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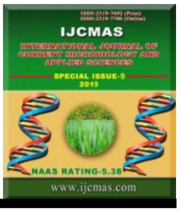

Original Research Article

Stability Analysis of Stress-Resilient Maize (*Zea mays* L.) Hybrids across stressed and non-stressed environments

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ABSTRACT

Field experiments were conducted during spring (heat stress), *kharif* (optimal) and *rabi* (moisture stress) 2018 at Agriculture College Farm, Bheemarayanagudi and Main Agricultural Research Station, Raichur to assess the stability of maize hybrids under stress and optimal conditions. Twelve maize hybrids along with five commercial checks were evaluated in Randomized Block design with three replications. Pooled analysis of variance revealed significant variations among the hybrids for all the traits, except shelling percentage. The mean sum of squares due to genotype × environment interactions and linear component of genotype × environment interaction were significant only for test-weight indicating the diversity among the selected environments. Based on stability parameters, hybrids *viz*., RCRMH-5, RCRMH-12 and RCRMH-2 for plant height, RCRMH-12 for number of kernels per cob, BGMH-2 for shelling percentage, RCRMH-10 and RCRMH-9 for test-weight and RCRMH-12 and RCRMH-4 for grain yield (kg ha^{-1}) were identified as stable as they recorded regression values nearer to unity, non-significant deviation from the regression across the locations.

Keywords

Climate change, Mann-Kendall test, Sen's estimator method, Test statistics (Z), Regression analysis

Introduction

Maize (*Zea mays* L.) is a cereal crop with a remarkable potential for production and is the third most important grain crop after wheat and rice. The considerable genotypic variability for different traits among various maize genotypes is a key to crop improvement. Globally, maize is cultivated in an area of 183.24 m ha with a production of 1036.07 m t and productivity of 5.65 t ha^{-1}. India stands sixth among the maize producing countries in the globe with an area, production and productivity of 9.60 m ha, 27.15 m t and 2.83 t ha^{-1}, respectively (Anon, 2018). Maize is grown from below sea level to altitudes higher than 3000 m, and in areas with 250 mm to more than 5000 mm of rainfall per year and with a growing cycle ranging from 3 to 10 months.

The production process of maize is highly dependent on suitable environmental factors. Though maize is called queen of cereals, yet it encounters both abiotic and biotic stresses during its cultivation. Global climate change is imposing negative effects on agriculture and has resulted in severe rise in temperature, frequent heat waves, drought, floods, desertification and weather extremes (Anon., 2009) . Further, reduction in the availability and quality of arable land and water resources as well as frequent extreme weather can cause many different types of abiotic stresses, such as salinity, drought, and extreme temperatures (heat, cold, and freezing) (Krasensky and Jonak, 2012).

Temperature is one of the most important environmental parameters affecting maize crop. Temperature stress can reduce maize quality and yield; and rise in temperature reduces its pollen viability and silk receptivity, resulting in poor seed set and reduced grain yield (Johnson, 2000). Extended exposure to temperature beyond 32.5°C would reduce pollen germination of many genotypes of maize to a zero level.

Each year, an average of 15 % to 20 % of the potential world maize production is lost due to heat and drought stresses (Lobell *et al.*, 2011). Further, temperature above 30 °C reduces the final yield of maize by 1 per cent under favourable growing conditions and by 1.7 per cent under drought-stressed conditions (Lobell *et al.*, 2011b). An increase in temperature of 2 °C would reduce maize yields by 13 % while 20 % increase in intraseasonal variability reduced maize yields by only 4.2 % (Cairns *et al.*, 2012).

Maize is very sensitive to water stress in the period, one week before flowering to two weeks after flowering. Drought during this period results in an easily measured increase in the anthesis-silking interval (ASI) as the silk emergence is delayed and also results in grain abortion. When the drought occurs at 75 per cent silking, grain yield loss to the extent of 53 per cent is noticed (Zaidi, 2007).

