-tolerant maize hybrids requires systematic evaluation of parental lines differing in their response to water deficit. Such assessments facilitate the identification of superior combinations capable of maintaining productivity under moisture-limited environments (Duvick *et al.*, 2004)^[6]. Furthermore, long-term genetic improvement in maize productivity has been attributed primarily to enhanced tolerance to environmental stresses rather than to increases in inherent yield potential alone (Tollenaar and Lee, 2002)^[7]. These findings emphasize the importance of incorporating stress adaptation and stability into modern maize breeding strategies.

Phenotypic stability is an important criterion for cultivar recommendation because it reflects the ability of a genotype to produce predictable performance across varying environments. Genotype $\times$ environment interaction is an inherent feature of quantitative traits, particularly grain yield and its associated components, and often complicates the identification of superior genotypes. Therefore, advanced breeding materials should be evaluated under multiple environmental conditions to accurately estimate their adaptability and stability before commercial release (Fan *et al.*, 2007)^[8]. Stability analysis provides a reliable framework for distinguishing genotypes with broad adaptation from those specifically adapted to either favourable or stress-prone environments.

Considering the increasing occurrence of drought and climatic variability, the identification of maize hybrids combining high yield potential with stable performance under both moisture stress and optimum moisture conditions has become a major breeding objective. Therefore, the present investigation was undertaken to evaluate the stability of single-cross maize hybrids under both stress and non-stress environments using genotype $\times$ environment interaction analysis, with the objective of identifying broadly adapted and high-yielding hybrids suitable for sustainable maize production.

Materials and Methods

Experimental site and climatic conditions

The present investigation was conducted during the kharif, rabi, and summer seasons of 2011-12, 2012-13, and 2013-14 at the Main Agricultural Research Station (MARS), College of Agriculture, Dharwad, Karnataka, India, located at 15°25' N latitude, 70° 25' E longitude, and an altitude of 678 m above mean sea level. Climatic observations, including daily rainfall and minimum and maximum temperatures recorded throughout the crop growth period, were obtained from the meteorological observatory of the research station and are presented in Appendix I.

During rabi 2011-12, the mean minimum and maximum temperatures ranged from 15.6 to 32.62 °C, with a total rainfall of 56.60 mm. In rabi 2012-13, temperatures varied from 15.65 to 29.20 °C, accompanied by 144.50 mm of rainfall. During the summer season of 2013-14, the corresponding temperatures ranged from 19.50 to 35.08 °C, with cumulative rainfall of 178.40 mm. Field evaluations were conducted under both managed drought stress and wellwatered (non-stress) conditions during the experimental period.

Plant materials and experimental design

Eight experimental single-cross maize hybrids developed during kharif 2011 were evaluated together with five widely cultivated commercial checks, namely 900M Gold, NK6240, Arjun, Bio-9681, and All Rounder. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications under both stress and non-stress environments.

The crop was sown on 14 December 2011, 12 October 2012, and 8 February 2013 for the respective evaluation seasons. Each experimental entry was planted in four rows, each measuring 4 m in length, with an inter-row spacing of 75 cm and a plant-to-plant spacing of 20 cm. Two seeds were dibbled manually at each hill, and thinning was carried out 10-15 days after sowing to retain one healthy plant per hill, thereby ensuring the desired plant population.

Stress and non-stress treatments

For the non-stress treatment, all recommended agronomic practices were followed, including regular furrow irrigation at intervals of 10-days throughout the crop growth period to maintain adequate soil moisture.

For the managed drought stress treatment, the crop received irrigation only up to 30 days after sowing. Thereafter, irrigation was withheld until harvest to induce moisture stress during the critical flowering and grain-filling stages. All other crop management practices were maintained uniformly across treatments. To minimize interference between moisture regimes, the irrigated and drought-stress experiments were separated by a 4 m-wide buffer strip planted with maize.

Data collection

Five healthy, competitive plants were randomly selected and tagged in each replication for every genotype. Observations The pooled analysis of variance (ANOVA) for stability parameters, following the model of Eberhart and Russell (1966)^[9], is presented in Table 1. Significant genotypic differences across environments were observed for seven traits, namely days to 50% anthesis, days to 50% silking, anthesis-silking interval (ASI), chlorophyll content at 60 days, 100-grain weight, grain yield (kg ha^{-1}), and shelling percentage. These results indicate the existence of considerable genetic variability among the evaluated hybrids, suggesting opportunities for selecting superior genotypes with enhanced adaptation to drought conditions.

The environmental effect was significant for most of the measured traits, reflecting substantial variation among the test environments. However, chlorophyll content at 60 days, plant height, ear height, number of kernel rows per cob, number of kernels per row, and shelling percentage were not significantly influenced by environmental variation. Genotype $\times$ environment ($G \times E$) interaction was significant for days to 50% anthesis, days to 50% silking, grain yield per plant, grain yield (kg ha^{-1}), 100-grain weight, and shelling percentage, demonstrating that the performance of these traits differed across environments.

