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Assessment of Genotype × Environment Interaction and Phenotypic Stability in Single Cross Hybrids Subjected to Drought Stress in Maize (*Zea mays* L.)

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ABSTRACT

Maize production and productivity are hampered by global climate change. The primary concern of crop breeders always have been about high and stable yields. The genotype × environment interaction alters the relative grain yield of genotypes in different environments and makes it difficult to select superior genotypes. Therefore the Eberhart and Russell model for genotype × environment interaction analysis was taken up in the present study for the prediction of performances and phenotypic stability of the single cross hybrids synthesized by crossing 15 inbreds with 3 testers in Line × Tester mating design. All the 18 parents, 45 F_{1s} and 3 checks were evaluated for fifteen quantitative and qualitative traits over three different environments *viz*., optimal environment, drought stress environment at tasseling stage, and drought stress environment at grain filling stage, during *spring* 2021, in a Randomized Complete Block Design with three replications. The ANOVA on the basis of pooled data unraveled significance of mean sum of squares due to genotypes and due to genotype × environment interaction which affirms existence of variability and interplay between genotypes and their environments. Out of 45, 39 hybrids expressed non-significant deviation from regression (S^2di) unveiling their higher predictability over changing environments for grain yield per plant. The hybrid L15×T2 had higher mean value than population mean along with regression coefficient equivalent to unity (bi=1) hence was recognized as highly stable and superior for grain yield per plant, and suitable for cultivation in different kinds of environments. Among other hybrids, L6×T2, L14×T2, L1×T3, L8×T1, L10×T1, L14×T1, L15×T1, L12×T2, L4×T3, L15×T3 were noted stable in performance over the environments for flowering traits. While L10×T2, L2×T2, L15×T2, L11×T1, L3×T2 and L5×T2 were recognized stable in performance for higher yield and its component traits over the environments.

Key words: *Genotype × Environment Interaction, Maize, Drought Stress, Stability, Regression Coefficient.*

Introduction

Maize (*Zea mays* L.) is the third major cereal crop in the world after wheat and rice and is used for both livestock feed and human consumption (Prasanna *et al*., 2001). The present day maize (*Zea mays* L.) is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions making it an all season crop in India. Among the maize growing countries, India rank 4^{th} in area and 7^{th} in production, representing around 4% of world maize area and 2% of total production. As the world human population is increasing, the demand of maize is also increasing at global level. Maize production and productivity are hampered by global climate change. The average maize yields in the developing countries are still low due to abiotic, biotic and socioeconomic constraints (Shiferaw *et al*., 2011). Drought is the most important abiotic stress factor for maize production in both the temperate and tropical environments and annual average yield losses to drought are estimated to be 15% of potential yield on a global basis (Edmeades, 2008). The primary concern of crop breeders always have been about high and stable yields. In this regard, development of maize hybrids tolerant to drought stress condition with fair yield levels becomes a necessity.

Yield, being a complex genetic trait, is governed by multiple genes which are influenced by genotype, environment, and genotype × environment interaction (G × E I). G×E interaction alters the relative grain yield of genotypes in different environments and makes it difficult to select superior genotypes (Cornelius and Crossa, 1999). To screen cultivars with high and stable yields, breeders conduct multi-environment testing of the genotypes in replicated trials, and observe their performances and analyze G × E interaction effect. When all the genotypes behave differently in different environments, interaction is recognized. Therefore, various statistical methods have been developed for study of G × E interaction for cultivar stability analysis in multi-environment trials. The Eberhart and Russell model (1966) for genotype × environment interaction analysis was taken up in the present study, which combines linear (b_i) and non-linear (S^2_{di}) components of genotype by environment interaction for prediction of performances of the parent inbreds and their crosses in a set of three different environments.

Materials and Methods

A set of 15 inbreds (female parents) were crossed to 3 narrow base testers (male parents) in a Line × Tester mating design during *rabi* 2019-20 at Instructional farm, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India. The source of the experimental material was All India Coordinated Research Project on Maize (AICRP on Maize), MPUAT, Udaipur. Thus, the 15 inbreds, 3 testers, their 45 F_{1s} and 3 commercial checks (Table 1) were evaluated during *spring* 2021 at Instructional farm, Rajasthan College of Agriculture, MPUAT, Udaipur, over three different environments *viz*., optimal environment, drought stress environment at tasseling stage, and drought stress environment at grain filling stage (Table 2), that were created by controlling irrigation at different crop growth stages, while each environment was spaced by a 2 m wide channel from the other environment in order to check the effect of moisture by lateral flow.

