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RESEARCH PAPER

Combining ability and heterosis for heat stress tolerance in maize (*Zea mays* L.)

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Abstract: Field experiments were conducted to estimate the combining ability and heterotic effects of maize hybrids under heat stress condition during summer (mid-March to June). The σ^2 GCA/ σ^2 SCA was less than unity for all characters *viz.,* days to 50 per cent anthesis, days to 50 per cent silking, anthesis to silking interval, tassel blast, leaf firing, plant height, ear length, ear girth, shelling %, number of kernels per cob, 100-grain weight and grain yield/plant except ear height indicating the role of non-additive gene action involved in governing these traits. The parental lines, *viz.*, VL1051 for ASI; VL107578, VL110232, ZL134937 and VL1018816 for days to anthesis and silking recorded significant *gca* effects in negative direction. The parents, ZL126643 and VL1110175 recoded significant *gca* effects in positive direction for number of kernels per cob and grain yield. The hybrids, ZL126643 × VL1010877 and VL108868 × VL1110175 recorded significant *sca* effects for days to 50% anthesis in negative direction. The hybrid, VL107578 × VL1010877 recorded significant sca effect in positive direction for plant height and grain yield. The hybrids, VL1011 × VL1110175 (67.13 %), ZL126643 × VL1010877 (40.82 %) and VL126643 × VL0556 (40.21 %) recorded significant standard heterosis for grain yield per plant and VL108868 × VL1110175 (30.45%) recorded significant standard heterosis for test weight under heat stress.

Key words: Combining ability, Heat stress, Heterosis, Maize

Introduction

Maize (*Zea mays* L.) is one of the major cereal crops which contributes to food security after rice and wheat. It gives highest average grain yield (5.82 metric tonnes ha^{-1}) as compared to major cereals such as wheat (3.39 metric tonnes ha^{-1}) and rice (4.45 metric tonnes ha^{-1}) (Anon, 2017). Maize is considered as a staple food in many parts of the world, especially in Latin America, Africa, Southern Europe and some Asian countries it is consumed as food grains. (Sandhu *et al.*, 2007). Besides human food, maize is also used as feed for animals and as a crop of industrial value (White and Johnson, 2003). It is a miracle C_4 crop having a very high genetic yield potential. There is no other cereal, which has such an immense genetic potential and thus, is called 'Queen of Cereals'.

Maize production and productivity are hampered by global climate change. 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., 2009a). Rowhani *et al,* (2011) reported that seasonal temperature increases have the most important impact on crop yields in Tanzania. By 2050 projected seasonal temperature increases by 2 °C reduce average maize, sorghum, and rice yields by 13%, 8.8%, and 7.6%, respectively. Potential changes in seasonal total precipitation as well as intra-seasonal temperature and precipitation variability may also impact crop yields by 2050, albeit to a lesser extent. A 20% increase in intra-seasonal precipitation variability reduces agricultural yields by 4.2%, 7.2% and 7.6%, respectively, for maize, sorghum and rice. According to Intergovernmental Panel on Climatic Change (Anon, 2007), global mean temperature will rise by 0.3 °C per decade reaching to approximately 1 °C and which will be 3 °C above the present value by the year 2025 and 2100, respectively, and which will result in global warming. Further, every degree increase in day temperature above 30 °C, yield decreases by 1% in optimum conditions and 1.7% under drought conditions (Lobell *et al.,* 2011). The yield potential of maize decreases by 2 to 5% for increase in temperature from 0.5 °C to 1.5 °C in India (Aggarwal, 2003). If current trends persist by 2050, maize yields may drop by 17%, wheat by 12%, and rice by 10% in irrigated areas in South Asia because of climate change induced heat and water stress (Anon., 2009b).