Partitioning of the environmental variance showed that the environmental linear component was significant for most traits, indicating that environmental differences contributed substantially to phenotypic expression. In contrast, the $G \times E$ (linear) interaction was nonsignificant for most characters, except 100-grain weight and shelling percentage, suggesting relatively consistent responses of the genotypes across environments. The pooled deviation (non-linear component of $G \times E$ interaction) was non-significant for almost all characters,

were recorded on important morphological, physiological, and yield-related characters throughout the crop growth period. The recorded traits included days to 50% anthesis, days to 50% silking, anthesis-silking interval (ASI), plant height, ear height, chlorophyll content, relative water content, number of cobs per plant, cob length, cob girth, number of kernel rows per cob, number of kernels per row, 100-grain weight, shelling percentage, grain yield per plant, and grain yield per hectare. Mean values computed from the five sampled plants were used for statistical analyses.

Statistical analysis

The mean values for each trait across replications and environments were subjected to stability analysis to assess genotype $\times$ environment interactions. Stability parameters, including the mean performance, regression coefficient (b), and deviation from regression (S^2d), were estimated according to the model proposed by Eberhart and Russell (1966)^[9]. These parameters were used to identify maize hybrids exhibiting stable performance and broad adaptability under both drought stress and non-stress environments.

1	KDMI-15 X NEI-9202B	8	CI-4 X H S-4
2	NEI-9208B X H S-15	9	900M Gold
3	H S-4 X NEI-9202B	10	NK-6240
4	CI-4 X CML-446	11	Arjun
5	CM-111 X NEI-9202B	12	Bio-9681
6	H S-2 X NEI-9202B	13	Allrounder
7	H S-15 X H S-17		

Statistical analysis was carried out by Eberhart and Russell (1966)^[9] in WINDOSTAT 8.0 software.

Results and Discussion

Stability of promising hybrid combinations for grain yield, anthesis-silking interval, and number of cobs per plant under drought stress

The pooled analysis of variance (ANOVA) for stability parameters, following the model of Eberhart and Russell (1966), is presented in Table 1. Significant genotypic differences across environments were observed for seven traits, namely days to 50% anthesis, days to 50% silking, anthesis-silking interval (ASI), chlorophyll content at 60 days, 100-grain weight, grain yield (kg ha^{-1}), and shelling percentage. These results indicate the existence of considerable genetic variability among the evaluated hybrids, suggesting opportunities for selecting superior genotypes with enhanced adaptation to drought conditions.

The environmental effect was significant for most of the measured traits, reflecting substantial variation among the test environments. However, chlorophyll content at 60 days, plant height, ear height, number of kernel rows per cob, number of kernels per row, and shelling percentage were not significantly influenced by environmental variation. Genotype $\times$ environment ($G \times E$) interaction was significant for days to 50% anthesis, days to 50% silking, grain yield per plant, grain yield (kg ha^{-1}), 100-grain weight, and shelling percentage, demonstrating that the performance of these traits differed across environments.

Partitioning of the environmental variance showed that the environmental linear component was significant for most traits, indicating that environmental differences contributed substantially to phenotypic expression. In contrast, the $G \times E$ (linear) interaction was non-significant for most characters,

except 100-grain weight and shelling percentage, suggesting relatively consistent responses of the genotypes across environments. The pooled deviation (non-linear component of $G \times E$ interaction) was non-significant for almost all characters, except relative water content at 90 days, number of cobs per plant, and number of kernels per row. This finding indicates that environmental responses of most hybrids were largely predictable.

To identify stable hybrids, the three stability parameters proposed by Eberhart and Russell (1966)^[9]—mean performance ($\bar{y}$), regression coefficient (b_i), and deviation from regression (S^2d_i)—were estimated for three economically important traits: anthesis-silking interval, number of cobs per plant, and grain yield. The corresponding stability estimates and environmental indices are presented in Tables 2 and 3.

The environmental index for anthesis-silking interval ranged from -0.167 to 0.286 , indicating appreciable environmental variation across the three evaluation seasons. Among the evaluated hybrids, NK6240 exhibited the longest anthesis-silking interval (2.89 days), whereas HS-15 $\times$ HS-17 recorded the shortest interval (1.44 days). The overall mean anthesis-silking interval across environments was 2.14 days. Since a shorter anthesis-silking interval is generally associated with improved drought tolerance through better synchronization of pollen shedding and silk emergence, the superior performance of HS-15 $\times$ HS-17 suggests its potential as a drought-adapted genotype. Subsequent evaluation of the stability parameters (mean performance, regression coefficient, and deviation from regression) facilitated the identification of hybrids exhibiting consistent performance across varying moisture-stress environments.

All hybrids exhibited non-significant regression coefficients (b_i) and deviations from regression (S^2d_i), except the hybrid CM-111 $\times$ NEI-9202B, which showed a significant deviation from regression, indicating unpredictable performance across environments. The commercial hybrids 900M Gold, NK6240, Arjun, Bio-9681, and Allrounder recorded mean anthesis-to-silking interval (ASI) values higher than the population mean, with regression coefficients not significantly different from unity and nonsignificant deviations from regression, suggesting average stability across the test environments.

