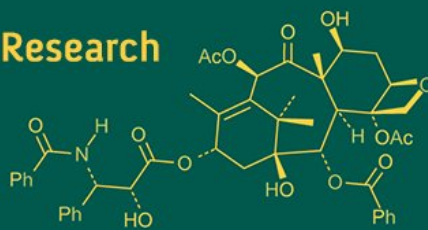


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To study stability in maize (*Zea mays* L.) under non-stress situation

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Abstract

Across the *kharif*, *rabi* and summer seasons of 2011-12, 2012-13 and 2013-14, eight single cross hybrids were assessed alongside five commercial checks (900M Gold, NK6240, Arjun, Bio-9681 and All-rounder) in a non-stress situation, the trial being laid out in a randomized complete block design (RCBD) with three replications. When pooled over environments, differences among the genotypes reached significance in nine characters, and the variance attributable to environments was likewise significant for most of the characters. The variance arising from $G \times E$, by contrast, failed to attain significance for most of the characters. Significance of the environment linear component extended to most of the traits, whereas the $G \times E$ (linear) interaction remained non-significant for most of the characters. Pooled deviation, the nonlinear portion of variance which constitutes the unpredictable component of the $G \times E$ interaction, attained significance in none of the characters. Stability analysis of the 13 single cross hybrids grown under non-stress showed eight hybrids, viz., 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, to be stable across seasons.

Keywords: Drought, Stability, maize, silking, hybrids

Introduction

Among the cereals grown globally, maize (*Zea mays* L.) ranks foremost. It is placed in the tribe Maydeae of the family Poaceae, carries $2n=20$ and is native to South America. Short day in its flowering behaviour and monoecious in nature, the crop was brought under domestication about 8, years ago. Two genera stand as its close relatives, namely *Tripsacum* (gama grass) and *Teosinte* (*Euchlena*).

Cultivation of maize extends throughout the world, and the crop has emerged as one whose genetic yield potential is the highest and whose adaptability spans widely varied agroclimatic conditions. Rising industrial requirements, together with the demand for value-added foods in a growing economy and population, indicate that maize will retain its share as a crop of consequence. Within India it ranks third among cereals for grain production, behind only rice and wheat. Its grain is directed mainly to feed, poultry, swine and fish accounting for about 52 percent and cattle about percent, while 23 percent serves as food and 13 percent as industrial raw material. In its role as a food crop the utilization pattern of maize is more diverse than that of other major crops, a consequence of the array of by-products developed from it and of the diverse types available, among them quality protein maize (QPM), sweet corn, popcorn and baby corn etc (Yadav *et al.*, 2014) ^[1].

Globally the crop occupies an area of 199 million hectares, returning a production of 1129.20 million tonnes at a productivity of 5820 kg ha^{-1} (Anon., 2024) ^[2]. The Indian figures stand at 461.49 lakh tonnes of grains produced from an area of 128.35 lakh hectare, corresponding to a productivity of 3595 kg ha^{-1} . Karnataka accounts for 19.02 lakh hectares under the crop, from which a production of 63.51 lakh tonnes is obtained at a productivity of 3339 kg ha^{-1} (Anon., 2025-26) ^[3].

Drought and low soil fertility rank foremost among the abiotic stresses that limit tropical maize production. Rainfed conditions account for the greater part of tropical maize production, and in such areas drought is regarded as the most important abiotic constraint to production (CIMMYT 1999).

Of all the limitations that keep maize from realizing its grain yield potential, drought is the most pervasive (Edmeades *et al.*, 2001) [4].

The way a genotype reacts to environmental conditions governs the stability of its yield, and that capacity rests on the genetic composition of the genotype (Borojevic, 1990) [5]. Identifying hybrids whose interaction with environments is least therefore calls for extensive testing of maize hybrids in different environments. For yield stability to be achieved efficiently in maize improvement, heterozygosity has been reported to be a prerequisite (Becker and Leon, 1988) [6]. Working with maize, Eberhart and Russell (1969) [7] showed heterogeneous populations to possess better yield stability than homozygous ones, and observed further that two single cross hybrids were as stable as any of the double crosses while yielding higher besides. There is a need to evaluate the yield stability of maize hybrids raised from parental lines differing in their levels of tolerance to drought (Duvick *et al.*, 2004) [8], and (Tollenaar and Lee, 2002) [9] observed that the yield gains realised genetically over the preceding 30 years owed themselves to greater stress tolerance rather than to any increase yield *per se*.