Most of the sub-tropical maize growing areas in South Asia are highly vulnerable to high temperature stress, particularly during pre-monsoon season, when maize is prone to heat stress during anthesis and early grain filling stages (Prasanna, 2011). In India including Karnataka, majority of the maize is grown during *kharif* under rain-fed conditions. During drought years, the temperature could rise close to 40 °C, and therefore maize crop may face combined drought and heat stress.

In this regard, it becomes necessary to develop maize hybrids tolerant to heat stress condition with good yield levels. In order to develop such hybrids, the mode of gene action governing various traits along with its reaction to heat stress need to be understood thoroughly. The knowledge on the genetic basis of hybrid performance under high temperature stress serves as a key to decide suitable breeding strategies. However, breeding for heat tolerance in tropical maize is in its infancy stage and warrants more attention.

The information on effect of heat stress on combining ability and heterosis in maize is limited (Hussain *et al.,* 2007; Akbar *et al.,* 2008; Dinesh *et al.,* 2016; Jodage, 2016). Hence, there is a need to understand as to how the different maize lines combine with each other and respond to heat stress. Further, information on *gca* and *sca* effects influencing yield and its components could be useful to plant breeders in the choice of suitable parents for developing potential heat resilient maize hybrids.

The application of heterosis has been one of the most important contributions of genetics to scientific agriculture in producing vigorous and high yielding hybrid maize. Heterosis often results in a considerable increase in the growth and productivity of crops. In view of this, the present investigation was carried out to estimate the combining ability of lines for various traits under heat stress in tropical maize using different mating designs and heterosis of hybrids under heat stress.

Materials and methods

The present investigation involved two sets of experiments. The material for experiment-I consisted of nine female and three male lines and were crossed in NCD-II mating design to generate 27 hybrids. The genetic material for experiment-II consisted of three female lines and five male testers which were mated in Line × Tester fashion to generate 15 hybrids. In both the experiments, the leading commercial hybrids *viz.,* 31Y45 (DuPont Pioneer), BIO9544 (Bioseed) and D2244 (Dow AgroSciences) were used as checks. The experiment-I (NCD-II) was carried out at 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. While, experiment-II (Line × Tester) was carried out at Main Agricultural Research Station, Raichur situated at 16° 12' N latitude and 72° 21' E longitude with an altitude of 389.37 m above mean sea level. The parental lines developed at CIMMYT-Asia, ICRISAT campus, Hyderabad were either tolerant or moderately tolerant to heat stress and were utilized for generating hybrids (Table 1). The hybrids were evaluated in alpha lattice design during summer (mid-March to a June), 2016. Each plot consisted of two rows of 3m length with spacing of 60 cm × 20 cm. Recommended agronomic practices were adopted to raise a healthy crop under drip irrigation till physiological maturity.

The climate data was collected from automatic weather stations situated at ARS, Bheemarayanagudi and MARS, Raichur. The temperature during the crop growth period ranged from 21.4 to 43.5 °C at Bheemarayanagudi and 20.9 to 43.4 °C at

Table 1. List of parental lines used for generating test hybrids and their reaction to heat stress

Sl.No.	Expt. No.	Name	Line/Tester	Reaction to heat stress	Mating design
1	Experiment-I	VL1018673	L1	Moderately tolerant	NCD-II
2		VL1051	L2	Tolerant	
3		VL107578	L3	Tolerant	
4		VL109126	L4	Tolerant	
5		VL1110232	L5	Tolerant	
6		VL145313	L6	Tolerant	
7		ZL126643	L7	Tolerant	
8		ZL134937	L8	Tolerant	
9		ZL134971	L9	Moderately tolerant	
10		VL1018816	T1	Moderately resistant	
11		VL1010877	T2	Resistant	
12		VL0556	T3	Moderately tolerant	
13	Experiment-II	VL108868	L1	Tolerant	Line × Tester
14		VL1011	L2	Tolerant	
15		VL062609	L3	Tolerant	
16		VL1110175	T1	Moderately tolerant	
17		VL107	T2	Tolerant	
18		ZL132102	T3	Tolerant	
19		ZL11959	T4	Tolerant	
20		ZL11953	T5	Tolerant	

