

Original Research Article

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Stability for Grain Yield and Other Traits in Tropical Maize (*Zea mays* L.) under Heat Stress and Optimal Conditions

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ABSTRACT

Twenty four newly developed maize hybrids along with three commercial checks were evaluated for their yield performance at three locations under heat stress and optimal conditions. Pooled analysis of variance revealed significant differences among hybrids for grain yield. Mean sum of squares due to environments and linear component of environments were significant for all the traits studied. Whereas, mean sum of squares due to hybrids \times environment interactions and linear component of hybrids \times environment interaction were significant only for grain yield indicating the diversity among the selected environments. Based on the stability parameters, the hybrids, VL 107 \times VL128 (0.97) and ZL 1110175 \times VL 1033 for days to 50 % anthesis, ZL 14501 \times VL 1032 for days to 50 % silking, VL 1011 \times VL 1033 for anthesis silking interval and ZL 11953 \times VL 1032 for grain yield were identified as stable as they recorded regression value nearer to unity and non-significant deviation from regression.

Keywords

Grain yield, Tropical maize (*Zea mays* L.), Optimal conditions

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Introduction

Maize (*Zea mays* L.) is one of the important cereal crops in the world and India next to wheat and rice and is known as queen of cereals because of its high yield potential among the cereals. Maize is grown in an area of 8.69 m ha with a production of 21.80 m t and an average productivity 2.51 t ha⁻¹ in

India. Karnataka is the one of important maize growing state in the country having a total area of 1.18 m ha with a production of 3.27 m t and an average productivity of 2.77 t ha⁻¹ (Anonymous, 2016).

Maize grain is used mainly as feed for poultry, swine and fish (52 percent) and for cattle about 11 percent. About 23 percent used as a

food and about 13 percent as an industrial raw material (Yadav *et al.*, 2014). In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc.

Though maize is called queen of cereals, yet it encounters both abiotic and biotic stresses during its cultivation. Further, maize production and productivity are prone to rapid and constant changes due to global warming related environmental changes (Porter, 2005; Wahid *et al.*, 2007). Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development (Wahid *et al.*, 2007). Heat stress for maize crop can be defined as temperature beyond a threshold level (Max temperature > 35°C and minimum temperature > 23°C). Rise in temperature by one degree each day above 30°C was seen to lower final yield of maize in optimum and drought conditions by 1 % and 1.7 %, respectively (Lobell *et al.*, 2011). Further, increase in air temperature by 4-5°C during the kernel development leads to 73 *per cent* decrease in kernel number per ear (Carcova and Otegui, 2001).

The main effects of progressive heat stress on maize production are associated with reduced growth duration, reduced light interception and reproductive failure. The reproductive phase is the most sensitive growth stage to heat stress. High temperatures during flowering reduce the quantity and viability of pollen produced resulting in reduced fertilization of ovules, thereby reducing the sink capacity (Lobell *et al.*, 2011). Kiniry and Ritchie (1985) reported high temperature could also cause kernel abortion, especially 10

days after pollination, as abortion commences early in kernel development before 12 days after pollination, at about the same period normal kernels undergo endosperm cell division and kernel enlargement begins. Cairns *et al.*, (2013) reported that rise in temperature by 2°C would lower maize yield by 13 % while, a 20 % variation in intra-seasonal rainfall would lower maize yields by 4.2 % only.

Development of maize hybrids with stable performance in diverse environments is a challenge and there is a need to develop / identify hybrids that perform stably under various environmental conditions including heat stress. However, there are limited breeding efforts on heat stress tolerance in tropical maize in India especially, on stability of hybrids under heat stress and optimal conditions. Angadi (2014) identified four inbreds and five hybrids tolerant to heat stress. Krishnaji *et al.*, (2017) and Dinesh *et al.*, (2016) reported non-additive gene action for various traits under heat stress conditions. Therefore, the present investigation was carried out with the objective of identifying stable maize hybrids under heat stress and optimal conditions.