The experiment was executed in a Randomized Complete Block Design with three replications for all the three environments. Each replicated entry had single row of 3 m length with a spacing of 60 cm between the rows and 20 cm between the plants. Ten randomly chosen plants of each entry in each replication were tagged to record observations on all the traits *viz*., total chlorophyll content (SCMR), leaf senescence score, plant height (cm), cob height (cm), cob length (cm), cob girth (cm), grain yield per plant (g), 100-grain weight (g) except days to 50 per cent tasseling, days to 50 per cent silking, anthesis-silking interval, proline content (ìg/100 mg fresh leaf tissue), grain protein content (%), grain oil content (%) and grain starch content (%) as they were recorded on plot basis.

The phenotypic stability of genotype for different characters was estimated according to model proposed by Eberhart and Russell (1966). Regression of the mean value of a trait of the individual genotype on the environmental index and deviation of the regression coefficient from unity were used to estimate phenotypic stability of all the genotypes for each trait. The stability parameters for prediction of hybrid performance have been presented in Table 3.

The statistical model of the analysis was as follows:

$Y_{ij} = m_i + b_i I_j + d_{ij}$

Where,

Y_{ij} = Mean performance of i^{th} genotype in j^{th} environment

m_i = Mean of i^{th} genotype over all the environments

b_i = The regression coefficient of i^{th} genotype

d_{ij} = Deviation from regression of the i^{th} genotype

I_j = the environmental index for j^{th} environment

Results

Eberhart and Russell (1966) specified a stable cultivar as one with a regression coefficient of cultivar means on the environmental indices equivalent to unity (b_i = 1) and approaching to zero or a minimum deviation from the regression line (S^2_{di} = 0). A significant deviation from the regression line (S^2_{di}) indicates that performance of that genotype is difficult or not possible to predict for a given range of environments whereas non-significant S^2_{di} validates for its predictability.

The ANOVA (Table 4) on the basis of pooled data unraveled significant mean sum of squares due to genotypes for all the characters, and also disclosed significant genotype × environments (G × E) interaction. The mean sum of squares due to environment (E) plus genotype × environments (G × E) interaction were noted significant for all the fifteen characters, which was further split into three components *viz*., environment (linear), G × E interaction (linear) and pooled deviation (non-linear). The regression analysis disclosed that mean sum of squares due to environment (linear) component variance were noted non-significant for all the characters except proline content and grain oil content, while mean sum of squares due to genotype × environments (G × E) interaction (linear) were noted significant for all the fifteen characters. The mean sum of squares due to pooled deviation were noted significant for all the characters taken under investigation except cob length and cob girth, which unravels that the genotypes possessed considerable variation for stability, and for such characters the prediction of performance of genotypes across the environments would be difficult.

The deviation from regression (S^2_{di}) for grain yield per plant was noted non-significant for 15 out of the 18 parent inbreds, denoting their predictable behavior for this character. Out of all hybrids, 39 hybrids expressed non-significant deviation from regression (S^2di) unveiling their higher predictability over changing environments for grain yield per plant. Among them, L15×T2 had higher mean value than population mean along with regression coefficient equivalent to unity (bi=1) hence was marked absolutely stable for grain yield per plant and suitable for cultivation in different kinds of environments. Among the others, L2×T1, L3×T1, L8×T1, L11×T1, L12×T1, L2×T2, L4×T2, L6×T2, L8×T2,

Table 1. Details of experimental material

S. No.	Symbol	Line Code	S. No.	Symbol	Line Code
1	L1	EI-11-3	12	L12	EI-2188
2	L2	EI-08	13	L13	EI-2518-1
3	L3	EI-2521	14	L14	EI-12-2
4	L4	EI-2448-1	15	L15	EI-03-3
5	L5	EI-2188-2	16	T1	EI-586-2
6	L6	EI-2449-2	17	T2	EI-2156
7	L7	EI-01-2	18	T3	EI-670-2
8	L8	EI-2448	19	C1	Pratap QPM Hybrid-1
9	L9	EI-2138-1	20	C2	Pratap Hybrid Maize-3
10	L10	EIQ-212	21	C3	Pratap Makka-9
11	L11	EI-561-1			

Table 2. Details of experimental environments

S. No.	Environment	Drought stress condition
1	Environment 1 (E1)	Normal irrigation
2	Environment 2 (E2)	Drought stress imposed at tasseling stage (for 20 days)
3	Environment 3 (E3)	Drought stress imposed at grain filling stage (for 20 days)

Table 3. Classification of stability parameters

Regression	Genotypic mean	Deviation from regression (S^2d_i)	Stability	Remarks
b_i =1	High	Low	Average (Absolute)	Well adapted to all environments
b_i =1	Low	Low	Average	Poor adapted to all environments
b_i >1	High	High	Below average	Specifically adapted to favorable environments
b_i <1	High	High	Above average	Specifically adapted to unfavorable environments

L11×T2, L1×T3, L4×T3 and L8×T3 disclosed higher mean values than the population mean along with regression coefficient more than unity (bi>1), displaying their stability and adaptability in favorable environments for higher grain yield per plant. The hybrids L10×T1, L14×T1, L15×T1, L3×T2, L5×T2, L7×T2, L10×T2, L12×T2, L14×T2, L3×T3, L6×T3 and L15×T3 disclosed higher mean values than the population mean along with regression coefficient less than unity (bi<1), displaying their stability and suitability for higher grain yield per plant in unfavorable environments.