Table 2. Estimates of GCA and SCA variances for various traits under heat stress condition

	Experiment-I (NCD-II)			Experiment-II (LxT)		
Characters	σ^2 GCA	σ^2 SCA	σ^2 GCA/σ^2 SCA	σ^2 GCA	σ^2 SCA	σ^2 GCA/σ^2 SCA
Days to 50 % anthesis	0.16	1.30	0.12	0.03	1.92	0.01
Days to 50 % silking	0.12	0.60	0.20	0.12	0.45	0.26
Anthesis to silking interval (days)	0.01	-0.02	-0.50	0.01	-0.34	-0.02
Tassel blast (%)	-0.01	-0.18	0.05	-	-	-
Leaf firing (%)	-0.01	-0.02	0.50	-	-	-
Plant height (cm)	13.18	27.93	0.47	9.25	-44.41	-0.20
Ear height (cm)	6.02	4.73	1.27	-0.55	-19.51	0.02
Ear length (cm)	0.02	0.31	0.06	-0.07	2.66	-0.02
Ear girth (cm)	0.01	0.10	0.10	0.05	0.64	0.07
No. of kernels/cob	43.67	-88.43	-0.49	226.90	-752.92	0.30
Shelling %	0.06	2.62	0.02	-0.14	6.71	-0.02
Test weight (g)	0.15	0.33	0.45	0.18	0.39	0.46
Grain yield/plant (g)	1.74	-3.53	-0.49	9.07	-30.11	-0.30

Table 3. General combining ability (*gca*) effects of parents for various traits under heat stress condition