Materials and Methods

The experimental material consisted of 24 single cross hybrids developed by crossing eight inbreds as females and three testers as males (Table 1) in NCD-II design and three checks viz., 31Y45, D2244 and DKC 9108. The parents were selected based on their performance under heat stress and were either tolerant or moderately tolerant to heat stress. The hybrids were evaluated in alpha lattice design with two replications. Each hybrids was sown in two rows with a row length of 3 meters and spacing of 60 cm x 20 cm at three locations viz., Agriculture College Faram, Bheemaranagudi, Karnataka (16° 44' N

latitude, 76° 47' E longitude and altitude of 458 m above mean sea level), CIMMYT (Asia), ICRISAT campus, Hyderabad, Telangana (17° 53' N latitude, 78° 27' E longitude and altitude of 545 m above mean sea level) and Bihar Agricultural University, Sabour, Bhagalpur, Bihar (25° 15' N latitude, 87° 2' E longitude and altitude of 46 m above mean sea level). At Bheemaranagudi and Hyderabad, the experiments were conducted during summer (March- June) 2016. Whereas, at Sabour, Bhagalpur, the experiment was sown during early spring (February –June) and the crop did not experience any stress (and considered optimal conditions). Recommended agronomic practices were followed for raising a good and healthy crop at all the locations. The observations were recorded on following characters *viz.*, days to 50 % anthesis, days to 50 % silking, anthesis to silking interval, plant height and cob height on five randomly selected plants from each entry from the two replications.

While grain yield was recorded on plot basis and expressed in t ha⁻¹. The weather parameters recorded at Bheemaranagudi and Hyderabad 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). The stability parameters for grain yield and its component traits were worked out as suggested by Eberhart and Russell (1966) by using WINDOWSTAT 9.2 software.

Results and Discussion

In any breeding programme, it is necessary to screen and identify phenotypically stable hybrids, which could perform more or less uniformly under different environmental conditions. Considering this fact in mind, the present investigation was carried out to identify stable maize hybrids under heat stress and optimal environmental conditions.

Pooled analysis of variance (Table 3) revealed significant differences among hybrids for grain yield. Mean sum of squares due to environments and linear component of environments were significant for all the traits studied. Similarly, Adu *et al.*, (2013) reported significant genotype and environment effects for grain yield in maize under heat stress. The mean sum of squares due to hybrids × environment interactions and linear component of hybrids × environment interaction was significant only for grain yield indicating the diversity among the selected environments for the present investigation. Earlier, Hassan and Badreldin (1995) reported significant cultivar × environment interaction for grains/ear, grain weight and yield and significant environment (linear) effect was for all characters. Abera *et al.*, (2004) reported significant year × location effects for all the traits using different stability models. Significant differences for grain yield, days to silking, days to anthesis and anthesis-silking interval were reported by Kamutando *et al.*, (2013) among genotypes, environments and genotype × environment interactions (GEI).

The magnitude of non-linear component (pooled deviation) was greater than the linear component (hybrid × environment interaction) thus, indicating the difficulty in predicting the actual performance of genotypes across the environments for selected traits under heat stress and optimal conditions. Hence, prediction of performance of hybrids based on stability parameters would be feasible and reliable.

Eberhart and Russell (1966) defined stability as the ability of a hybrid to show a minimum interaction with the environment in which it is being grown. Stability of hybrids is often interlinked with significant hybrid × environment interaction. A hybrid is considered to be more adaptive / stable one, if it has high mean yield but a low degree of

fluctuation in yielding ability when grown over diverse environments. A stable hybrid is one which has above average mean yield, a regression coefficient of unity ($b_i = 1$) and non-significant mean square for deviations from regression ($S^2_{di} = 0$). High value of regression ($b_i > 1$) indicates that the hybrid is more responsive for input rich environment, while, low regression value ($b_i < 1$) is an indication of a hybrid adapted to poor environment. The phenotypic stability of hybrids was estimated by mean performance over locations, the regression coefficient (b_i)

and deviation from regression. Based on stability parameters, the hybrids *viz.*, VL 107 × VL 128 (0.97) and VL 062609 × VL 1033 (1.05) exhibited regression value nearer to unity and non-significant deviation from regression, indicating their higher stability and wider adaptability across the environments for days to 50 % anthesis, but with respect to the mean performance, these hybrids recorded little longer duration (data not shown). Earlier, Selvarajeswari (2016) also reported stable hybrids for days to 50 *per cent* tasselling across locations in maize.