The University of Agricultural Sciences (UAS), Raichur is working in collaboration with CIMMYT (Asia), ICRISAT campus, Patancheru, Hyderabad, Telangana to identify abiotic stress tolerant maize hybrids for the Hyderabad-Karnataka region. Angadi *et al.* (2016) identified heat tolerant inbred lines *viz.*, CI-4, CM-111, R-111 and YP- 58 that could be used as potential donors for the development of heat stress tolerant hybrids. Similarly, Gazala *et al.* (2017) identified good general combiners (VL101886, VL0556, VL1110175 and VL107) for flowering and plant height under heat stress. Archana *et al.* (2018) from their study identified the stable hybrids (VL062609 x VL128 and VL107 x VL1033) for grain yield under heat stress and also optimal conditions across India. Therefore, the present investigation was carried out with the objective of identifying the stable maize hybrid from among the recently developed abiotic stress hybrids for cultivation in Karnataka.

Materials and methods

The experimental material consisted of 10 single cross hybrids, two three-way hybrids and five commercial hybrids as checks (Table 1). The evaluation of maize hybrids was carried out at two locations *viz.*, Agriculture College Farm, Bheemarayanagudi (Karnataka) situated at 16° 44' N latitude and 76° 47' E longitude with an altitude of 458 m above mean sea level and Main Agricultural Research Station, Raichur (Karnataka) situated at 16° 15' N latitude and 77° 20' E longitude with an altitude of 389 m above mean sea level. The environments for evaluation included spring/summer and *kharif* seasons at Raichur and *kharif* and under managed drought condition (during post rainy season) at Bheemarayanagudi. The experiments were conducted in randomized block design with three replications at each location and season.

Each replicated entry had four rows of 4 m length. The genotypes were planted with a spacing of and 60 cm between the rows and 20 cm between plants. After thorough land preparation, furrows were opened and seeds were hand dibbled at the rate of two seed per hill and later thinned to retain one seedling per hill. The crop was applied with recommended dose of fertilizers (150 kg N, 75 kg P_2O_5 and 40 kg K_2O). One third of nitrogen and the entire dose of P_2O_5, K_2O was applied as basal dose and one third nitrogen was applied as top dressing in at fourth week after sowing and the rest at sixth to seventh week after sowing. The recommended agronomic practices such as weeding, irrigation and other cultural practices were adopted timely to raise healthy crop at each location and season. The weather parameters recorded at Bheemarayanagudi and Raichur indicated that the experiments were under heat stress as the T_{max} and T_{min} recorded were above the values prescribed for the optimal growth of maize (Table 2).

Data collection and analysis

The following observations were recorded at each location *viz*., plant height (cm), number of kernels per cob, 100-grain weight (g) and shelling percentage were recorded on randomly selected five plants in each replication and the mean of five plants was computed. While, grain yield was recorded on plot basis and expressed in kg ha^{-1}. The data was statistically analysed as per Eberhart and Russel (1966) model which interprets the variance of regression deviations as a measure of cultivar stability and the liner regression coefficient (b_i) as a measure of environmental index. The hybrids with b_i value 1.0 are more stable. Whereas, a hybrid with $b_i > 1.0$ is considered less than average stability and $b_i < 1.0$ as greater than average stability.

Results and Discussion

Pooled analysis of variance for five characters over two environments and four environments are presented in the Table 3. Analysis of variance revealed significance of mean sum of squares due to environments and environments (Linear) for all the traits indicating the diversity among the chosen environments. Similarly, significant variations among the hybrids were observed for all the traits, except shelling percentage. Archana *et al*. (2018) reported significant genotype and environment effects for grain yield in maize under heat stress. The mean sum of squares due to genotype × environment interactions and linear component of genotype × environment interaction were significant only for test-weight. Abera *et al*. (2004) reported significant year × location effects for all the traits using different stability models. Pooled deviation was significant for all the characters, except shelling percentage indicating that the non-linear component of G × E interaction was predominant.

The stability parameters *viz*., mean ($\overline{X}$), regression coefficient (bi) and mean square deviation from regression line (S^2di) were estimated for five traits and the results obtained are presented in the Table 4 and 5.