Parents	Days to 50% anthesis	Days to 50% silking	ASI (days)	Tassel blast (%)	Leaf firing (%)	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of kernels / cob	Shelling (%)	Test weight (g)	Grain yield/ plant (g)
Experiment-I (NCD-II)													
Females													
VL1018673	2.33*	2.57*	0.25	-0.74	-0.25	-0.13	-0.78	0.19	-0.58*	-22.16	0.79	0.01	-4.43
VL1051	1.50*	0.74	-0.90*	-0.68	-0.19	-15.13*	-5.37	1.29	0.25	-25.36	-0.88	1.41	-5.07
VL107578	-1.50*	-1.09	0.42	0.61	-0.19	-10.13*	-9.53*	0.00	0.04	23.40	0.11	0.07	4.68
VL109126	0.50	0.24	-0.24	0.21	-0.19	19.02*	13.38*	0.03	0.34	-15.56	1.27	1.79	-3.51
VL1110232	-2.33*	-2.25*	0.09	-0.68	0.70	-12.22*	-5.37	0.53	-0.44	34.83	2.11*	-2.90*	6.96
VL145313	-0.33	-0.25	0.09	-0.68	-0.19	18.19*	10.04*	0.06	0.12	-32.26	1.27	1.52	-6.45
ZL126643	0.50	0.40	-0.07	0.21	-0.19	-2.63	-3.70	0.09	0.63*	51.83*	0.44	-0.78	10.36*
ZL134937	-1.66*	-1.42*	0.25	1.11	0.70	-8.47*	-7.03*	1.06	-0.25	-34.79	-3.55*	-1.15	-6.95
ZL134971	1.00	1.07	0.09	0.61	-0.19	11.52*	8.38*	0.00	-0.11	22.07	0.01	0.00	4.41
Males													
VL1018816	-1.33*	-0.87*	0.48*	-0.40	0.08	-9.02*	-7.59*	-0.26	0.57*	1.13	0.50	0.79	0.22
VL1010877	-0.05	-0.37	-0.29	0.05	0.10	-2.50	-0.64	-0.50	-0.65*	-20.41	-0.61	-1.66*	-4.08
VL0556	1.38*	1.24*	-0.18	0.35	-0.19	11.52*	8.24*	0.77*	0.07	19.28	0.11	0.87	3.85
CD at 5% female	1.08	1.31	0.71	0.39	0.16	6.80	5.87	0.88	0.56	46.78	1.68	1.83	9.35
S.E m±	0.52	0.63	0.34	0.18	0.07	3.30	2.85	0.42	0.27	22.75	0.82	0.89	4.55
CD at 5% male	0.62	0.75	0.41	0.22	0.09	3.92	3.38	0.50	0.32	27.00	0.97	1.06	5.40
S.E m±	0.30	0.36	0.19	0.10	0.04	1.91	1.64	0.24	0.15	13.13	0.47	0.51	2.62
Experiment-II (LxT)													
Lines													
VL108868	-1.20	-0.96	0.23	-	-	4.12	0.16	-0.37	-0.74*	21.78	-0.96	-0.98	4.35
VL1011	0.70	0.133	-0.56	-	-	-5.44	-0.07	0.76*	0.89*	28.76	1.63	0.95	5.75
VL062609	0.50	0.83	0.33	-	-	1.32	-0.08	-0.38	-0.15	-50.55*	-0.66	0.03	-10.11*
Testers													
VL1110175	-0.33	0.30	0.63	-	-	0.30	-0.24	0.06	0.61	67.38*	-0.56	2.14*	13.47*
VL107	-1.66	-2.20*	-0.53	-	-	18.00*	5.09	0.88*	-0.59	-18.95	1.43	0.44	-3.79
ZL132102	1.00	1.63	0.63	-	-	-11.88	-5.90	-0.15	-0.69	-18.42	1.60	-1.95*	-3.68
ZL11959	1.33	1.13	-0.20	-	-	0.56	4.06	-0.05	-0.33	-29.28	-2.73	-1.02	-5.85
ZL11953	-0.33	-0.86	-0.53	-	-	-6.98	-3.00	-0.73	1.01*	-0.72	0.26	0.39	-0.14
CD at 5% female	1.33	1.66	1.00	-	-	11.27	8.30	0.65	0.72	43.15	2.35	1.34	8.63
S.E m±	0.62	0.77	0.46	-	-	5.25	3.87	0.30	0.33	20.12	1.09	0.62	4.02
C.D. at 5% male	1.71	2.14	1.29	-	-	14.55	10.72	0.85	0.93	55.71	3.03	1.73	11.14
S.E m±	0.80	0.99	0.60	-	-	6.78	4.99	0.39	0.43	25.97	1.41	0.81	5.19

*& ** significant at 0.05 and 0.01 level of probability respectively

Table 4. Specific combining ability (*sca*) effects of single cross experimental hybrids for various traits under heat stress condition in experiment-I (NCD-II)

