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Combining ability and heterosis in tropical maize (*Zea mays* L.) under heat stress

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Abstract
Maize cultivars tolerant to heat stress could play a pivotal role in adapting to the intermittent high temperature at critical growth stages and cope-up with climate-change induced high temperature spells. Field experiments were conducted to analyze combining ability and heterotic effects in maize under heat stress and optimal conditions during summer and early spring, 2016. Analysis of variance for combining ability revealed that all the traits except cob height (at Hyderabad) under heat stress and days to 50 per cent silking (at Sabour, Bhagalpur) under optimal conditions, were predominantly governed by non-additive gene action. The study revealed that inbred lines VL1011 and VL1032 were good general combiners for days to 50 per cent anthesis and days to 50 per cent silking, respectively. VL107 was the good general combiner among females for the traits *viz*., plant height and cob height while, ZL11953 was a good general combiner among females for grain yield (t ha^{-1}). VL128 was a good general combiner among males for the traits *viz*., cob height and grain yield (t ha^{-1}) under heat stress and optimal conditions. VL107 × VL128 was the best hybrid combination among the hybrids having the highest specific combining ability effects for days to 50 per cent anthesis, days to 50 per cent silking and grain yield under heat stress and optimal conditions in desirable direction. The hybrid, VL107 × VL128 (55.77) showed high desirable heterosis for grain yield at Hyderabad under heat stress.

Keywords: *Zea mays* L., maize, heat stress, combining ability, heterosis, across locations

Introduction
In India, over 80% maize is grown under rainfed condition which is highly vulnerable to extreme weather events, including drought and high temperatures. Therefore, there is a strong need for fast-tracking development and deployment of stress-resilient maize for realizing improved-stable maize production. Since opportunities are limited for further expansion of maize area, increase in maize supply to meet demands will have to be achieved through intensification of current maize production systems, such as expansion of maize area during Spring season. Karnataka is the one of most important maize growing states of India with a total area of 1.18 m ha and production of 3.27 m t with an average productivity of 2.77 t ha^{-1} (Anonymous, 2016) [1]. Maize encounters both abiotic and biotic stresses during its cultivation. Further, production and productivity of maize are prone to rapid and constant changes due to global warming related environmental changes (Porter, 1995) [12].
Spring maize is grown during the hot-summer period of the year (Feb–May) is invariably exposed to high temperature regimes during most of the critical crop growth period, starting from late vegetative stage until early grain filling. In addition, during summer-rainy season, the main maize crop season there is an increasing frequency of drought years with combined drought and heat stress, which significantly limits maize productivity. 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 and therefore reduced sink capacity (Lobell *et al*., 2011) [11]. Kiniry and Ritchie (1985) [10] 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) [2] highlighted that heat stress is more important than moisture stress as 2 ºC elevated temperature would lower maize yield by 13 % while, a 20 % variation in intra-seasonal rainfall would lower maize yields by 4.2 % only. The total yield loss depends on the occurrence of stress during crop growth, as well as the duration and the severity of the stress.

The optimal temperatures for growth of tropical maize is between 25 °C to 33 °C, while night temperatures range between 17 °C to 23 °C (Ellis et al., 1992) [4]. The temperature above 35 °C for a long period is considered to be unfavourable for maize cultivation and over 40 °C cause irreversible damage to yield levels. Therefore, adaptation strategies to climate change in maize systems are likely to include improved germplasm with tolerance to heat stress and improved management practices. The knowledge on general combining ability is helpful in selecting superior inbred lines (parental lines) which can be used to derive best hybrids and knowledge on specific combining ability gives us idea about best performing cross or hybrid (Sprague and Tatum, 1942) [13].

Hussain *et al*. (2007) [6] identified several inbreds *viz.,* L1, L2, L3 and T1, T3 and hybrids *viz.,* L1×T3, L2×T4, L3×T3 and L5×T1 that proved to be the excellent combiners with high *gca* and *sca* effects, respectively for most of the traits under heat stress. The dominant type of gene action was observed to be predominant for all the traits hence hybrids have higher capability to tolerate to heat stress than their parents. Jodage *et al*. (2016) [7] assessed the general combining ability of parents and specific combining ability of hybrids and heterosis of hybrids under heat stress. They identified one line (L2) in experiment-I as good general combiner for tassel blast, ear girth, shelling per cent, test weight and grain yield. Whereas, L2 of experiment-II was a good general combiner for tassel blast and shelling per cent. The lines, L27 and L40 of experiment-III were reported as good general combiners for plant height, ear height, ear girth, number of kernel rows per cob and grain yield per plant. Dinesh *et al*. (2016) [3] reported three inbreds *viz.,* L78, L73 and L37 that exhibited good general combining ability for grain yield. Further, two hybrids *viz*., L118 x L2 and L143 x L1 were identified as good specific combiners for grain yield under heat stress from the same experiment.