The average height of plant (cm) over different environments was 185.20 cm. Among the 16 genotypes, three genotypes *viz.,* BGMH-2, NK6240 and P3550 showed significant deviation from regression across the locations and seasons. The hybrid, RCRMH-5 was found stable for plant height across the location and adaptable to all environments. RCRMH-3 exhibited b_i value less than unity and high mean, and thereby showed above average stability indicating the adaptability of this genotype to unfavourable environment. Three genotypes *viz.,* RCRMH-4, P3436 and P3550 exhibited below average stability by recording regression coefficient more than one with high mean indicating the adaptability of these hybrids to favourable environments. The results were in accordance with those reported by Archana *et al.* (2018) who evaluated 24 hybrids under heat stress across three locations and identified ZL132102 x VL1033 and VL1011 x VL1033 as stable hybrids for plant height (cm).

Hybrid RCRMH-12 was found stable for the traits, such as number of kernels per cob with high mean, regression coefficient near to unity and deviation from the regression nearer to zero. Three hybrids *viz.,* BGMH-1, RCRMH-5 and RCRMH-10 showed above average stability as they recorded b_i value less than unity with high mean, indicating the adaptability of these hybrids to unfavourable environments. Three hybrids *viz.,* RCRMH-13, P3550 and 900MG exhibited below average stability by recording regression coefficient (b_i) more than unity and high mean indicating the adaptability of these hybrids to favourable environments.

The average 100-grain weight was 29.38 g over the locations and seasons. RCRMH-12 showed significant regression coefficient value while three hybrids *viz.,* RCRMH-14, RCRMH-3 and BGMH-1 showed significant deviation from regression. The hybrids, RCRMH-10 and RCRMH-9 had regression values nearer to unity and mean values were greater than grand mean across the locations indicating their stability for test weight. Five genotypes *viz.,* RCRMH-3, RCRAMH-14, NK6240, P3436 and P3550 exhibited below average stability as they recorded regression coefficient more than unity with high mean indicating the adaptability of these genotypes to favourable environments. One hybrid (RCRMH-4) exhibited above average stability by recording regression coefficient less than unity and high mean indicating the adaptability of this hybrid to unfavourable environments. Similar results were reported by Sowmya *et al.* (2018) evaluated 20 maize hybrids over three environments for stability and the study revealed that genotype DMH 100-16 showed high mean along with regression coefficient more than unity ($bi > 1$) and mean deviation from the regression ($S^2di = 0$) close to zero indicating that the hybrid could be specifically adapted to favorable environments. Further, it was revealed that the genotype DMH 100-13 was specifically adapted to poor environments for shelling percentage as indicated by its high mean, regression co-efficient less than unity and deviation from regression close to zero ($S^2di = 0$).

Stability analysis for shelling percentage revealed that BGMH-2 was a stable across locations and seasons. Three genotypes *viz.,* RCRMH-6, P3436 and 900MG exhibited above average stability as they recorded regression coefficient (b_i) values less than unity and high mean indicating adaptability of these genotypes to unfavourable environment. Four hybrids *viz.,* BGMH-1, RCRMH-3, RCRMH-4 and P3550 exhibited below average stability by recording regression coefficient (b_i) value more than unity and high mean indicating adaptability of these genotypes to favourable environment.

The hybrids *viz.,* RCRMH-12 and RCRMH-4 were found stable across locations and environments for grain yield (kg ha^{-1}). Out of 16 hybrids, one genotype (RCRMH-14) exhibited above average stability as it recorded regression coefficient (b_i) less than unity high mean indicating adaptability of these genotypes to unfavourable environment. Five hybrids *viz.*, RCRMH-6, 900MG, P3436, P3550 and RCRMH-2 exhibited below average stability with regression coefficient (b_i) more than unity and high mean indicating adaptability of these genotypes to favourable environment. Divya (2018) evaluated 64 hybrids under heat stress across locations identified that the hybrids *viz.*, ZH1673 (4.32 t ha^{-1}), ZH16878 (5.69 t ha^{-1}), ZH16930 (4.58 t ha^{-1}) and ZH16900 (3.26 t ha^{-1}) as stable for grain yield per hectare.