Table.1 List of parental lines used for crossing and their reaction to heat stress

Sl. No.	Line/Tester	Name	Source	Reaction to heat stress
1	L1	ZL14501	CIMMYT-Asia, Hyderabad	T
2	L2	ZL11959	CIMMYT-Asia, Hyderabad	T
3	L3	VL1110175	CIMMYT-Asia, Hyderabad	MT
4	L4	ZL132102	CIMMYT-Asia, Hyderabad	T
5	L5	VL062609	CIMMYT-Asia, Hyderabad	T
6	L6	VL1011	CIMMYT-Asia, Hyderabad	T
7	L7	VL107	CIMMYT-Asia, Hyderabad	T
8	L8	ZL11953	CIMMYT-Asia, Hyderabad	T
9	T1	VL1032	CIMMYT-Asia, Hyderabad	T
10	T2	VL1033	CIMMYT-Asia, Hyderabad	T
11	T3	VL128	CIMMYT-Asia, Hyderabad	MT

T- Tolerant, MT- Moderately Tolerant

Table.2 Meteorological data recorded during cropping period (2016) recorded

Week	Bheemaranagudi			Hyderabad				Sabour, Bhagalpur					
	Rainfall (mm)	Temperature (°C)		Rainfall (mm)	Temperature (°C)		Relative humidity		Rainfall (mm)	Temperature (°C)		Relative Humidity	
		Maximum	Minimum		Maximum	Minimum	8.30 AM	5.30 PM		Maximum	Minimum	8.30 AM	5.30 PM
1 st week		36.9	21.7		34.40	20.51	73.71	35.71	0	24.4	8.5	95	58
2 nd week		39.4	21.4		36.80	20.37	63.43	26.43	0	28.4	10.6	84	43
3 rd week		40.9	22.9		37.73	22.06	75.57	25.14	0	29.1	11.8	85	46
4 th week		40.7	24.1		38.71	20.20	66.00	17.43	0	28.5	14	87	47
5 th week		40.5	24.9		38.51	22.60	68.86	24.29	0	32	15.5	82	47
6 th week		39	23.7		39.34	24.51	53.86	18.71	2.4	31.3	15.2	82	41
7 th week		42.9	28.8		41.03	26.09	57.71	19.86	0	32.2	15.7	77	38
8 th week		43.5	25.9		40.97	25.40	49.86	17.86	0	33.5	19.3	81	48
9 th week		42	26.8		41.26	25.84	60.00	28.00	23.2	33.4	21.1	79	57
10 th week		40.5	22.9		37.06	22.46	74.43	35.29	0	40.6	20.5	88	22
11 th week		40.7	26.3		37.57	23.31	80.00	32.71	0	38.7	22.9	75	37
12 th week		40.7	24.4		36.89	24.40	76.14	40.43	23.2	41.1	21.1	69	27
13 th week		40.1	26.9		39.17	26.06	66.29	30.71	-	-	-	-	-
14 th week		39.7	23.4		35.40	22.74	84.71	47.57	-	-	-	-	-
15 th week		35.1	24.7		31.97	22.74	86.00	58.00	-	-	-	-	-
16 th week		37.2	23		32.71	22.71	83.71	53.86	-	-	-	-	-
17 th week		33	23.2		31.89	21.60	88.29	61.14	-	-	-	-	-

Table.3 Pooled ANOVA of stability for selected traits under heat stress and optimal conditions

Source of Variation	df	Days to 50 % anthesis	Days to 50 % silking	Anthesis to silking interval (d)	Plant height (cm)	Cob height (cm)	Grain yield (t ha ⁻¹)
Replications	3	0.25	0.63	1.05	352.81	168.11	1.76*
Hybrids	29	6.52	8.18	0.93	209.70	141.39	1.19*
Environments	2	955.81**	1143.86*	22.69**	3518.31*	2872.23*	191.42**
G × E interaction	58	4.21	4.70	1.07	136.64	82.29	1.22*
Environment (linear)	1	1911.62**	2287.72**	45.37**	7036.62**	5744.47**	382.83**
G × E interaction (Linear)	29	2.91	3.82	0.59	46.95	41.41	1.82**
Pooled deviation	30	5.24**	5.39**	1.49**	218.79**	119.06**	0.51**
Pooled error	87	1.96	2.61	0.68	122.69	40.27	0.19
Total	89	26.35	31.43	1.51	236.44	164.24	5.48

*Significance at p=0.05 **Significance at p=0.01

Table.4 *Per se* performance and stability parameters of hybrids for anthesis to silking interval (d) under Heat stress and optimal conditions