The performance of maize hybrids differs with location due to G x E interaction. If the parents are chosen based on the *gca* effects across locations comprising of heat stress and optimal conditions, the chances of producing heat stress resilient maize hybrid may improve. Further, there is a need to identify hybrids which show high heterosis for yield across varied locations and also identify parents with good general combining ability across locations for future breeding programme. Hence, the present investigation was carried out to find general combining ability of parents, specific combining ability and heterosis of hybrids for grain yield and other traits of maize under heat stress and optimal conditions across different locations.

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 hybrid 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 Farm, Bheemarayanagudi, 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 Bheemarayanagudi 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 weather parameters recorded at Bheemarayanagudi 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).

During the course of investigation following traits *viz.,* days to 50 % anthesis, days to 50 % silking, anthesis to silking interval, plant height and cob height were recorded on five randomly selected plants from each entry from the two replications. While and grain yield was recorded on plot basis and expressed in t ha^{-1} at 12.5 % moisture. The data was analysed as per Kempthorne (1957) [9] in WINDOSTAT 9.2.

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

S. 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	Bheemarayanagudi			Hyderabad					Sabour, Bhagalpur				
	Rainfall (mm)	Temperature (ºC)		Rainfall (mm)	Temperature (ºC)		Relative humidity		Rainfall (mm)	Temperature (ºC)		Relative humidity	
		Maximum	Minimum		Maximum	Miminum	8.30 AM	5.30 PM		Maximum	Minimum	8.30 AM	5.30 PM
1st week	0	36.9	21.7	0.00	34.40	20.51	73.71	35.71	0	24.4	8.5	95	58
2nd week	0	39.4	21.4	0.00	36.80	20.37	63.43	26.43	0	28.4	10.6	84	43
3rd week	0	40.9	22.9	0.00	37.73	22.06	75.57	25.14	0	29.1	11.8	85	46
4th week	0	40.7	24.1	0.00	38.71	20.20	66.00	17.43	0	28.5	14	87	47
5th week	0	40.5	24.9	0.63	38.51	22.60	68.86	24.29	0	32	15.5	82	47
6th week	0	39	23.7	0.00	39.34	24.51	53.86	18.71	2.4	31.3	15.2	82	41
7th week	0	42.9	28.8	0.06	41.03	26.09	57.71	19.86	0	32.2	15.7	77	38
8th week	0	43.5	25.9	0.00	40.97	25.40	49.86	17.86	0	33.5	19.3	81	48

9th week	0	42	26.8	0.81	41.26	25.84	60.00	28.00	23.2	33.4	21.1	79	57
10th week	0.18	40.5	22.9	15.74	37.06	22.46	74.43	35.29	0	40.6	20.5	88	22
11th week	0.36	40.7	26.3	8.00	37.57	23.31	80.00	32.71	0	38.7	22.9	75	37
12th week	0.29	40.7	24.4	3.43	36.89	24.40	76.14	40.43	23.2	41.1	21.1	69	27
13th week	0	40.1	26.9	0.63	39.17	26.06	66.29	30.71					
14th week	1.07	39.7	23.4	9.03	35.40	22.74	84.71	47.57					
15th week	1.50	35.1	24.7	1.77	31.97	22.74	86.00	58.00					
16th week	2.25	37.2	23	2.49	32.71	22.71	83.71	53.86					
17th week	1.17	33	23.2	9.31	31.89	21.60	88.29	61.14					

Results and Discussion

Combining ability analysis

The pooled analysis of variance for combining ability for different traits across locations under heat stress and optimal conditions (Table 3) revealed that the variances due to hybrids and environments were significant for all the six traits indicating the importance of environment in causing variations among hybrids. Variances due to female effect were significant for plant height whereas, variances due to male effect were significant for days to 50 per cent silking and cob height. Variances due to female × male interaction were significant for all the traits except plant height.