Among the hybrids, L6×T2 for 50 per cent tasseling, L14×T2 and L1×T3 for 50 per cent silking, and L6×T1, L8×T1, L10×T1, L14×T1, L15×T1, L9×T2, L12×T2, L4×T3, L7×T3 and L15×T3 for anthesis-silking interval had lower mean values than population mean, non-significant deviation from regression (S^2di) along with regression coefficient equivalent to unity (bi=1) which says about their predictability and stability over different environments for early flowering. For the physiological traits relevant to drought tolerance, the hybrids L10×T2 and L12×T3 for total chlorophyll content, and L2×T2 for leaf senescence score had higher mean value than population mean and lower mean value than population mean, respectively, and non-significant deviation from regression (S^2di) along with regression coefficient equivalent to unity (bi=1) which advocated their stable performance and suitability for cultivation in various kinds of environments. None of the hybrids exhibited higher mean value with regression coefficient equivalent to unity (bi=1) on pooled basis for proline content. For the yield attributing traits, the hybrids L4×T1 for cob height, L15×T2 for cob length, and L11×T1, L3×T2, L5×T2 and L9×T2 for cob girth had higher mean value than population mean and non-significant deviation from regression (S^2di) along with regression coefficient equivalent to unity (bi=1) which denotes that they were absolutely

Table 4. Analysis of Variance for pooled data of fifteen characters

SN	Characters	Genotype [65]	E+(G x E) [132]	E (L) [1]	G x E (L) [65]	Pool dev. [66]	Pool Error [390]
1	Days to 50% Tasseling	42.19**	2.94**	0.02	3.25**	2.67**	1.17
2	Days to 50% Silking	41.63**	8.92**	0.20	15.58**	2.49**	1.15
3	Anthesis-Silking Interval	0.59**	3.37**	0.09	6.77**	0.08**	0.04
4	Total Chlorophyll Content (SCMR)	46.74**	42.01**	1.16	83.65**	1.63**	0.60
5	Proline content (ìg/100 mg FLT)	3422.10**	3643.66**	82.47**	7124.82**	269.21**	0.67
6	Leaf senescence score	1.91**	5.42**	0.12	10.69**	0.31**	0.05
7	Plant height (cm)	2351.85**	549.79**	5.30	874.14**	238.60**	55.21
8	Cob height (cm)	2238.21**	770.17**	13.79	1396.03**	165.25**	29.24
9	Cob length (cm)	10.14**	3.41**	0.08	6.37**	0.55	0.66
10	Cob girth (cm)	0.40**	0.19**	0.00	0.36**	0.03	0.04
11	Grain yield per plant (g)	1523.58**	300.27**	5.63	570.34**	38.76**	25.71
12	100-Grain weight (g)	36.26**	14.95**	0.31	26.41**	3.88**	1.33
13	Grain protein content (%)	2.07**	0.49**	0.01	0.98**	0.02**	0.01
14	Grain oil content (%)	0.70**	0.73**	0.02**	1.44**	0.05**	0.00
15	Grain starch content (%)	24.79**	19.89**	0.56	39.61**	0.76**	0.26

*, ** Significant at 5% and 1% respectively

Table 5. Hybrids found stable for various traits

S. No.	Stable Hybrids	Traits
1.	L6×T2	Grain yield per plant and days to 50 per cent tasseling
2.	L14×T2, L1×T3	Grain yield per plant and days to 50 per cent silking
3.	L8×T1, L10×T1, L14×T1, L15×T1, L12×T2, L4×T3, L15×T3	Grain yield per plant and anthesis-silking interval
4.	L10×T2	Grain yield per plant and total chlorophyll content
5.	L2×T2	Grain yield per plant and leaf senescence score
6.	L15×T2	Grain yield per plant and cob length
7.	L11×T1, L3×T2, L5×T2	Grain yield per plant and cob girth

stable in performance and suitable for cultivation in varying environments. None of the hybrids exhibited mean value lower than population mean and regression coefficient equivalent to unity (bi=1) for plant height and cob height. For the quality traits, the hybrids L7×T3, L9×T3 and L13×T3 for grain protein content, and L1×T1 for grain starch content had higher mean value than population mean and non-significant deviation from regression (S^2di) along with regression coefficient equivalent to unity (bi=1) hence were found stable in performance and adaptable to varying environments.