SL No	Hybrid name	Bheemaranagudi		Hyderabad		Sabour		Mean		Stability Parameters	
		Days	Rank	Days	Rank	Days	Rank	Days	Rank	bi	s ² di
1	ZL14501 × VL1032	1.42	6	1.97	25	4.11	28	2.50	13	1.54	1.71
2	ZL14501 × VL1033	2.49	15	1.58	20	3.43	21	2.50	14	1.14	-0.64
3	ZL14501 × VL128	2.58	18	1.55	18	3.38	20	2.50	15	0.57	-0.68
4	ZL11959 × VL1032	2.17	10	1.47	16	3.36	19	2.33	10	-0.05	-0.53
5	ZL11959 × VL1033	2.47	13	0.68	2	2.35	1	1.83	5	1.24	-0.36
6	ZL11959 × VL128	1.17	5	0.47	1	2.36	2	1.33	1	-0.05	-0.53
7	VL1110175 × VL1032	2.03	8	1.29	9	3.17	12	2.17	7	0.82	-0.55
8	VL1110175 × VL1033	0.52	3	1.39	12	3.59	22	1.83	6	0.92	2.69
9	VL1110175 × VL128	2.90	19	2.12	27	3.99	27	3.00	25	1.70	-0.58
10	ZL132102 × VL1032	2.03	9	1.29	11	3.17	13	2.17	8	0.82	-0.55
11	ZL132102 × VL1033	3.56	24	1.65	21	3.29	17	2.83	21	0.67	-0.21
12	ZL132102 × VL128	2.41	12	2.52	30	4.57	30	3.17	27	1.60	0.62
13	VL062609 × VL1032	2.35	11	1.41	14	3.25	15	2.33	11	2.01	-0.65
14	VL062609 × VL1033	3.88	26	2.21	28	3.91	25	3.33	29	1.81	-0.47
15	VL062609 × VL128	6.68	30	1.42	15	2.40	3	3.50	30	-0.09	13.30
16	VL1011 × VL1032	2.49	16	2.04	26	3.97	26	2.83	22	1.08	-0.29
17	VL1011 × VL1033	3.02	21	1.39	13	3.09	10	2.50	16	0.93	-0.50
18	VL1011 × VL128	4.49	28	1.08	7	2.43	4	2.67	18	1.14	3.49
19	VL107 × VL1032	3.96	27	1.73	22	3.31	18	3.00	26	1.29	0.27
20	VL107 × VL1033	3.59	25	0.95	3	2.46	5	2.33	12	0.47	1.14
21	VL107 × VL128	2.48	14	1.13	8	2.89	7	2.17	9	1.19	-0.66
22	ZL11953 × VL1032	0.42	2	0.97	5	3.11	11	1.50	2	1.54	1.71
23	ZL11953 × VL1033	2.53	17	1.79	23	3.67	23	2.67	19	0.82	-0.55
24	ZL11953 × VL128	1.09	4	0.95	4	2.96	8	1.67	4	0.46	0.15
25	31Y45 (Check)	0.16	1	1.07	6	3.28	16	1.50	3	0.04	2.81
26	D2244 (Check)	1.87	7	2.26	29	4.37	29	2.83	24	1.85	1.28
27	DKC9108 (Check)	5.08	29	1.55	19	2.88	6	3.17	28	0.58	3.97
Mean		2.63		1.53		3.25		Grand mean= 2.47			
Environmental indices		-0.16		0.94		-0.78					
CV (%)		63.70		49.84		25.35					
CD (0.05)		3.43		1.56		1.69					
CD (0.01)		4.62		2.11		2.27					

Table.5 *Per se* performance and stability parameters of hybrids for grain yield (t ha⁻¹) under heat stress and optimal conditions