Cross	DA	DS	ASI	TB (%)	LF (%)	PH (cm)	EH (cm)	EL (cm)	EG (cm)	NKC	SP	TW (g)	GYP (g)
VL1018673×VL1018816	-0.50	-0.79	-0.31	0.28	-0.20	4.44	-0.32	0.41	-0.26	-22.63	0.61	1.96	-4.52
VL1018673×VL1010877	2.22*	2.20	-0.03	0.00	-0.04	-7.08	-2.26	-1.39	-0.52	-16.68	-0.61	-1.44	-3.33
VL1018673×VL0556	-1.72	-1.40	0.35	-0.29	0.25	2.63	2.59	0.97	0.79	39.31	-0.88	-0.52	7.86
VL1051×VL1018816	-0.66	-0.96	-0.14	0.40	-0.08	-4.30	-1.99	-1.38	0.05	14.96	1.00	0.19	2.99
VL1051×VL1010877	-0.94	-0.96	0.13	-0.05	-0.10	7.91	6.06	1.10	0.19	23.31	-0.38	-0.92	4.66
VL1051×VL0556	1.61	1.92	0.01	-0.35	0.19	-3.61	-4.07	0.27	-0.24	-38.28	-0.61	0.73	-7.65
VL107578×VL1018816	-0.16	-0.13	0.01	-0.89	-0.08	-1.80	4.67	0.06	-0.14	56.89	3.50*	0.28	21.38*
VL107578×VL1010877	-1.44	-0.63	0.79	-1.34	-0.10	12.91*	6.48	0.62	0.43	-31.24	-3.88*	-1.21	-6.25
VL107578×VL0556	1.61	0.75	-0.81	2.24	0.19	-11.11	-11.15*	-0.68	-0.29	-25.64	0.38	0.93	-5.13
VL109126×VL1018816	0.83	0.53	-0.31	-0.49	-0.08	4.02	-5.74	0.51	0.34	14.36	0.83	-0.14	2.87
VL109126×VL1010877	-0.44	-0.96	-0.53	-0.94	-0.10	-5.00	1.06	-0.84	0.24	5.81	1.44	0.74	1.16
VL109126×VL0556	-0.38	0.42	0.85	1.44	0.19	0.97	4.67	0.32	-0.58	-20.18	-2.27	-0.60	-4.03
VL1110232×VL1018816	-0.33	0.53	0.85	0.40	-0.98	-4.72	-0.74	0.08	0.35	-5.35	-1.00	0.71	-1.07
VL1110232×VL1010877	1.38	0.53	-0.87	-0.05	1.68*	3.75	-2.68	0.12	-0.60	-1.37	2.11	0.54	-0.27
VL1110232×VL0556	-1.05	-1.07	0.01	-0.35	-0.70	0.97	3.42	-0.20	0.25	6.72	-1.11	-1.25	1.34
VL145313×VL1018816	0.16	0.53	0.35	0.40	-0.08	-8.88	-4.90	-0.34	0.63	-3.33	-0.16	-0.55	-0.66
VL145313×VL1010877	-0.61	-0.96	-0.37	-0.05	-0.10	4.58	-1.85	0.53	-0.25	28.31	1.44	0.33	5.66
VL145313×VL0556	0.44	0.42	0.01	-0.35	0.19	4.30	6.75	-0.19	-0.37	-24.98	-1.27	0.22	-4.99
ZL126643×VL1018816	1.83	1.37	-0.48	-0.49	-0.08	0.69	3.84	-1.03	-0.82	-68.33	-1.83	-1.95	-13.66
ZL126643×VL1010877	-1.94*	-1.63	0.29	-0.94	-0.10	-0.83	-3.10	1.05	0.95	55.01	-1.22	3.54*	11.00
ZL126643×VL0556	0.11	0.25	0.18	1.44	0.19	0.13	-0.74	-0.02	-0.12	13.31	3.05*	-1.58	2.66
ZL134937×VL1018816	-1.50	-1.29	0.18	1.29	1.70*	4.02	4.67	0.48	0.28	20.39	-2.33	-1.07	4.08
ZL134937×VL1010877	1.72	1.70	-0.03	0.84	-1.00	-2.50	-2.26	-0.72	-0.39	-33.74	-0.22	-1.54	-6.75
ZL134937×VL0556	-0.22	-0.40	-0.14	-2.14	-0.70	-1.52	-2.40	0.24	0.11	13.35	2.55	2.62	2.67
ZL134971×VL1018816	0.33	0.20	-0.14	-0.89	-0.08	6.52	0.50	1.18	-0.42	-6.96	0.11	0.56	-1.39
ZL134971×VL1010877	0.05	0.70	0.63	2.54	-0.10	-13.75*	-1.43	-0.47	-0.04	-29.41	-0.11	-0.02	-5.88
ZL134971×VL0556	-0.38	-0.90	-0.48	-1.64	0.19	7.22	0.92	-0.70	0.47	36.38	0.11	-0.54	27.27*
C.D. at 5%	1.88	2.27	1.23	3.03	1.53	11.78	10.16	1.52	0.98	81.02	2.92	3.18	16.20
S.E m±	0.91	1.10	0.59	1.47	0.74	5.73	4.94	0.74	0.47	39.41	1.42	1.54	7.88