Knowledge of phenotypic stability serves a further purpose, being useful both for the selection of crop varieties and for the conduct of breeding programmes. Wherever a set of genotypes (cultivars) is evaluated over environments that differ widely, genotype $\times$ environment interaction emerges as a universal phenomenon. Traits of agronomic and economic importance, grain yield foremost among them, are quantitatively inherited and routinely display $G \times E$ interaction. Genotypes must consequently be evaluated over a number of environments once selection has reached its advanced stages (Fan *et al.*, 2007) [10]. The present study, entitled "to study stability in maize (*zea mays* L.) under non-stress situation", was accordingly planned and executed.

Materials and Methods

Main Agricultural Research Station, Dharwad, situated at 150° 25' N Latitude and 70° 25' East longitude with an altitude of 678m above mean sea level, served as the site of the present investigation, which spanned the *kharif*, *rabi* and summer seasons of 2011-12, 2012-13 and 2013-14. Appendix I furnishes the data on climatic parameters registered over the period of crop growth, namely rainfall and the minimum and maximum temperature.

The Botanical garden of Main Agricultural Research Station, College of Agriculture, Dharwad, was where the experiment was carried out, during *rabi* and summer. Climatic parameters over the period of crop growth, namely rainfall and the minimum and maximum temperature registered, are set out in Appendix I.

The weather data over the total crop growth period indicated mean minimum and maximum temperatures lying between 15.6 and 32.62 °C with 56.60 mm rainfall during *rabi* 2011-12, while for *rabi* 2012-13 the temperatures ranged from 15.65 to 29.20 °C with 144.50 mm rainfall, and summer 2013-14 registered temperatures from 19.50 to 35.08 °C with 178.40 mm rainfall. The experiments in every season were conducted in *rabi* / summer, covering stress as well as non-stress situations.

Eight single cross hybrids were produced during *kharif* 2011, and these single cross hybrids were subsequently assessed, together with five commercial checks (900M Gold, NK6240, Arjun, Bio-9681 and All-rounder), under

non-stress situations in a randomized complete block design (RCBD) replicated three times. Sowing was taken up on 14.12.2011, 12.10.2012 and 08.02.2013, respectively. Each entry occupied a four row plot, 4 meter in length, at a spacing of 75x20 cm. Two seeds per hill were placed by hand dibbling and thinned out to maintain a single plant per hill during the second week after sowing (10-15 days after sowing). Besides the recommended cultural practices, the genotypes under non-stress received regular irrigation (furrow) at an interval of 10-days, so that they did not experience any stress.

Five competitive plants selected at random were tagged separately. Observations on morphological traits and yield contributing traits were recorded from five randomly selected competitive plants per replication per genotype. For every character the mean value of the five observations was computed, and these means were used for stability analysis. The single cross hybrids along with the checks are listed as follows:

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 followed the procedure of Eberhart and Russell (1966) [11] and was performed in WINDOSTAT 8.0 software.

Results and Discussion

For each of the eight single cross hybrids and the five checks, the data gathered on the different character were evaluated over three years under non-stress, the object being to find out the performance of each genotype over environment.

Table gives the pooled ANOVA for stability of the different characters (Eberhart and Russell, 1966) [11]. Nine characters showed significant genotypic differences when pooled over environments, 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. For most of the characters the variance arising from environments proved significant; plant height, cob length, number of kernel rows per cob, grain yield per plant and shelling percentage formed the exceptions. Variance due to $G \times E$, on the other hand, did not attain significance in most characters, those excepted being 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.

For most of the traits the environment linear component proved significant, chlorophyll at 90 days, plant height, cob length, number of kernel rows per cob, grain yield per plant and shelling percentage being left aside. Non-significance marked the $G \times E$ (linear) interaction in most characters, those excepted being 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. Pooled deviation represents the nonlinear portion of variance and hence the unpredictable component of the $G \times E$ interaction;

here non-significance held throughout, save in days to 50 per cent anthesis, chlorophyll at 90 days and cob length. For three important traits, estimates were obtained of the environmental index together with three stability parameters, viz, mean ($\bar{x}$), regression coefficient b_i and the deviation from linear regression line (S^2d_i); Table and present the results obtained.

An environmental index extending from -0.214 to 0.31 points to significant variations over three years. *Maximum anthesis to silking interval* (ASI) (3.33days) was shown by the hybrids Bio-9681, whereas the minimum anthesis to silking interval (ASI) (1.88 days) was required by KDMI-15 $\times$ NEI-9202B, with 2.38 days as the mean over three environments. Among the entries only the hybrids viz., CI-4 $\times$ CML-446 gave a significant value for regression coefficient higher than unity; for every other hybrid both the regression coefficient and the deviation from regression proved non-significant. Mean values above the population mean were recorded by the hybrids viz., NK6240, 900M and Bio-9681, their b_i and S^2d_i values departing significantly neither from 1 nor from 0, respectively.