Sl. No	Hybrid name	Bheemaranagudi		Hyderabad		Sabour		Mean		Stability Parameters	
		Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	bi	s ² di
1	ZL14501 × VL1032	1.70	20	1.43	20	5.96	20	3.03	20	0.77	-0.11
2	ZL14501 × VL1033	2.60	6	2.33	6	6.86	6	3.93	6	1.28	1.15
3	ZL14501 × VL128	1.21	29	0.94	29	5.47	29	2.54	29	0.73	-0.04
4	ZL11959 × VL1032	2.22	14	1.95	14	6.48	14	3.55	14	1.17	-0.24
5	ZL11959 × VL1033	1.27	25	1.00	25	5.53	25	2.60	25	0.91	0.10
6	ZL11959 × VL128	2.80	4	2.53	4	7.06	4	4.13	4	1.51	1.21
7	VL1110175 × VL1032	1.56	21	1.29	21	5.82	21	2.89	21	0.92	0.38
8	VL1110175 × VL1033	2.51	8	2.24	8	6.77	8	3.84	8	1.60	0.69
9	VL1110175 × VL128	2.03	19	1.76	19	6.29	19	3.36	19	1.17	0.27
10	ZL132102 × VL1032	1.24	26	0.97	26	5.50	26	2.57	26	0.43	-0.24
11	ZL132102 × VL1033	0.91	30	0.64	30	5.17	30	2.24	30	0.41	-0.22
12	ZL132102 × VL128	1.36	23	1.08	23	5.61	23	2.68	23	0.70	-0.16
13	VL062609 × VL1032	2.35	12	2.08	11	6.61	11	3.68	11	0.69	-0.04
14	VL062609 × VL1033	2.44	9	2.17	9	6.70	9	3.77	9	0.77	1.82
15	VL062609 × VL128	2.59	7	2.31	7	6.84	7	3.91	7	0.99	0.19
16	VL1011 × VL1032	2.93	2	2.66	2	7.19	2	4.26	2	1.43	-0.18
17	VL1011 × VL1033	2.67	5	2.40	5	6.93	5	4.00	5	1.56	-0.13
18	VL1011 × VL128	1.37	22	1.10	22	5.63	22	2.70	22	0.57	0.13
19	VL107 × VL1032	2.11	15	1.84	15	6.37	15	3.44	15	1.15	0.43
20	VL107 × VL1033	2.41	10	2.13	10	6.66	10	3.74	10	1.02	-0.23
21	VL107 × VL128	1.23	27	0.96	27	5.49	27	2.56	28	0.36	1.91
22	ZL11953 × VL1032	2.06	17	1.78	17	6.31	17	3.39	17	0.93	-0.17
23	ZL11953 × VL1033	1.32	24	1.05	24	5.58	24	2.65	24	0.57	-0.13
24	ZL11953 × VL128	2.05	18	1.77	18	6.30	18	3.37	15	1.14	-0.19
25	31Y45 (Check)	2.27	13	1.99	13	6.52	13	3.60	13	1.40	0.50
26	D2244 (Check)	2.89	3	2.62	3	7.15	3	4.22	3	1.14	2.19
27	DKC9108 (Check)	3.19	1	2.92	1	7.45	1	4.52	1	1.56	1.47
Mean		2.12		1.70		6.27		Grand mean=3.36			
Environmental indices		1.24		1.66		-2.91					
CV (%)		26.48		18.48		13.68					
CD (0.05)		1.15		0.64		1.75					
CD (0.01)		1.55		0.86		2.36					

Hybrid, ZL 14501 × VL 1032 recorded regression value equal to unity and non-significant deviation from regression (-1.20), indicating its higher stability and wider adaptability across the environments for days to 50 % silking. Another hybrid, ZL 1110175 × VL 128 also recorded regression value equal to unity and non-significant deviation from regression. But with respect to the mean performance, this hybrid recorded little longer duration (data not shown).

The mean performance of hybrids, VL 1011 × VL 1033 and VL 1011 × VL 1032 was 2.50 and 2.83 days for anthesis-silking interval, respectively (Table 4).

These hybrids recorded regression value of 0.93 and 1.08, respectively, and non-significant deviation from regression, indicating their stability and wider adaptability across the environments.

The hybrid, VL 1110175 × VL 1032 was identified as a stable hybrid across environments as it recorded mean value of 59.33 cm for cob height under heat stress and optimal environmental conditions and regression value nearer to unity and non-significant deviation from regression (Table 5). On the same account, the hybrid VL 107 × VL 1033 was identified as a stable for grain yield. Syed *et al.*, (2011); Balestre *et al.*, (2009); Banik *et al.*, (2010) reported stable maize cultivars across environments for grain yield.

From the present investigation, the hybrids, VL 1011 × VL 1033 and VL 1011 × VL 1032 and VL 107 × VL 1033 were identified as stable for anthesis silking interval and for grain yield, respectively.

These hybrids need to be re-tested under various environments including heat stress conditions before their commercialization.

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