A perusal at *GCA* and *SCA* variances for the traits revealed higher magnitude of *SCA* variance for all the traits except days to 50 % silking under optimal condition (Table 4) indicating the predominance of non-additive gene action in governing these traits under heat stress and optimal conditions. However, the magnitude of *GCA* variance was higher than *SCA* variance across locations for plant height, cob height and grain yield indicating the importance of additive gene action in the control of these traits. Dinesh *et al.* (2016) [3], Gazala *et al.* (2017) [5] and Jodage *et al.* (2018) [8] reported non-additive gene action for heat stress adaptive traits under heat stress conditions.

Table 3: Pooled analysis of variance for combining ability 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})
Replicates	1	0.06	6.25	5.84*	87.89	170.09	0.62
Hybrids	23	11.07**	14.82**	2.67*	505.00 *	330.85**	2.42**
Environments	2	1531.17**	1761.81**	31.94**	4800.26**	3263.68**	235.37**
Female effect	7	10.29	14.90	1.06	1017.14 *	313.83	1.50
Male effect	2	30.53	43.75*	6.58	192.69	1130.05*	3.29
Female × Male effect	14	8.69*	10.64*	2.91*	293.56	225.19**	2.75**
Error	69	3.75	5.37	1.36	276.84	88.34	0.39
Total	143	29.09	34.28	2.11	401.23	203.24	4.94

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

Table 4: Estimates of *GCA* and *SCA* variances for selected traits under heat stress and optimal conditions

Characters	σ^2 *GCA*				σ^2 *SCA*				σ^2 *GCA*/σ^2 *SCA*			
	L1	L2	L3	P	L1	L2	L3	P	L1	L2	L3	P
Days to 50 % anthesis	0.21	1.01	0.11	0.55	1.94	8.51	0.26	0.88	0.10	0.11	0.42	0.63
Days to 50 % silking	0.22	1.08	0.44	0.77	0.56	9.21	-0.06	0.89	0.39	0.12	7.33	0.87
Anthesis to silking interval (d)	0.16	0.02	0.09	0.05	0.46	0.05	0.42	0.14	0.35	0.40	0.21	0.36
Plant height (cm)	2.68	15.16	3.36	12.85	83.79	142.34	6.68	6.33	0.03	0.10	0.50	2.03
Cob height (cm)	38.39	22.86	9.75	16.10	13.01	33.13	16.97	9.50	2.95	0.69	0.58	1.69
Grain yield (t ha^{-1})	0.14	0.01	0.36	0.05	0.17	0.26	2.66	0.03	0.82	0.04	0.14	1.67

L1-Bheemarayanagudi, L2-Hyderabad, L3-Sabour and P-Pooled

Combining ability effects

The *GCA* effects of parents and *SCA* effects of hybrids are presented in Table 5 and Table 6, respectively. The results indicated that none of the parents recorded desirable *GCA* effects at any of the locations. Pooled data across locations revealed that ZL131202 and VL1011 among females and VL1032 among males were good general combiners as they recorded desirable *GCA* effects for days to 50% anthesis and days to 50% silking. While, VL107 was a good general combiner on the same account for plant height and cob height. Further, ZL 11953 and VL128 among males proved to be good general combiner for grain yield as they recorded significant *GCA* effects for grain yield (Table 5). Dinesh *et al.* (2016) [3] identified three inbreds *viz.*, L78, L73, and L37 as good general combiners for grain yield among 145 inbred lines used in his study. Gazala *et al.* (2017) [5] identified parental lines having desirable *gca* for traits like ASI, days to %0% anthesis, days to 50% silking, number of kernels and grain yield. Similarly, Jodage *et al.* (2018) [8] identified ZL135005 and CAL1730 from L x T experiment and ZL132088 and CZL0522 from NCD-II experiment as good general combiners for traits like leaf firing, tassel blast and yield contributing traits.

VL107 × VL128 and ZL132102 x VL1033 were good specific combiners among the hybrids as they recorded desirable specific combining ability effect for days to 50 per cent anthesis, days to 50 per cent silking and plant height under heat stress condition at Hyderabad and grain yield across locations. While the cross, ZL11959 × VL1033 was a good specific combiner for grain yield under heat stress at Hyderabad and optimal conditions at Sabour, Bhagalpur as it recorded desirable *sca* effects. The hybrid, VL062609 × VL128 recorded desirable *sca* effects for days to 50 per cent anthesis and days to 50 per cent silking under heat stress at Hyderabad. The hybrids *viz.*, ZL11959 x VL1033, VL062609 x VL1032 and VL107 x VL1033 recorded significant *sca* effects for grain yield across locations. Dinesh *et al.* (2016) [3] identified two crosses, L118 x L2 and L143 x L1 as good specific combiners for grain yield under heat stress from among 290 hybrids. Jodage *et al.* (2018) [8] identified hybrids showing desirable *sca* effects for maximum number of traits from L x T (ZL134989 x CML470 and ZL135003 x CML 470) and DCD-II experiment (VL1010963 x ZL132070 and VL062655 x CAL1427).