* &** significant at 0.05 and 0.01 level of probability respectively

DA-days to 50% anthesis, DS-days to 50% silking, ASI-anthesis silking interval,, TB-tassel blast, LF-leaf firing, PH-plant height, EH-ear height, EL-ear length, EG-ear girth., NKC-number of kernels/cob, SP-shelling %, TW-test weight, GYP-grain yield/plant

Table 5. Specific combining ability (*sca*) effects of single cross experimental hybrids for various traits under heat stress condition in experimen-II (Line ×Tester)

Cross	DA	DS	ASI	PH (cm)	EH (cm)	EL (cm)	EG (cm)	NKC	SP	TW (g)	GYP (g)
VL108868×VL1110175	-3.46*	-2.20	1.26	-1.77	-7.43	0.52	-0.23	-47.02	-3.03	0.32	-9.40
VL108868×VL107	0.36	0.3	-0.06	-5.52	1.53	-1.15	0.86	7.01	-0.53	-1.00	1.40
VL108868×ZL132102	0.70	-0.03	-0.73	2.21	1.88	0.18	1.12	24.48	-2.20	2.45	4.89
VL108868×ZL11959	0.86	0.46	-0.40	5.76	3.97	1.96*	-1.64*	30.84	4.63	-0.67	6.16
VL108868×ZL11953	1.53	1.46	-0.06	-0.68	0.03	-1.51*	-0.10	-15.32	1.13	-1.10	-3.06
VL1011×VL1110175	1.13	0.20	-0.93	7.59	9.81	-1.30	0.31	0.50	0.36	0.45	0.10
VL1011×VL107	0.96	1.70	0.73	-11.46	2.32	0.88	-1.03	5.53	-2.13	0.86	1.10
VL1011×ZL132102	-1.20	-1.63	-0.43	-3.87	-5.52	-1.25	0.25	21.2	1.70	-2.18	4.24
VL1011×ZL11959	0.46	0.86	0.40	-0.32	-10.84	1.05	0.38	-17.03	1.53	1.17	-3.40
VL1011×ZL11953	-1.36	-1.13	0.23	8.07	4.22	0.62	0.07	-10.20	-1.46	-0.30	-2.04
VL062609×VL1110175	2.33	2.00	-0.33	-5.82	-2.38	0.77	-0.08	46.52	2.66	-0.78	9.30
VL062609×VL107	-1.33	-2.00	-0.66	16.98	-3.86	0.26	0.17	-12.54	2.66	0.14	-2.50
VL062609×ZL132102	0.50	1.66	1.16	1.66	3.63	1.07	-1.38	-45.68	0.50	-0.27	-9.13
VL062609×ZL11959	-1.33	-1.33	0.00	-5.43	6.87	-3.01*	1.25	-13.81	-6.16*	-0.49	-2.76
VL062609×ZL11953	-0.16	-0.33	-0.16	-7.38	-4.26	0.89	0.03	25.52	0.33	1.40	5.10
C.D. at 5%	2.97	3.71	2.24	25.21	18.57	1.47	1.61	96.49	5.25	3.01	19.29
S.Em±	1.38	1.73	1.04	11.75	8.65	0.68	0.75	44.99	2.45	1.40	8.99

* &**significant at 0.05 and 0.01 level of probability respectively

DA-days to 50% anthesis; DS-days to 50% silking; ASI-anthesis silking interval; TB-tassel blast
LF-leaf firing; PH-plant height; EH-ear height; EL-ear length
EG-ear girth; NKC-number of kernels/cob; SP-shelling %; TW-test weight
GYP-grain yield/plant

Raichur (data not shown). The vapour pressure deficit was also calculated (Abtew and Melesse, 2013) for the cropping period and was more than 3 kPa indicating high heat stress (data not shown). Thus, the hybrids were appropriately screened for heat stress.