The environmental index for number of cobs per plant ranged from -0.084 to 0.130 , indicating considerable environmental variation over the three evaluation years. The overall mean number of cobs per plant was 1.22. Among the evaluated genotypes, Bio-9681 recorded the highest mean number of cobs per plant (1.33), whereas HS-15 $\times$ HS-17 recorded the lowest (1.13). None of the hybrids exhibited regression coefficients significantly different from unity. However, CI-4 $\times$ CML-446, NK6240, and Bio-9681 showed significant deviations from regression, indicating instability due to non-linear genotype $\times$ environment interaction. In contrast, NEI-9208B $\times$ HS-15 and CM-111 $\times$ NEI-9202B recorded mean values above the population mean with regression coefficients close to unity and nonsignificant deviations from regression, indicating stable performance over environments.

The environmental index for grain yield ranged from -286.27 to $567.49 \text{ kg ha}^{-1}$, reflecting substantial environmental variability among seasons. The hybrid KDMI-15 $\times$ NEI-9202B recorded the highest mean grain yield ($4456.47 \text{ kg ha}^{-1}$), whereas CI-4 $\times$ CML-446 produced the lowest mean grain yield ($2791.71 \text{ kg ha}^{-1}$). The overall mean grain yield across environments was $3753.69 \text{ kg ha}^{-1}$.

All hybrids exhibited non-significant regression coefficients and deviations from regression for grain yield, indicating predictable responses across environments. Among them, CM-111 $\times$ NEI-9202B, HS-4 $\times$ NEI-9202B, 900M, CI-4 $\times$ HS-4, HS-2 $\times$ NEI-9202B, HS-15 $\times$ HS-17, and KDMI-15 $\times$ NEI-9202B recorded grain yields above the population mean with regression coefficients close to unity and non-significant deviations from regression. According to the stability model of Eberhart and Russell (1966)^[9], these hybrids can be considered widely adapted and stable across the tested environments. Their consistent performance under stress conditions indicates their potential utility in breeding programmes aimed at improving drought tolerance and yield stability in maize.

Stability of promising hybrid combinations for grain yield (kg/ha), anthesis to silking interval and number of cobs per plant under non-stress situation

The data collected on different character in each of the eight single cross hybrids and five checks were evaluated for three years under non-stress to find out performance of each genotype over environment.

Pooled ANOVA for stability of different characters (Eberhart and Russell, 1966)^[9] are given in (Table 4). Genotypic differences pooled over environments were significant for nine characters viz., days to 50 per cent anthesis, days to 50 per cent silking, anthesis to silking interval (ASI), relative water content at 60 days, plant height, ear height, cob girth, number of kernels per row and 100 seed weight. Variance due to environments was significant for most of the characters except plant height, cob length, number of kernel rows per cob, grain yield per plant and shelling percentage. Variance due to $G \times E$ was non-significant for most of the characters except days to 50 per cent anthesis, days to 50 per cent silking, anthesis to silking interval (ASI), ear height, cob girth and 100-seed weight.

Environment linear component was significant for most of the traits except chlorophyll at 90 days, plant height, cob length, number of kernel rows per cob, grain yield per plant and shelling percentage. Whereas, $G \times E$ (linear) interaction was non-significant for most of the characters except days to 50 per cent anthesis, days to 50 per cent silking, anthesis to silking interval (ASI), plant height, ear height, cob girth and 100-seed weight. As regard to pooled deviation (nonlinear portion of variance), which is unpredictable portion of $G \times E$ interaction was non-significant for all the characters except days to 50 per cent anthesis, chlorophyll at 90 days and cob length.

The three stability parameters viz., mean ($\bar{x}$), regression coefficient b_i and deviation from linear regression line (S^2d_i) and environmental index were estimated for three important traits and the results obtained are present in the (Table 5 and 6). The environmental index ranging from -0.214 to 0.31 indicates significant variations over three years. The hybrids Bio-9681 maximum anthesis to silking interval (ASI) (3.33 days) while, KDMI-15 $\times$ NEI-9202B required minimum anthesis to silking interval (ASI) (1.88 days) and mean over three environments was 2.38 days. The hybrids viz., CI-4 $\times$ CML-446 showed significant value for regression coefficient higher than unity and all other hybrids showed non-significant value for regression coefficient and deviation from regression. The hybrids viz., NK6240, 900M and Bio-9681 were found to have higher mean value than population mean with b_i and S^2d_i values not significantly different from 1 and 0, respectively.

The environmental index ranging from -0.116 to 0.127 indicates significant variations over three years. The mean of number of cobs per plant over three environments was 1.25. The maximum

(1.42) and minimum (1.15) number of cobs per plant were recorded in the hybrids viz., CI-4 × CML-446 and KDMI-15 × NEI-9202B, respectively. None of the hybrids had the significant regression values and deviation from regression either lower or higher than unity. The hybrids viz., NEI-9208B × HS-15, 900M, Bio-9681, CI-4 × HS-4 and CI-4 × CML-446 were found to have higher mean value than population mean with *bi* and *S²di* values not significantly different from 1 and 0, respectively.