Table 5: General combining ability (*GCA*) effects of parents for selected traits under heat stress and optimal conditions

S. No.	Parents	Days to 50 % anthesis				Days to 50 % silking				Anthesis to Silking interval(d)				Plant height (cm)				Cob height (cm)				Grain yield (t ha^{-1})			
		B.GUDI	HYD	SAB	P	B.GUDI	HYD	SAB	P	B.GUDI	HYD	SAB	P	B.GUDI	HYD	SAB	P	B.GUDI	HYD	SAB	P	B.GUDI	HYD	SAB	P
Females																									
1	ZL14501	2.48	0.38	-3.29	-0.15	2.73	0.48	-2.83	0.13	0.25	0.10	0.38	0.24	21.19	8.02	-6.50	7.57	14.21	4.16	-10.19	2.73	0.43	0.67	-1.63	-0.10
2	ZL11959	-0.52	-0.29	-0.29	-0.37	-0.44	-0.19	1.65	-0.21	0.08	0.10	0.38	0.19	-6.30	-9.47	0.00	-8.26 *	-7.86	-10.00	-6.02	-7.96 **	0.19	0.14	0.58	0.10
3	VL1110175	-0.52	1.54	0.04	0.35	0.56	1.65	-0.17	0.68	1.08	0.10	-0.29	0.30	-4.63	4.68	1.66	0.57	-6.61	0.83	1.98	-1.26	0.22	-0.27	-0.32	-0.04
4	ZL132102	-1.02	-1.79	0.04	-0.92*	-1.60	-1.85	-1.17	-1.54 **	-0.58	-0.06	-0.46	-0.37	-9.63	-12.81	-2.66	-8.37 *	4.21	-4.16	1.65	0.56	0.22	-0.24	-0.84	-0.51 **
5	VL062609	-0.02	1.71	0.88	0.85	-0.44	1.98	1.00	0.85	-0.42	0.27	0.04	-0.04	-0.05	1.35	5.00	2.10	-5.36	1.66	4.81	0.37	0.00	0.00	0.86	0.29*
6	VL1011	-0.52	-2.63	0.21	-0.98*	-1.10	-2.85	0.67	-1.01 *	-0.58	-0.23	0.04	-0.26	-4.63	3.85	7.16	2.12	-1.19	-4.16	0.31	-1.68	0.68	0.12	0.80	0.03
7	VL107	-0.02	1.54	1.71	1.08*	-0.27	1.65	1.50	0.96	-0.25	0.10	-0.29	-0.15	21.61	3.02	10.33	11.65 **	6.71	8.33	5.31	6.78**	0.01	-0.44	-0.04	-0.18
8	ZL11953	0.15	-0.46	0.71	0.13	0.56	-0.85	1.00	0.24	0.42	-0.40	0.21	0.08	-17.55	1.35	-6.00	-7.39	-4.11	3.33	2.15	0.45	0.43	0.02	0.58	0.41 **
Males																									
9	VL1032	-0.42	-0.54	-1.00	-0.65*	-0.73	-0.67	-1.73	-1.04 **	-0.31	-0.13	-0.44	-0.29	0.10	-2.18	-2.90	-1.66	-4.792	-1.771	-2.23	-2.93*	-0.32	0.23	-0.73	-0.28 **
10	VL1033	-0.54	0.02	-0.19	-0.24	0.21	0.15	0.27	0.21	0.75	0.13	0.38	0.41*	-2.24	2.18	0.54	-0.56	-3.073	-2.083	-2.85	-2.67	0.36	-0.04	-0.23	0.03
11	VL128	0.96	0.52	1.19	0.89 **	0.52	0.52	1.46	0.83*	-0.44	0.00	0.06	-0.13	2.13	0.00	2.35	2.22	7.865	3.854	5.08	5.60 **	-0.04	-0.19	0.96	0.25**
CD @ 5 % Female		0.91				1.09				0.55				7.82				4.42				0.29			
CD at 1 % Female		1.21				1.45				0.73				10.38				5.87				0.39			
S.E m±		0.46				0.55				0.27				3.92				2.22				0.15			
CD at 5 % Male		0.56				0.67				0.34				4.79				2.71				0.18			
CD at 1 % Male		0.74				0.89				0.45				6.36				3.59				0.24			
S.E m±		0.28				0.33				0.17				2.40				1.36				0.09			