The combination of drought and heat stress had a significantly greater detrimental effect on the growth and productivity of maize compared to each of stresses applied individually. The results of present investigation indicated that the hybrids *viz.*, RCRMH-12 and RCRMH-4 were found stable and superior for grain yield and could be tested extensively across environments for their wide adaptation in diverse and stress prone ecological regions of the country for improving the productivity of stress prone areas.

Table.1 List of abiotic stress tolerant hybrids and checks used for stability analysis

Sl. No.	Hybrids	Duration	Remarks
1	BGMH-1	Medium	Tolerant to drought
2	BGMH-2	Medium	Tolerant to drought
3	RCRMH-3	Medium	Tolerant to heat
4	RCRMH-4	Medium	Tolerant to drought
5	RCRMH-5	Medium	Tolerant to drought
6	RCRMH-6	Medium	Tolerant to drought
7	RCRMH-9	Medium	Tolerant to heat
8	RCRMH-10	Early	Three way hybrid, tolerant to heat
9	RCRMH-11	Early	Three way hybrid, tolerant to heat
10	RCRMH-12	Medium	Tolerant to drought
11	RCRMH-13	Medium	Tolerant to heat
12	RCRMH-14	Medium	Tolerant to heat
	Checks		
1	900MG	Late	High yielding hybrid from Monsanto Ltd
2	NK6240	Late	High yielding hybrid from Syngenta Ltd
3	P3436	Late	A drought tolerant hybrid from Pioneer Ltd
4	P3550	Late	A drought and heat tolerant hybrid from Pioneer Ltd
5	RCRMH-2	Medium	A heat tolerant hybrid released by UAS, Raichur

Table.2 Meteorological data recorded during cropping period (2018) at MARS, Raichur and Agricultural College Farm, B'gudi

Main Agricultural Research Station, Raichur				
Months	**Temperature (^{o}C)**		**Rainfall (mm)**	**Relative humidity (%)**
	Maximum	**Minimum**		
March	37.1	22.9	0.0	41.9
April	39.1	26.5	4.4	42.2
May	39.3	27.5	14.2	49.1
June	35.6	25.1	8.8	60.1
July	35.5	23.9	31.6	67.0
August	32.5	23.2	52.5	70.8
September	33.5	23.2	77.1	65.0
October	33.4	21.6	27.5	58.6
November	32.2	19.8	0.0	51.4
December	30.4	18.5	0.0	62.1
Agricultural Research Station, Bheemarayanagudi				
Months	**Temperature (^{o}C)**		**Rainfall (mm)**	**Relative humidity (%)**
	Maximum	**Minimum**		
July	35.0	23.0	39.6	67.2
August	31.5	22.6	46.6	72.2
September	33.2	22.1	62.4	68.6
October	34.6	20.0	9.6	62.2
November	34.0	17.7	0.0	61.9
December	31.6	16.7	0.0	59.5
January (2019)	32.0	14.1	0.0	50.8
February (2019)	35.0	17.3	0.0	42.1

Table.3 Pooled analysis of variance for stability analysis (Eberhart and Russell, 1966) in maize over two locations and four environments

Source of variation	**df**	**Plant height (cm)**	**Number of kernels per cob**	**Test weight (g)**	**Shelling percentage**	**Grain yield (kg ha^{-1})**
Rep within Env	8	321.84	966.30	2.88	22.59	1344830.53
Genotypes	15	338.05*	6710.56**	38.46**	17.68	3051448.71**
Env.+ (Gen* Env.)	48	2460.43**	11271.73**	39.84**	30.49	5450253.45**
Environments	3	37144.07**	146630.46**	477.8**	171.20**	72053910.44**
Genotypes * Env.	45	148.18	2247.81	10.64**	21.11	1010009.65
Environments (Lin.)	1	111432.21**	439891.40**	1433.43**	513.62**	216161731.33**
Genotypes* Env.(Lin.)	15	116.90	2190.15	23.02**	22.44	1334486.85
Pooled Deviation	32	153.59**	2134.35**	4.18**	19.16	794785.36*
Pooled Error	120	72.46	956.31	2.19	16.12	471030.10
Total	63	1955.10	10185.73	39.51	27.44	4879109.46

* and ** indicate significant at 0.05 and 0.01 levels of probability, respectively.