The environmental index ranging from -421.204 to 361.071 indicates significant variations over three years. The hybrids viz., H S-2 × NEI-9202B showed the highest (5959.94 kg) mean value, while, CI-4×CML-446 showed the lowest (4536.43 kg) mean value for grain yield (kg/ha). The average grain yield (kg/ha) over three environments was 5389.38 kg. All hybrids showed non-significant regression coefficient and deviation from regression except the hybrid viz., CM-111×NEI-9202B showed significant deviation from regression. The hybrid viz., KDMI-15 × NEI-9202B have regression coefficient equal to unity. The hybrids viz., Arjun, NEI-9208B×HS-15, NK6240, CM-111 × NEI-9202B, 900M, CI-4 × HS-4, KDMI-15 × NEI-9202B, HS-4 × NEI-9202B and HS-2×NEI-9202B were found to have higher mean value than population mean with *bi* and *S²di* values not significantly different from 1 and 0, respectively.

The results of DSI presented in Table 7. Indicated among eight single cross hybrids and five checks, the hybrids viz. (NEI-9208B × H S-15) recorded highest (0.65) and (H S-15×H S-17) lowest (0.26) DSI values for grain yield (kg/ha) with an overall mean of (0.44).

Once the genotype × environment interactions were found to be significant, the next test is to identify stable genotypes, which interact less with the environments. Many stability models have been developed to identify the stable genotype. Eberhart and Russell (1966) [9] model is the one which has been used in maize and in other crops by several workers. According to Eberhart and Russell (1966) [9], a variety is said to be stable when regression coefficient (*bi*) is equal to one, deviation from regression (*S²di*) as close to zero as possible with high mean performance. Allard and Bradshaw (1964) [10] suggested selection of stable genotype depends upon genotype having less interact with environments.

The above three measures of assessing the stability of genotype viz., mean, regression coefficient (*bi*) and the mean square deviation (*S²di*) were employed in assessing the stability of genotypes included in the present study. The linear regression (*bi*) could simply be regarded as the measure of response of a particular genotype and it is of greater than one then the genotypes is said to be sensitive to environment changes but adopted to favourable environments. If it is less than one it indicates above average stability. If this is accompanied by the high mean value then, the genotype is said to be better adapted to widely differing situations for unfavourable environment and if the mean value is low, greater G×E interaction indicated (Finlay and Wilkinson, 1963) [11]. On the other hand, deviation around the regression line is considered as a better measure of stability. With respect to the non-linear component of the G×E interaction, the genotype with the lowest standard deviation will be the most stable and vice-versa. The results of present study on stability parameter are discussed below.

Considering stability parameters of genotypes tested over environments, none of the genotypes had stable performance. Among these HS-15×HS-17 was the earliest to anthesis to silking interval while, 900M was late to anthesis to silking

interval. The genotypes which require minimum number of days to anthesis to silking interval are more desirable. So, H S-15 × H S-17 was the stable and ideal genotype for days to anthesis to silking interval. The hybrids CI-4×CML-446, RMH-2, 900M, Bio-9681, H S-15×HS-17, Arjun and NK-6240 had the regression value more than unity, indicating its suitability to favourable environments. These findings are in accordance with Arun and Singh (2004b) [12], Kaundal and Sharma (2006) [13], Nagabhushan (2008) [14] and Vijaykumar (20008).

The stability parameters for number of cobs per plant exhibited the genotypes Arjun and H S-15×HS-17 as stable across the environments, statistically regression (*bi*) value is equal to unity and *S²di* approaches to zero. Among these Bio-9681 was the highest number of cobs per plant while, H S-15×HS-17 was lowest number of cobs.

The hybrids KDMI-15×NEI-9202B, CI-4 × H S-4, 900M, H S-4×NEI-9202B, CI-4 × CML-446 and Allrounder had the regression value more than unity and non significant *S²di* indicating its suitability for specific favourable environments. The hybrids NEI-9208B×H S-15, RMH-2, H S-2×NEI-9202B and CM-111×NEI-9202B statistically regression coefficient is less than unity and non significant *S²di*. Thus, these hybrids possessing above average stability would be adoptable to unfavorable environments or specifically adoptable to poor environments. CI-4×CML-446 had the regression value more than unity and significant *S²di*. NK-6240 and Bio-9681 had the regression value less than unity and significant *S²di* indicating its suitability for specific favourable environments with unpredictable performance.

Considering stability parameters of genotypes tested over environments, the hybrids NK-6240, CM-111 × NEI-9202B, RMH-2, H S-15×HS-17, H S-4×NEI-9202B, CI-4×CML-446, KDMI-15 × NEI-9202B and NEI-9208B×HS-15 which had regression value less than unity whereas, the hybrids Bio-9681, H S-2 × NEI-9202B, Arjun, CI-4 × H S-4, 900M and Allrounder had regression value more than unity are suitable for poor and favourable environments respectively.