*Significance at p=0.05 **Significance at p=0.01
B.GUDI-Bheemarayanagudi, HYB-Hyderabad, SAB-Sabour and P-pooled

Table 6: Specific combining ability (*sca*) effects of hybrids for selected traits under heat stress and optimal conditions

Hybrids	Days to 50 % anthesis				Days to50 % silking				Anthesis to Silking interval(d)				Plant height (cm)				Cob height (cm)				Grain yield (t ha^{-1})			
	B. GUDI	HYB	SAB	P	B. GUDI	HYB	SAB	P	B. GUDI	HYB	SAB	P	B. GUDI	HYB	SAB	P	B. GUDI	HYB	SAB	P	B. GUDI	HYB	SAB	P
ZL14501 × VL1032	0.08	-0.04	-0.08	-0.29	-1.10	-0.19	0.50	-0.96	-1.19	-0.15	0.56	-0.76	-20.10	-2.08	-2.29	-1.31	-6.88	-1.56	-0.85	-2.01	-0.61	0.12	-0.28	-0.51
ZL14501 × VL1033	-2.29	-1.04 *	-0.46	-0.38	-2.04	-1.06	0.31	-0.21	0.25	-0.02	0.88	0.19	13.49	0.73	1.40	0.76	2.66	2.50	4.71	-0.86	0.77	-0.21	-0.83	0.55*
ZL14501 × VL128	2.21	1.08 *	0.54	0.67	3.15	1.25	-0.81	1.17	0.94	0.17	-1.44 *	0.57	6.62	1.35	0.90	0.64	4.22	-0.94	-3.85	2.87	-0.16	0.09	1.11	-0.05
ZL11959 × VL1032	-3.42	-1.71 **	-0.08	-0.73	-3.44	-1.69 *	-1.17	-1.13	-0.02	0.02	-0.94	-0.38	-1.35	-11.25*	2.21	3.69	7.71	-1.56	2.48	3.51	0.13	0.82 **	2.34**	0.32
ZL11959 × VL1033	2.71	-0.71	0.04	0.51	1.63	-0.06	0.65	-0.04	-1.08	0.65	0.88	-0.58	-1.51	-10.94*	-14.10	0.09	2.24	-15.00 *	-7.46	4.17	0.01	-0.28	-1.90 **	0.76**
ZL11959 × VL128	0.71	2.42 **	0.04	0.22	1.81	1.75*	0.52	1.17	1.10	-0.67	0.06	0.96*	2.87	22.19**	11.90	-3.78	-9.95	16.56**	4.98	-7.68 *	-0.14	-0.54 *	-0.43	-1.07**
VL1110175 × VL1032	0.58	-2.54**	-1.42	0.71	-0.44	-2.52 **	-0.50	0.65	-1.02	0.02	0.23	-0.15	-3.02	-3.75	-7.63	4.69	-1.04	4.27	4.65	3.82	-0.94 *	0.10	0.12	-0.42
VL1110175 × VL1033	-0.79	1.96**	1.21	-1.70 *	1.13	2.60 **	0.81	-1.01	1.92	0.65	-0.96	0.64	1.82	14.06 *	11.56	-8.40	-1.51	-1.67	-0.79	-0.69	0.26	0.45	0.97	-0.06
VL1110175 × VL128	0.21	0.58	0.21	1.00	-0.69	-0.08	-0.31	0.44	-0.90	-0.67	0.73	-0.49	1.20	-10.31	-3.94	3.72	2.55	-2.60	-3.85	-3.13	0.68	-0.55 *	-1.09	0.48
ZL132102 × VL1032	-1.42	-1.21*	0.25	0.99	-1.27	-0.69	-0.17	0.70	0.15	0.52	-0.27	0.18	14.48	-15.42 **	0.21	1.13	-1.88	-11.56	-3.35	-4.01	0.71*	-0.32	1.00	-0.25
ZL132102 × VL1033	0.21	-1.21*	-1.13	-0.43	1.79	-2.06 **	-1.35	0.46	1.58	-0.85	0.04	0.64	-10.68	12.31 *	-2.10	-5.96	-14.84	10.00	3.71	-8.02 *	-0.44	0.39	-2.75**	0.62*
ZL132102 × VL128	1.21	2.42 **	0.88	-0.56	-0.52	2.75 **	1.52	-1.17	-1.73	0.33	0.23	-0.82	-3.80	3.02	1.90	4.83	16.72	1.56	-0.35	12.04 **	-0.36	-0.08	1.75 *	-0.37
VL062609 × VL1032	0.58	-1.21 *	1.42	-0.13	0.56	-1.69 *	0.50	-0.01	-0.02	-0.48	-0.77	0.01	-3.85	-1.25	1.54	-5.26	5.21	2.60	11.98 *	1.18	0.18	0.01	-1.29	0.59*
VL062609 × VL1033	-0.29	5.79 **	-0.96	-0.71	-0.88	5.94 **	-0.69	-1.26	-0.58	0.15	0.54	-0.53	3.49	6.56	1.73	1.82	2.24	1.67	-2.96	3.67	0.20	-0.03	2.08 **	-0.75 **
VL062609 × VL128	-0.29	-4.58 **	-0.46	0.83	0.31	-4.25**	0.19	1.28	0.60	0.33	0.23	0.51	0.37	-5.31	-3.27	3.44	-7.45	-4.27	-9.02	-4.85	-0.39	0.02	-0.79	0.16