During the course of investigation the following plant characters were recorded *viz.,* days to 50% anthesis, days to 50% silking, anthesis to silking interval (days), tassel blast (%), leaf firing (%), plant height (cm), ear height (cm), ear length (cm), ear girth (cm), number of kernels per cob, 100-grain weight (g), shelling % and grain yield per plant (g). Leaf firing/ tassel blast was recorded by the counting the number of plants that showed leaf firing/tassel blast symptoms in the total number of plants in a particular plot. Then the value was expressed in percentage. In the second experiment, none of the plants manifested tassel blast and leaf firing symptoms; hence the results were not recorded. The mean data of experiments was subjected for analysis as per Kempthorne (1957) by using WINDOSTAT 9.2 software.

Results and discussion

GCA and SCA variances

The variances (σ^2 GCA and σ^2 SCA) and the ratios (σ^2 GCA/ σ^2 SCA) for various traits of experiment-I (NCD-II) and experiment-II (Line × Tester) under heat stress condition are presented in Table 2. The σ^2 GCA/σ^2 SCA ratio was less than unity for all the characters under study except ear height in experiment-I (NCD-II) indicating the role of non-additive gene action in governing all the traits. Previously, dominance gene action has been reported for days to 50 % anthesis, days to 50 % silking, plant height, ear length and grain yield per plant by Hussain *et al.* (2007), Akbar *et al.* (2008) and Dinesh *et al.* (2016); anthesis to silking interval by Hussain *et al.* (2007) and Jodage (2016); tassel blast, leaf firing, ear girth and shelling% by Jodage *et al.* (2017); number of kernels per cob by Akbar *et al.* (2008), Khodarahmpour (2011) and Jodage (2016) and for 100-grain weight by Hussain *et al.* (2007) and Akbar *et al.* (2008).

The parental lines used in experiment-I (NCD-II), *viz.,* VL107578, VL1110232, ZL134937 and VL1018816 for days to 50% anthesis; VL1110232, ZL134937 and VL1018816 for days to 50% silking and VL1051 for ASI recorded significant gca effects in negative direction (Table 3). The lines *viz.,* VL109126, VL145313, ZL134971 and VL0556 for plant height; VL109126, VL145313, ZL134971 and VL0556 for ear height and ear length; ZL126643, VL1018816 for ear girth; VL1110232 for shelling % and ZL126643 for number of kernels per cob and grain yield per plant recorded significant *gca* effects in positive direction. These lines could be regarded as good general combiners as they recorded significant *gca* effects in desirable direction.

In experiment-II (Line × Tester), among the lines, VL1011 was a promising general combiner for ear length and ear girth. Among the testers, VL1110175 was a good general combiner for number of kernels per cob, test weight and grain yield per plant. Another tester, VL107 was good general combiner for days to 50% silking, plant height and ear length as it recorded significant *gca* effects in desirable direction under heat stress condition.

Table 6. Per cent standard heterosis of selected hybrids over check for selected traits under heat stress condition in experiment-I (NCD-II)