The hybrids CM-111 × NEI-9202B, HS-4 × NEI-9202B, 900M, CI-4 × HS-4, HS-2 × NEI-9202B, HS-15 × HS-17 and KDMI-15 × NEI-9202B had higher mean performance, nonsignificant regression coefficient and deviation from regression, which revealed their adaptation to all the environments. While, KDMI-15 × NEI-9202B exhibited the highest and CI-4 × CML-446 exhibited the lowest mean value. Similar results are also reported by Satyanarayan and Kumar (1995), Single crosses as stable as double crosses were reported (Machado *et al.*, 2008) [15] indicating prospects for identifying elite hybrids. Whereas, Romay *et al.* (2010) [16] reported that commercial hybrids were high yielding and more stable than populations under stress. Kuchanur (2010) [17], Lata *et al.* (2011) [18], Ijaz-Ul-Hassan *et al.* (2011) [19], Badu-Apraku and Oyekunle (2012) [20], Khalil (2013) [21] and Paulo Roberto *et al.* (2014) [22].

Considering stability parameters of 13 genotypes tested over environments, none of the genotypes had stable performance. Among these KDMI-15 × NEI-9202B was require minimum days to anthesis to silking interval while, Bio-9681 was requires maximum days to anthesis to silking interval. The genotypes which require minimum number of days to anthesis to silking interval are more desirable. So, KDMI-15 × NEI-9202B was the ideal genotype for days to anthesis to silking interval.

The hybrids Bio-9681, CM-111 × NEI-9202B, KDMI-15 × NEI-9202B, RMH-2, NK-6240, H S-2×NEI-9202B and Allrounder had the regression value more than unity, indicating

its suitability to favourable environments. The hybrids Arjun, 900M, H S-4 × NEI-9202B, NEI-9208B × HS-15, H S-15 × HS-17 and CI-4 × HS-4 statistically regression coefficient is less than unity and non significant S^2d_i . Thus, these hybrids possessing above average stability would be adoptable to unfavorable environments or specifically adoptable to poor environments. CI-4 × CML-446 had significant regression value indicating its suitability to favourable environments. These findings are in accordance with [Arun and Singh \(2004b\)](#) ^[12], [Kaundal and Sharma \(2006\)](#) ^[13], [Nagabhushan \(2008\)](#) ^[14] and [Vijaykumar \(20008\)](#).

The stability parameters for number of cobs per plant exhibited the genotype Arjun as stable across the environments, statistically regression (b_i) value is equal to unity and S^2d_i approaches to zero. Among these CI-4 × CML-446 was the highest number of cobs per plant while, RMH-2 was lowest number of cobs. The hybrids NEI-9208B × HS-15, 900M, Bio-9681, CI-4 × HS-4 and CI-4 × CML-446 were found to have higher mean value than population mean

The hybrids CM-111 × NEI-9202B, H S-4 × NEI-9202B, H S-15 × H S-17, KDMI-15 × NEI-9202B, NEI-9208B × H S-and Bio-9681 had the regression value more than unity and non significant S^2d_i , indicating its suitability for specific favourable environments. The hybrids Allrounder, NK-6240, CI-4 × CML-446, 900M, H S-2 × NEI-9202B and CI-4 × H S-4 statistically regression coefficient is less than unity and non significant S^2d_i . Thus, these hybrids possessing above average stability would be adoptable to unfavorable environments or specifically adoptable to poor environments.

The stability parameters for grain yield (kg/ha) exhibited the genotype KDMI-15 × NEI-9202B as stable across the environments, statistically regression (b_i) value is equal to unity and S^2d_i approaches to zero, Considering stability parameters of 14 genotypes tested over environments, the hybrids NK-6240, Arjun, H S-15 × HS-17; 2 NEI-9208B × HS-15, H S-4 × NEI-9202B and H S-2 × NEI-9202B which had regression value less than unity whereas, the hybrids 900M, RMH-2, CI-4 × CML-446, Bio-9681, Allrounder and CI-4 × H S-4 had regression value more than unity are suitable for poor and favourable environments respectively.

The hybrids Arjun, NEI-9208B × HS-15, NK6240, 900M, CI-4 × HS-4, KDMI-15 × NEI-9202B, HS-4 × NEI-9202B and HS-2 × NEI-9202B had higher mean performance, nonsignificant regression coefficient and deviation from regression, which revealed their adaptation to all the environments. While, H S-2 × NEI-9202B exhibited the highest and CI-4 × CML-446 exhibited the lowest mean value. CM-111 × NEI-9202B significant deviation from regression indicating their average sensitivity to environments with unpredictable performance. Similar results are also reported by [Satyanarayan and Kumar \(1995\)](#) ([Machado et al., 2008](#)) ^[15], [Nagabhushan \(2008\)](#) ^[14] and [Vijaykumar \(20008\)](#), [Kuchanur \(2010\)](#) ^[17], [Romay et al. \(2010\)](#) ^[16] and [Badu-Apraku and Oyekunle \(2012\)](#) ^[20].