VL1011 × VL1032	4.08 *	2.13 **	0.58	0.88	5.23*	2.15 **	1.50	1.76	1.15	0.02	1.31 *	0.90	14.32	-12.60*	2.56	11.37	11.82	5.00	0.38	3.14	-0.25	-0.27	0.91	0.24
VL1011 × VL1033	0.21	-2.38**	-0.79	1.29	-1.71	-3.23 **	-1.69	0.85	-1.92	-0.85	-1.29	-0.30	1.20	-6.98	2.06	-1.34	-6.62	-3.44	5.81	1.37	-0.19	-0.25	-1.22	0.11
VL1011 × VL128	-4.29*	0.25	0.21	-2.17**	-3.52	1.08	0.19	-2.61**	0.77	0.83	-0.10	-0.51	35.73	3.75	5.71	10.10	-3.13	5.10	-9.69	-4.15	-0.08	-0.65 *	-2.37**	0.078
VL107× VL1032	-0.92	4.13**	-1.58	-1.51	0.40	4.31 **	-1.83	-0.79	1.31	0.19	-0.10	0.63	-23.18	-0.94	4.90	-5.91	-1.09	-0.83	5.38	-0.33	-0.07	-0.35	1.52 *	-0.77**
VL107 × VL1033	-0.29	-1.88**	3.04 *	0.74	-0.54	-1.56 *	2.98	0.46	-0.25	0.31	0.21	-0.25	-12.55	-2.81	-10.60	-4.11	4.22	-4.27	4.31	4.48	0.15	1.00**	0.85	0.61**
VL107 × VL128	1.21	-2.25**	-1.46	0.78	0.15	-2.75**	-1.15	0.33	-1.06	-0.50	-0.10	-0.38	-6.35	10.42*	4.88	-2.92	5.21	4.27	0.98	6.18	0.08	-0.608 *	0.18	0.62*
ZL11953 × VL1032	0.42	0.46	0.92	0.01	0.06	0.31	1.17	-0.24	-0.35	-0.15	-0.10	-0.43	2.24	-9.27	-5.94	6.23	-1.51	-1.67	-2.96	-1.08	-0.48	0.30	0.00	-0.58*
ZL11953 × VL1033	0.54	-0.54	-0.96	0.68	0.63	-0.56	-1.02	0.85	0.08	-0.02	-0.29	0.19	4.12	-1.15	1.06	-3.31	-3.70	-2.60	1.98	-5.10	0.40	0.30	-0.18	-0.04
ZL11953 × VL128	-0.96	0.08	0.04	-0.78	-0.69	0.25	-0.15	-0.61	0.27	0.17	0.40	0.24	3.16	-1.92	0.98	-2.76	-2.62	-2.31	1.21	-4.92	0.16	0.22	-0.11	-0.03
CD (0.05)	3.77	0.94	3.00	1.58	4.87	1.41	3.07	1.89	2.40	1.17	1.29	0.95	37.80	10.40	15.17	13.55	16.92	11.75	11.19	7.66	0.77	0.49	1.21	0.50

*Significance at p=0.05 **Significance at p=0.01 B.GUDI-Bheemarayanagudi, HYB-Hyderabad, SAB-Sabour and P-pooled