Variations over three years are likewise significant, the environmental index here extending from -0.116 to 0.127. Averaged over three environments, number of cobs per plant stood at 1.25. The hybrids viz., CI-4 $\times$ CML-446 and KDMI-15 $\times$ NEI-9202B accounted respectively for the maximum (1.42) and the minimum (1.15) number of cobs per plant. No hybrid returned significant regression values or deviation from regression, whether below unity or above it. Mean values exceeding the population mean were found in the hybrids viz., NEI-9208B $\times$ HS-15, 900M, Bio-9681, CI-4 $\times$ HS-4 and CI-4 $\times$ CML-446, whose b_i and S^2d_i values departed significantly neither from 1 nor from 0, respectively.

Significant variations over three years are indicated by an environmental index running from -421.204 to 361.071. For grain yield (kg/ha) the highest (5959.94 kg) mean value belonged to the hybrids viz., H S - 2 $\times$ NEI - 9202B, while the lowest (4536.43 kg) mean value was that of CI-4 $\times$ CML-446. Averaged over three environments, grain yield (kg/ha) stood at 5389.38 kg. Non-significant regression coefficient and deviation from regression characterised all hybrids apart from the hybrid viz., CM-111 $\times$ NEI-9202B, which showed significant deviation from regression. Regression coefficient equal to unity was obtained by the hybrid viz., KDMI-15 $\times$ NEI-9202B. Mean values higher than the population mean, coupled with b_i and S^2d_i values not significantly different from 1 and 0 respectively, were found in the hybrids viz., Arjun, NEI-9208B $\times$ HS-15, NK6240, CM-111 $\times$ NEI-9202B, 900M, CI-4 $\times$ HS-4, KDMI-15 $\times$ NEI-9202B, HS-4 $\times$ NEI-9202B and HS-2 $\times$ NEI-9202B

Table sets out the results of DSI. Of the eight single cross hybrids and five checks, highest (0.65) DSI values for grain yield (kg/ha) were recorded by the hybrids viz. (NEI-9208B $\times$ HS-15) and lowest (0.26) by (HS-15 $\times$ HS-17), the overall mean working out to (0.44).

Once the genotype $\times$ environment interactions stand established as significant, identifying stable genotypes, those that interact least with the environments, becomes the next test. Several models exist for the purpose, among them that of Eberhart and Russell (1966) ^[11], which a number of workers have applied to maize and to other crops. On the criteria of Eberhart and Russell (1966) ^[11], stability in a variety implies a regression coefficient (b_i) equal to one, a

deviation from regression (S^2d_i) lying as close to zero as possible, and high mean performance. For Allard and Bradshaw (1964) ^[12], the selection of a stable genotype rests on the genotype having less interact with environments.

The three measures named above, viz., mean, regression coefficient (b_i) and the mean square deviation (S^2d_i), were the means by which stability was assessed among the genotypes included in the present study. Response of a particular genotype may simply be measured by the linear regression (b_i): a value greater than one marks the genotypes as sensitive to environment changes but adopted to favourable environments, while a value below one points to above average stability. Where the latter goes together with a high mean value, such a genotype counts as better adapted to widely differing situations for unfavourable environment, whereas a low mean value points to greater G $\times$ E interaction (Finlay and Wilkinson, 1963) ^[13]. Deviation around the regression line, however, ranks as the better measure of stability. Taking the non-linear component of the G $\times$ E interaction, whichever genotype carries the lowest standard deviation will prove the most stable, and vice-versa. Findings of the present study with respect to stability parameter are discussed below.

When the stability parameters of the genotypes tested over environments are considered, stable performance was not attained by any of the genotypes. _ KDMI-15 $\times$ NEI-9202B among them took the fewest days to anthesis to silking interval, Bio-9681 the most. Since a smaller number of days to anthesis to silking interval is the more desirable attribute, KDMI-15 $\times$ NEI-9202B emerged as the ideal genotype in this respect.

Regression values above unity, which point to suitability to favourable environments, were returned by the hybrids Bio-9681, CM-111 $\times$ NEI-9202B 4 KDMI-15 $\times$ NEI-9202B, RMH-2, NK-6240, H S-2 $\times$ NEI-9202B and Allrounder. A regression coefficient statistically below unity, coupled with non-significant S^2d_i , was found in the hybrids Arjun, 900M, H S-4 $\times$ NEI - 9202B, NEI-9208B $\times$ H S-15, H S-15 $\times$ HS-17 and CI-4 $\times$ HS-4 ; ; such hybrids, having above average stability, are adoptable to unfavorable environments, or more specifically to poor environments. In CI-4 $\times$ CML-446 a significant regression value again indicates suitability to favourable environments. Agreement with these findings is found in Arun and Singh (2004b) ^[14], Kaundal and Sharma (2006) ^[15], Nagabhushan (2008) ^[16] and Vijaykumar (20008).