The results of DSI indicated among eight single cross hybrids and five checks, single cross hybrids viz. (H S-15 × H S-17) exhibited lowest DSI values for grain yield (kg/ha). Similar results are also reported by [Jafaria et al. \(2009\)](#), [Kuchanur \(2010\)](#) ^[17], [Majid et al. \(2010\)](#) ^[23], [Lata et al. \(2011\)](#) ^[18], [Ijaz-Ul-Hassan et al. \(2011\)](#) ^[19], [Badu-Apraku and Oyekunle \(2012\)](#) ^[20], [Moradi et al. \(2012\)](#), [Khalil \(2013\)](#) ^[21] and [Paulo Roberto et al. \(2014\)](#) ^[22].

Table 1: Pooled analysis of variance for stability analysis ([Eberhart and Russell, 1966](#)) ^[9] for grain yield (kg/ha) in maize over three years under stress situation at College of Agriculture Dharwad

Sources of variation	df	Grain yield (kg/ha)
Rep within Env	6	2553327.00 **
Varieties	13	885331.30**
Env.+ (Var.* Env.)	28	22758.00*
Environments	2	3381587.00**
Var.* Env.	26	87463.48
Environments (Lin.)	1	6763173.00**
Var.* Env.(Lin.)	13	65963.56
Pooled Deviation	14	101180.30
Pooled Error	78	187925.80
Total	41	501134.90

& ** - Significant at 0.05 and 0.01 level of probability, respectively

Table 2: Environmental indices for grain yield (kg/ha) in maize over three years under stress situation at College of Agriculture Dharwad

Characters	Environmental index		
	Env. 1	Env. 2	Env. 3
Grain yield kg/ha	-281.23	-286.27	567.49

Table 3: Stability parameters of single cross hybrids of maize for grain yield (kg/ha) in maize over three years under stress situation at College of Agriculture Dharwad

Genotypes / Varieties	Grain yield (kg/ha)		
	Mean	b_i	S^2d_i
KDMI-15 x NEI-9202B	4456.47*	0.51	-345332**
NEI-9208B x H S-15	3002.77	0.46	-7375
H S-4 x NEI-9202B	4008.20	0.75	-352507**
CI-4 x CML-446	2791.71	0.68	-354141
CM-111 x NEI-9202B	3806.28	0.93	-256331
H S-2 x NEI-9202B	4322.98	1.13	-220703
H S-15 x H S-17	4395.42	0.80	-352297**
CI-4 x H S-4	4263.73	1.39	-356815**
900M (check)	4120.05	1.42	-22069
NK-6240 (check)	3634.94	0.95	-338912
Arjun (check)	3647.86	1.28	-298403
Bio-9681 (check)	3710.98	1.12	-356482**
Allrounder (check)	3241.93	1.75	-54265
Population Mean	3753.69		

- Significant at 5% probability level ** - Significant at 1% probability level b_i – Regression coefficient S^2d_i – Deviation from regression

Table 4: Pooled analysis of variance for stability analysis ([Eberhart and Russell, 1966](#)) ^[9] for grain yield (kg/ha) in maize over three years under non stress situation at College of Agriculture Dharwad

Sources of variation	df	Grain yield (kg/ha)
Rep within Env.	6	2343130.00**
Varieties	13	558495.10
Env.+ (Var.* Env.)	28	390051.00
Environments	2	2179799.00*
Var.* Env.	26	252378.10
Environments (Lin.)	1	4359597.00**
Var.* Env.(Lin.)	13	26470.58
Pooled Deviation	14	444122.40
Pooled Error	78	263739.50
Total	41	443460.10

& ** - Significant at 0.05 and 0.01 level of probability, respectively

Table 5: Environmental indices for grain yield (kg/ha) in maize over three years under non stress situation at College of Agriculture Dharwad

Characters	Environmental index		
	Env. 1	Env. 2	Env. 3
Grain yield kg/ha	60.13	-421.20	361.07

Table 6: Stability parameters of single cross hybrids of maize for grain yield (kg/ha) in maize over three years under non stress situation at College of Agriculture Dharwad

Genotypes / Varieties	Grain yield (kg/ha)		
	Mean	bi	s ² di
KDMI-15 x NEI-9202B	5765.74*	1.00	-185.63
NEI-9208B x H S-15	5471.15	0.65	-45.91
H S-4 x NEI-9202B	5802.78*	0.63	452.37
CI-4 x CML-446	4536.44	1.21	160.94
CM-111 x NEI-9202B	5495.96	1.31	-53.14
H S-2 x NEI-9202B	5959.94*	0.55	346.73
H S-15 x H S-17	5370.62	0.69	-7.04
CI-4 x H S-4	5748.19*	1.42	565.63
900M (check)	5610.44	1.05	-216.77
NK-6240 (check)	5472.41	0.90	-217.68
Arjun (check)	5401.00	0.85	-232.32
Bio-9681 (check)	5272.04	1.27	890.14*
Allrounder (check)	4967.72	1.32	-199.02
Population Mean	5389.39		

- Significant at 5% probability level ** - Significant at 1% probability level
 bi – Regression coefficient S²di – Deviation from regression

Table 7: Drought susceptibility index of 13 F hybrids for grain yield (kg/ha)