Table 7: Standard heterosis (%) of hybrids for selected traits under heat stress and optimal conditions

Cross	Days to 50 per cent anthesis			Days to 50 per cent silking			Anthesis to silking interval			Plant height (cm)			Cob height (cm)			Grain yield (t ha^{-1})		
	B.GUDI	HYB	SAB	B.GUDI	HYB	SAB	B.GUDI	HYB	SAB	B.GUDI	HYB	SAB	B.GUDI	HYB	SAB	B.GUDI	HYB	SAB
ZL14501 × VL1032	0.00	-2.83 *	-0.83	-6.14	-2.75	2.40	-70.00 *	0.01	80.00 *	-5.17	0.00	-14.07 *	-19.40	-8.33	-19.89*	-49.01 **	9.89	-41.10 **
ZL14501 × VL1033	-4.81	-3.77 **	0.83	-6.14	-3.67 *	4.00	-20.00	0.01	80.00 *	16.38	3.92	-10.78	-5.97	8.33	-4.55	8.87	-16.76	-33.97 **
ZL14501 × VL128	6.73	-2.83 *	0.83	3.51	-2.75	-0.80	-30.00	0.01	-20.00	14.66	-1.96	-13.77 *	8.96	-12.5	-18.18 *	-28.17	8.52	-25.49 *
ZL11959 × VL1032	-12.50 *	-2.83 *	-0.83	-15.79 *	-2.75	0.80	-50.00	0.01	40.00	-11.21	-7.84	-12.28	-28.36	-4.17	-16.48	-58.87 **	42.03 *	-13.72
ZL11959 × VL1033	-0.96	0.00	1.67	-5.26	0.92	5.60	-50.00	33.33	100.00 **	-12.93	-5.88	-20.96**	-32.84 *	-16.67	-18.75 *	-42.96 **	-26.65	-47.69 **
ZL11959 × VL128	-1.92	2.83 *	0.00	-4.39	0.92	2.40	-30.00	-66.67	60.00	-6.90	13.73 *	-8.08	-34.33 *	20.83	-8.52	-58.31 **	-32.69	-44.51 **
VL1110175 × VL1032	-4.81	-3.77 **	-1.67	-8.77	-2.75	-0.80	-50.00	33.33	20.00	-11.21	-5.88	-16.17 *	-37.31 *	0.00	-10.23	-63.38 **	-10.71	-47.74 **
VL1110175 × VL1033	-7.69	5.66 **	5.00	-4.39	7.34**	3.20	30.00	66.67	-40.00	-9.48	9.80	-3.59	-35.82 *	0.00	-7.39	-10.56	0.55	-24.87 *
VL1110175 × VL128	-2.88	0.00	1.67	-7.02	-0.92	-1.60	-50.00	-33.33	20.00	-6.90	-15.69 **	-15.57 *	-17.91	-16.67*	-14.77	-9.72	-45.88*	-61.02 **
ZL132102 × VL1032	-9.62	-7.55**	0.83	-14.04 *	-5.50 **	0.80	-60.00	66.67	0.01	-2.59	-15.69 **	-9.88	-25.37	-16.67	-14.77	-40.99 *	-11.81	-22.48 *
ZL132102 × VL1033	-6.73	-6.60 **	0.83	-7.02	-7.34 **	0.80	-10.00	-33.33	0.01	-21.55	7.84	-10.18	-38.81 **	29.17 *	2.27	-56.62 **	18.68	-50.92 **
ZL132102 × VL128	-1.92	-2.83 *	2.50	-10.53	-1.83	2.40	-100.00 **	33.33	0.01	-13.79	-5.88	-10.48	11.94	0.00	-6.25	-65.49 **	1.65	-14.00
VL062609 × VL1032	-3.85	-2.83 *	3.33	-8.77	-2.75	4.00	-60.00	0.00	20.00	-8.62	3.92	-6.29	-28.36	8.33	-1.14	-44.51 **	4.95	-57.28 **
VL062609 × VL1033	-5.77	11.32 **	1.67	-9.65	11.93 **	4.00	-50.00	33.33	60.00	-5.17	11.76 *	-5.09	-29.85 *	16.67	-9.09	-24.79	-6.04	-6.36
VL062609 × VL128	-2.88	-11.32 **	0.83	-7.02	-10.09 **	2.40	-50.00	33.33	40.00	-4.31	-3.92	-10.78	-28.36	-8.33	-19.89 *	-52.39 **	5.49	-51.53 **
VL1011 × VL1032	1.92	0.00	1.67	-1.75	0.00	4.80	-40.00	0.00	80.00*	-19.83	21.57 **	-6.29	-35.82 *	-8.33	-14.2	-60.99 **	33.52	-24.15 *
VL1011 × VL1033	-5.77	-7.55 **	1.67	-12.28 *	-9.17 **	1.60	-80.00 *	-66.67	-40.00	-0.86	-1.96	-0.90	-13.43	12.50	2.27	-61.55 **	-18.68	-4.13
VL1011 × VL128	-11.54 *	-5.66 **	1.67	-14.91 *	-4.59 *	1.60	-50.00	33.33	0.00	-6.90	-3.92	-3.89	-22.39	-16.67	4.55	-70.85 **	-8.79	-41.05 **
VL107× VL1032	-6.73	10.38 **	0.00	-8.77	10.09 **	0.80	-30.00	0.00	20.00	33.62	9.80	-4.49	-23.88	37.50 *	-22.73 *	-54.65 **	-35.44	-61.63**
VL107 × VL1033	-5.77	0.00	10.00 **	-8.77	0.00	10.40 **	-40.00	0.00	20.00	-8.62	7.84	-3.89	-19.4	37.50 *	3.41	-35.07 *	-27.2	-4.96
VL107 × VL128	0.00	-3.77 **	0.83	-7.02	-5.50 **	0.80	-80.00 *	-66.67	0.00	1.72	0.00	-15.87 *	0.00	16.67	-1.70	-40.14 *	55.77 **	-25.60 *
ZL11953 × VL1032	-3.85	-0.94	3.33	-7.89	-0.92	5.60	-50.00	0.00	60.00	-22.41	11.76 *	-10.18	-26.87	8.33	-14.2	-29.72	-46.43 *	-36.36 **
ZL11953 × VL1033	-3.85	-1.89	2.50	-5.26	-1.83	4.00	-20.00	0.00	40.00	-18.10	-1.96	-15.57 *	-32.84 *	8.33	-9.66	-26.2	-4.67	-24.99 *
ZL11953 × VL128	-3.85	-3.77 **	2.50	-7.02	-3.67 *	2.40	-40.00	0.00	60.00	-13.79	-0.96	-14.07 *	-22.39	-8.33	-7.95	-12.39	3.85	-40.27 **
CD (0.05)	4.61	1.15	3.68	5.96	1.73	3.76	2.93	1.43	1.58	46.30	12.73	18.58	20.73	14.38	13.71	0.94	0.59	1.59