Among the stability parameters for number of cobs per plant, the genotype Arjun emerged as stable across the environments, with its regression (b_i) value statistically equal to unity and S^2d_i approaching to zero. The highest number of cobs per plant belonged to CI-4 $\times$ CML-446 and the lowest number of cobs to RMH-2. Mean values above the population mean were shown by the hybrids NEI-9208B $\times$ HS-15, 900M, Bio-9681, CI-4 $\times$ HS-4 and CI-4 $\times$ CML-446.

The hybrids CM-111 $\times$ NEI-9202B, H S-4 $\times$ NEI-9202B, H S-15 $\times$ H S-17, KDMI-15 $\times$ NEI-9202B, NEI-9208B $\times$ H S-15 and Bio-9681 combined regression values above unity with non-significant S^2d_i , which points to suitability for specific favourable environments. In the hybrids Allrounder, NK-6240, CI-4 $\times$ CML-446, 900M, H S-2 $\times$ NEI-9202B and CI-4 $\times$ H S-the regression coefficient stands statistically below unity with non-significant S^2d_i ; these, with their above average stability, would prove adoptable to

unfavorable environments and specifically to poor environments.

Among the stability parameters for grain yield (kg/ha), the genotype KDMI-15 × NEI-9202B emerged as stable across the environments, its regression (b_i) value standing statistically equal to unity with S^2d_i approaching to zero. Of the genotypes tested over environments, regression values below unity belonged to the hybrids NK-6240, Arjun, H S-15 × H S-17, NEI-9208B × HS-15, H S - 4 × NEI - 9202B and H S-2 × NEI-9202B, and values above unity to the hybrids 900M, RMH-2, CI-4 × CML-446, Bio-9681, Allrounder and CI-4 × H S-4, rendering them suitable for poor and favourable environments respectively.

Adaptation to all the environments was revealed in 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, which combined higher mean performance with nonsignificant regression coefficient and deviation from regression. The highest mean value fell to H S-2 × NEI-9202B and the lowest to CI-4 × CML-446. In CM-111 × NEI-9202B a significant deviation from regression

indicates average sensitivity to environments with unpredictable performance. Reports of a similar nature come from Satyanarayan and Kumar (1995) (Machado *et al.*, 2008) [17], Nagabhushan (2008) [16] and Vijaykumar (20008), Kuchanur (2010) [18], Romay *et al.* (2010) [19] and Badu-Apraku and Oyekunle (2012) [20].

As regards DSI, among the eight single cross hybrids and five checks it was the single cross hybrids viz. (H S-15 × H S-17) that returned the lowest DSI values for grain yield (kg/ ha). Findings of a similar nature have also been reported by Jafaria *et al.* (2009), Kuchanur (2010) [18], Majid *et al.* (2010) [21], Lata *et al.* (2011) [22], Ijaz-Ul-Hassan *et al.* (2011) [23], Badu-Apraku and Oyekunle (2012) [20], Moradi *et al.* (2012), Khalil (2013) [24] and Paulo Roberto *et al.* (2014) [25].

To conclude, of the 13 single cross hybrids subjected to stability analysis under nonstress, eight proved stable across seasons, 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.

Table 1: Pooled analysis of variance for stability analysis (Eberhart and Russell, 1966) [11] 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 2: 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 3: 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	b_i	s^2d_i
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 b_i - Regression coefficient
 S^2d_i - Deviation from regression

Table 4: Drought susceptibility index of 13 F₁ 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

Conclusion

The present study demonstrated substantial variation among maize (*Zea mays* L.) hybrids across three seasons under non-stress conditions. Environmental effects were significant for most traits, whereas genotype × environment interaction was generally non-significant, indicating comparatively consistent hybrid performance. Significant linear environmental effects and largely non-significant pooled deviations further suggested that most responses were predictable. Among the tested entries, KDMI-15 × NEI-9202B showed desirable stability for grain yield, with a

regression coefficient close to unity and minimal deviation from regression. HS-2 × NEI-9202B recorded the highest mean grain yield, while HS-15 × HS-17 exhibited the lowest drought susceptibility index. Overall, eight 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—were identified as stable across seasons. These hybrids may support cultivation and future breeding programmes targeting reliable performance under non-stress environments and variable seasonal conditions in practice.

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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	-	-	-	-	-	-	-	-	-	-	-	-