Table.4 Stability parameters of hybrids for plant height (cm), number of kernels per cob and test weight (g) under different environments

Genotypes	Plant height (cm)			Number of kernels per cob			Test weight (g)		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
BGMH-1	176.30	1.10	-43.50	486.80	0.76	-838.60	26.66	-0.11	9.28 **
BGMH-2	171.50	0.95	187.50 *	435.40	0.93	1218.70	28.91	1.57	-0.34
RCRMH-3	191.30	0.87	-75.80	425.00	1.07	5074.40 **	34.78	1.30	7.55 *
RCRMH-4	187.60	1.04	-61.40	437.60	0.97	-518.60	31.72	0.76	0.03
RCRMH-5	185.70	1.00	55.40	507.30	0.75	4504.10 **	22.50	0.90	-2.03
RCRMH-6	180.50	1.23	-19.30	544.20	0.96	5351.20 **	25.81	1.54	-0.17
RCRMH-9	180.90	1.04	-59.80	432.10	1.03	-104.70	31.04	0.91	-1.67
RCRMH-10	171.80	0.81	150.60	473.60	0.45	829.60	30.66	0.90	0.29
RCRMH-12	201.90	0.99	-69.00	480.20	0.95	-823.70	29.26	0.40*	-1.52
RCRMH-13	185.20	0.84	-59.40	497.40	1.21	1760.50	27.05	0.26	2.32
RCRMH-14	175.80	0.89	85.70	411.30	0.98	128.40	30.45	1.83	6.46 *
Checks									
900MG	182.50	0.94	-36.60	521.90	1.35	-470.60	26.62	0.83	2.96
NK6240	184.50	0.82	547.80 **	439.50	1.01	-681.70	31.33	1.28	0.24
P3436	200.50	1.14	70.40	450.80	1.20	1310.30	29.66	1.18	-1.63
P3550	192.30	1.17	376.20 **	497.30	1.66	1559.90	29.91	1.20	10.76 **
RCRMH-2	194.20	1.08	-0.20	410.70	0.66	538.80	33.76	1.20	-1.44
Grand mean	185.20			465.70			29.38		

* and ** indicate significant at 0.05 and 0.01 levels of probability, respectively.

Table.5 Stability parameters of hybrids for shelling percentage and grain yield (kg ha^{-1}) under different environments

Genotypes	Shelling percentage			Grain yield (kg ha^{-1})		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
BGMH-1	88.49	3.30	181.96 **	6117.50	0.84	228763.90
BGMH-2	83.66	0.80	-2.12	5795.70	0.80	654955.60
RCRMH-3	84.24	1.76	5.55	6905.68	0.96	766420.20
RCRMH-4	83.21	1.25	-14.69	8083.00	1.04	571960.60
RCRMH-5	80.44	-0.23	-12.72	6292.00	0.80	75371.40
RCRMH-6	83.23	0.29	-4.22	7439.80	1.35	-180570.20
RCRMH-9	81.31	1.65	-9.62	6216.80	0.33	484225.60
RCRMH-10	82.35	1.00	-14.62	6386.80	0.83	-310944.20
RCRMH-12	80.57	1.12	-15.17	8353.30	1.00	183177.50
RCRMH-13	80.15	0.01*	-15.58	6553.90	0.73	221731.40
RCRMH-14	81.41	0.90	-9.87	7627.50	0.76	-403469.50
Checks						
900MG	84.12	0.46	-10.77	7776.10	1.48*	-512646.30
NK6240	81.18	0.88	-11.61	7186.70	0.95	84074.60
P3436	82.72	0.26	-10.78	8422.30	1.46	-355088.50
P3550	83.13	1.47	-14.79	7823.09	1.40	3153113.40 **
RCRMH-2	80.46	1.00	1.32	8289.30	1.21	-371514.40
Grand mean	82.54			7204.34		

* and ** indicate significant at 0.05 and 0.01 levels of probability, respectively.

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