*Significance at p=0.05 **Significance at p=0.01 B.GUDI-Bheemarayanagudi HYB-Hyderabad and SAB-Sabour

Heterosis

Among the three check hybrids used, 31Y45 was considered as the best check and standard heterosis was expressed over it and presented in Table 7. The hybrid, VL107 × VL128 recorded desirable standard heterosis for days to 50 per cent anthesis (-3.77 %), days to 50 per cent silking (-5.50 %) and grain yield (55.77 %) at Hyderabad and anthesis to silking interval (-80.00 %) at B'gudi under heat stress condition. Negative heterosis was desirable for days to 50% anthesis, days to 50% silking and anthesis-silking interval so that the hybrids which mature earlier and can escape from heat stress during growth period of crop. Positive heterosis is desirable for grain yield and hybrids with high yield levels in spite of heat stress condition during crop growth were appreciated. Out of 171 hybrids evaluated in three different experiments, L1 x T3 [(CA14515/CA14502)-F2-10-2-B*9 x (CML20xCML329)-17-3-3-1-B*11] and L4 x T1 [(POOL16BNSEQC3F37x3-2-2-3-2-B*5) x (DT/LN/EM-46-3-1xCML311-2-1-3)-B-F216-1-1-1-B*5] (experiment -I), L7 x T1 [(CML488-B*4-#) x (CLQ-RCYQ12-B-1-B*6-#)] and L1 x T5 [(PHZ51-#) x (CA14514-8-3-2-B*4-#)] (experiment -II) and L22 x T2 and L25 x T2 (experiment -III) were exhibited desirable heterosis for heat stress tolerant traits as well as grain yield Jodage *et al*. (2016) [7].

From the present study, it is concluded that the most of the characters of tropical maize under heat stress are governed by non-additive gene action. ZL131202 and VL1011 were identified as good general combiners for days to 50% anthesis and days to 50% silking across locations.

VL107 × VL128 was identified as the potential hybrid across locations and under heat stress.

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