Hybrids	Drought susceptibility index
KDMI-15 X NEI-9202B	0.33
NEI-9208B X H S-15	0.65
H S-4 X NEI-9202B	0.44
CI-4 X CML-446	0.55
CM-111 X NEI-9202B	0.44
H S-2 X NEI-9202B	0.39
H S-15 X H S-17	0.26
CI-4 X H S-4	0.37
900M (check)	0.38
NK-6240 (check)	0.48
Arjun (check)	0.47
Bio-9681 (check)	0.43
Allrounder (check)	0.50
Mean	0.44

In conclusion the investigation concluded that stability analysis of 13 single cross hybrids under stress indicated that seven hybrids viz., CM-111 × NEI-9202B, HS-4 × NEI-9202B, 900M, CI-4 × HS-4, HS-2 × NEI-9202B, HS-15 × HS-17 and KDMI-15 × NEI-9202B were stable across seasons and locations and stability analysis of 13 single cross hybrids under non-stress indicated that eight hybrids viz., Arjun, NEI-9208B × HS-15, NK6240, 900M, CI-4 × HS-4, KDMI-15 × NEI-9202B, HS-4 × NEI-9202B and HS-2 × NEI-9202B were stable across seasons.

References

- Yadav OP, Karjagi CG, Kumar B, Jat SL, Chawla JS, Kaul J, *et al.* Maize improvement in India. 12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed. 2014.
- Edmeades GO, Cooper M, Lafitte R, Zinselmeier C, Ribaut JM, Habben JE, *et al.* Abiotic stress and staple crops. In:

Nosberger J, Geiger HH, Struic PC, editors. Crop science: Progress and Prospects. Proc. of Third Int. Crop Sci. Congress. Wallingford, Oxon, U. K.: CAB Int.; 2001:137-154.

- Borojevic S. Principles and Methods of Plant Breeding. Developments in Crop Science Vol.17. New York: Elsevier science Publishing Company INC; 1990.
- Becker HC, Léon J. Stability analysis in plant breeding. Plant Breed. 1988;101(1):1-23.
- Eberhart SA, Russell WA. Yield and Stability for a 10-Line Diallel of Single-Cross and Double-Cross Maize Hybrids¹. Crop Science. 1969;9(3):357-361. <https://doi.org/10.2135/cropsci1969.0011183x00090030034x>
- Duvick DN, Smith JCS, Cooper M. Long-term selection in a commercial hybrid maize breeding program. In: Janick J, ed. Plant breeding reviews: longterm selection: crops, animals, and bacteria, Vol. 24, Part 2. New York: John Wiley & Sons; 2004:109-151.
- Tollenaar M, Lee EA. Yield potential, yield stability and stress tolerance in maize. Field Crops Res. 2002;75(2):161-169.
- Fan XM, Kang MS, Chen H, Zhang Y, Tan J, Xu C. Yield stability of maize hybrids evaluated in multi-environment trials in Yunnan, China. Agron. J. 2007;99:220-228.
- Eberhart SA, Russell WA. Stability parameters for comparing varieties. Crop Sci. 1966;6:36-40.
- Allard RW, Bradshaw AD. Implication of genotype x environmental interaction in applied plant breeding. Crop Sci. 1964;4:503-505.
- Finlay KW, Wilkinson GN. Analysis of adaptation in plant breeding programme. Aust. J. Agric. Res. 1963;14:742-754.
- Arun kumar, Singh NN. Stability studies of inbred and single crosses in maize. Ann. Agric. Res. 2004b;25:142-148.
- Kaundal R, Sharma BK. Genotype x environment interaction and stability analysis for yield and other quantitative traits in maize (*Zea mays* L.) under rainfed and high rainfall valley areas of the submontane. Res. Crop. 2006;7(1):171-180.
- Nagabhushan. Relative stability analysis of public and private bred hybrids of maize (*Zea mays* L.). MSc Thesis. University of Agricultural Sciences, Dharwad, Karnataka (India); 2008.
- Machado JC, Souza JC, Ramalho AP, Lima JL. Yield stability in single and double crosses of maize originated from the same gene pool. Bragantia. 2008;67(3):627-631.
- Romay MC, Malvar RA, Campo L, Alvarez A, Gonzalez JM, Ordas A, *et al.* Climatic and genotypic effects for grain yield in maize under stress conditions. Crop Sci. 2010;50(1):51-58.
- Kuchanur PH. Identification of drought tolerance maize (*Zea mays* L.) germplasm. Ph.D. Thesis. Univ. Agril. Sci., Dharwad, Karnataka (India); 2010.
- Lata SS, Guleria JD, Katna G, Sood BC, Kalia V, Anand Singh. Stability analysis in maize (*Zea mays* L.) hybrids across locations. Electronic J. Pl. Breed. 2011;1(3):239-243.
- Ijaz-Ul-Hassan S, Tariq M, Islam N. Assessment of newly developed maize single cross hybrids in two seasonal regimes. J. Agric. Soc. Sci. 2011;7:139-142.
- Badu BA, Oyekuncle H. Genetic analysis of grain yield and other traits of extraearly yellow maize inbred lines and