Discussion

The significance of mean sum of squares due to genotypes and due to genotype × environment interaction affirms that the inbreds and hybrids had significant influence of genotype, environment and G × E interaction effect on their phenotypic performances. The mean sum of squares due to environment (linear) component variance were noted non-significant for most of the traits which indicated existence of considerable non-additive environmental variance for all the traits, while significance of mean sum of squares due to genotype × environments (G × E) interaction (linear) for all the fifteen characters infers that genotypes had great variations in their linear responses across the three different environments. Significance of the mean sum of squares due to pooled deviation for all the traits except cob length and cob girth unravels that the genotypes possessed considerable variation for phenotypic stability, and for such characters the prediction of performance of genotypes across the environments would be difficult. Significance of mean sum of squares for pooled deviations and mean sum of squares for genotype × environments (G × E) interaction (linear) implies that both the components played significant roles in building up of G × E interaction and part of the variability is unpredictable in nature. The outcomes of this study were in line with Admassu *et al*. (2008), Ahmad *et al*. (2017), Pavani *et al*. (2019) and Abate (2020).

The analysis of single cross hybrids for phenotypic stability revealed that the hybrid L15×T2 was recognized as superior for grain yield per plant and possessed greater phenotypic stability along with immense adaptability to diverse environmental conditions. The hybrids, L2×T1, L3×T1, L8×T1, L11×T1, L12×T1, L2×T2, L4×T2, L6×T2, L8×T2, L11×T2, L1×T3, L4×T3 and L8×T3 disclosed higher mean values along with regression coefficient more than unity (bi>1), which displayed their stable performance in favorable environments while the hybrids L10×T1, L14×T1, L15×T1, L3×T2, L5×T2, L7×T2, L10×T2, L12×T2, L14×T2, L3×T3, L6×T3 and L15×T3 disclosed higher mean values along with regression coefficient less than unity (bi<1) displaying their stable performance in unfavorable environments for higher grain yield per plant. Hence such hybrids must be encouraged to undergo further multi-location testing before their commercialization. Similar results were reported by Admassu *et al*. (2008), Shiri (2013), Ahmad *et al*. (2017), Haruna *et al*. (2017) and Yue *et al*. (2020).

Among the other hybrids, L6×T2 for 50 per cent tasseling, L14×T2 and L1×T3 for 50 per cent silking, and L6×T1, L8×T1, L10×T1, L14×T1, L15×T1, L9×T2, L12×T2, L4×T3, L7×T3 and L15×T3 for anthesis-silking interval were found absolutely stable over varying environments for early flowering, therefore these hybrids should be taken under consideration for multi-location trials aimed at identifying hybrids for early flowering under stressed and non-stressed environments. The similar reports were advocated by Haruna *et al*. (2017), Sowmya *et al*. (2018), Raj *et al*. (2019) and Arunkumar *et al*. (2020).

For drought tolerance and grain yield attributing traits, the hybrids L10×T2 and L12×T3 for total chlorophyll content, L2×T2 for leaf senescence score, L4×T1 for cob height, L15×T2 for cob length, and L11×T1, L3×T2, L5×T2 and L9×T2 for cob girth were found absolutely stable over varying environments. For the quality traits, the hybrids L7×T3, L9×T3 and L13×T3 for grain protein content, and L1×T1 for grain starch content were found absolutely stable over varying environments. The outcomes were in accordance with Adebayo and Menkir (2014), Raj *et al*. (2019), Arunkumar *et al*. (2020) and Chouhan *et al*. (2021). The hybrids found stable over the different environments for higher grain yield and other traits have been listed in Table 5. Therefore all the above discussed hybrids should be subjected to multi-location trials in maize improvement programmes aimed at drought tolerance, yield and quality enhancement, before their commercial release.

Conclusion

Climate change and various other constraints have played vital role in global food crisis. Drought stress has been one of the major constraints in global maize production and productivity. Therefore the present study conducted in keeping the above issues in eye, encourages inclusion of drought tolerance and high yield traits in maize germplasm, and advocates development and commercialization of hybrids with such traits.

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Authors' Contribution

Conceptualization of research: Dr. R.B. Dubey and B. Goswami
Designing of the experiment: Dr. R.B. Dubey
Contribution of experimental materials: Dr. R.B. Dubey
Execution of field/lab experiments and data collection: B. Goswami, M.K. Yadav and Dr. G. Jat
Analysis of data and interpretation: B. Goswami and Dr. R.B. Dubey
Preparation of the manuscript: B. Goswami
Declaration: The authors do not have any conflict of interest.

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