- hybrid performance under contrasting environments. *Field Crops Res.* 2012;129:99-110.
21. Khalil MAG. Stability Analysis for Promising Yellow Maize Hybrids under different locations. *Alex J. Agric. Res.* 2013;58(3):279-286.
 22. Paulo RDS, Dilson AB, Ana BL, Lindolfo S. Adaptability and stability of corn hybrids grown for high grain yield. *Acta Scientiarum.* 2014;36(2):175-181.
 23. Majid S, Rajab C, Eslam M, Farokh D. Estimation of combining ability and gene action in maize using line × tester method under three irrigation regimes. *J. Res. Agric. Sci.* 2010;6:19-28.
 24. Joshi P, Mane M. Effectiveness of the Slump Test in Diagnosing and Managing Lower Back Pain in Fast Bowlers: A Study on Rehabilitation outcomes. *Social Science Reports.* 2026.<https://doi.org/10.51470/SSR.2026.10.01.106>
 25. Kaukab S, Mishra A, Sunita T. Application of Convolutional Neural Networks for Ripeness Classification of Fruits. *Agriculture Reviews: An International Journal.* 2025.<https://doi.org/10.51470/AR.2025.4.2.15>
 26. Chauhan K. The Impact of Microfinance and Self-Help Groups on Women's Empowerment and Social Inclusion. *Discover Economics and Finance: An International Journal.* 2026.<https://doi.org/10.51470/DEF.2026.4.1.01>
 27. Debnath A. Molecular Regulation of Salt Stress Tolerance in Fruit Crops with Special Emphasis on WRKY Transcription Factors. *Plant Science Review.* 2020.<https://doi.org/10.51470/PSR.2020.01.01.09>
 28. Debnath A, Sarkar A. Genetic and Molecular Basis of Stress Tolerance in Temperate and Tropical Fruit Crops. *Agriculture Reviews: An International Journal.* 2022.<https://doi.org/10.51470/AR.2022.1.1.01>
 29. Debnath A. Hormonal Crosstalk and Signal Transduction Mechanisms Regulating Plant Reproductive Development. *Agriculture Reviews: An International Journal.* 2022.<https://doi.org/10.51470/AR.2022.1.1.05>
 30. Debnath A. Climate Resilient Horticultural Crops and Breeding Strategies for Abiotic Stress Adaptation. *Xplore Environment: An International Journal.* 2021.<https://doi.org/10.51470/XE.2021.1.1.01>
 31. Debnath A. Environmental Implications of Peat-Based Growing Media on Carbon Balance and Greenhouse Gas Emissions in Horticultural Systems. *Xplore Environment: An International Journal.* 2021.<https://doi.org/10.51470/XE.2021.1.2.01>
 32. Satyanarana E, Kumar RS. Phenotypic stability studies for grain and straw yields in maize composites. *J. Maharashtra Agric. Univ.* 1995;20:225-226.
 33. Vijaykumar. Stability analysis of maize (*Zea mays* L.) inbred lines/introductions for yield parameters. MSc Thesis, Univ. Agril. Sci., Dharwad, Karnataka (India). 2008.
 34. Nutrition and Environmental Security 30 Oct- 1 Nov 2014 Bangkok, Thailand, pp. 263-273. 2014.

Appendix I: Mean monthly meteorological data during 2011, 2012, 2013 and 2014 (experimental years) of Main Agricultural Research Station, Dharwad

Month	Rainfall (mm)				Temperature (°C)								Relative humidity (%)			
					Mean maximum				Mean minimum							
	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014
January	1.0	0.0	0.0	0.0	29.2	29.8	31.2	29.5	12.6	14	14.5	14.7	60.1	55.5	47.0	
February	21.6	0.0	2.2	0.0	30.8	32.3	32.6	31.1	14.0	15.9	16.8	16.1	48.5	53.4	51.0	
March	0.8	0.0	42.0	11.4	35.2	35.8	35.3	34.5	18.6	15.9	19.2	18.5	43.9	40.7	48.0	
April	78.0	56.6	10.0		34.9	35.7	36.9		20.2	18.4	20.2		55.7	57.1	51.0	
May	66.6	3.8	124.2		34.7	35.6	35.5		21.3	21.2	21.8		61.6	50.8	61.0	
June	194.0	43.4	75.4		27.5	30.6	28.0		21.3	21.5	20.8		83.8	73.7	82.0	
July	133.0	112.2	170.2		26.9	27.2	25.4		20.6	20.9	20.3		85.8	84.6	89.0	
August	124.2	90.0	98.4		26.7	32	26.7		20.7	19.3	19.9		86.7	80.4	85.0	
September	82.8	89.6	133.6		28.1	28	27.9		19.9	19.8	20.2		79.7	75.8	81.0	
October	219.7	89.2	75.6		29.9	28.4	28.8		19.5	17.8	19.4		73.6	64.7	76.0	
November	4.6	35.7	2.2		29.8	27.7	29.0		15.8	15.5	15.8		55.9	57.7	64.0	
December	0.0	19.6	0.0		29.5	29.5	28.4		13.8	14.8	14.7		56.3	55.9	56.1	
Total	926.3	540.1	733.8	11.4	-	-	-	-	-	-	-	-	-	-	-	-