Cross	ASI (days)		Plant height (cm)		Tassel blast (%)		Leaf firing (%)		No. of kernels / cob		Test weight (g)		Grain yield/ plant (g)	
	Mean	%standard heterosis	Mean	%standard heterosis	Mean	%standard heterosis	Mean	%standard heterosis	Mean	%standard heterosis	Mean	%standard heterosis	Mean	%standard heterosis
VL1018673× VL1010877	2.00	0.00	131.25*	-13.22*	0.36	0.00	0.36	0.00	313.10	-24.90	20.03	-11.60	62.62	-3.90
VL1051× VL1018816	1.50	-25.00	112.50*	-25.62*	0.36	0.00	0.36	0.00	363.10	-12.90	25.54	12.66	72.62	11.45
VL1051× VL1010877	1.00	-50.00	131.25*	-13.22*	0.36	0.00	0.36	0.00	349.90	-16.07	21.95	-3.15	69.98	7.40
VL107578× VL1018816	3.00*	50.00	120.00*	-20.66*	0.36	0.00	0.36	0.00	453.80	8.85	24.28	7.13	90.76	39.29*
VL107578× VL1010877	3.00*	50.00	141.25	-6.61	0.36	0.00	0.36	0.00	344.10	-17.46	20.32	-10.35	68.82	5.62
VL107578× VL0556	1.50	-25.00	131.25*	-13.22*	4.24	1085.17	0.36	0.00	389.40	-6.60	25.02	10.37	77.88	19.52
VL109126× VL0556	2.50	25.00	172.50*	14.05*	3.05	751.33	0.36	0.00	353.90	-15.11	25.20	11.18	70.78	8.62
VL1110232× VL1018816	3.50*	75.00	115.00*	-23.97*	0.36	0.00	0.36	0.00	402.98	-3.34	21.73	-4.10	80.60	23.69
VL145313× VL1018816	3.00*	50.00	141.25	-6.61	0.36	0.00	0.36	0.00	337.90	-18.95	24.89	9.82	67.58	3.71
VL145313× VL0556	2.00	0.00	175.00*	15.70*	0.36	0.00	0.36	0.00	334.40	-19.79	25.76	13.63	66.88	2.64
ZL126643× VL1010877	2.00	0.00	135.00	-10.74	0.36	0.00	0.36	0.00	458.80	10.05	24.22	6.84	91.76	40.82*
ZL126643× VL0556	2.00	0.00	150.00	-0.83	3.05	751.33	0.36	0.00	456.80	9.57	21.63	-4.57	91.36	40.21*
ZL134971× VL0556	1.50	-25.00	171.25*	13.22*	0.36	0.00	0.36	0.00	450.10	7.96	23.47	3.55	90.02	38.15*
BIO9544 (Check)	2.00	-	151.25	-	0.01	-	0.01	-	416.90	-	22.66	-	83.38	-
C.D. at 5%	1.74	-	16.66	-	4.29	-	2.17	-	114.58	-	4.50	-	22.91	-

* &** significant at 0.05 and 0.01 level of probability respectively

Table 7. Per cent standard heterosis of hybrids over check for selected traits under heat stress condition in experiment-II (LxT)

Hybrids	ASI (days)		Plant height (cm)		No. of kernels / cob		Test weight (g)		Grain yield/ plant(g)	
	Mean	Per cent standard heterosis	Mean	Per cent standard heterosis	Mean	Per cent standard heterosis	Mean	Per cent standard heterosis	Mean	Per cent standard heterosis
VL108868× VL1110175	5.00	66.67	120.50	-5.93	350.80	-2.45	27.48*	30.45**	70.16	44.66
VL108868×VL107	2.50	-16.67	134.45	4.96	318.50	-11.43	24.45	16.07	63.70	31.34
VL108868× ZL132102	3.00	0.00	112.30	-12.33	336.50	-6.42	25.52*	21.13*	67.30	38.76
VL108868× ZL11959	2.50	-16.67	128.30	0.16	332.00	-7.68	23.31	10.66	66.40	36.91
VL108868× ZL11953	2.00	-16.67	114.30	-10.77	314.40	-12.57	24.31	15.38	62.88	29.65
VL1011× VL1110175	2.50	-33.33	120.30	-6.09	405.30	12.71	29.56*	40.33**	81.06	67.13*
VL1011×VL107	2.50	-16.67	118.95	-7.14	324.00	-9.90	28.26*	34.16**	64.80	33.61
VL1011x ZL132102	2.50	-16.67	96.65	-24.55	340.20	-5.39	22.81	8.31	68.04	40.29
VL1011× ZL11959	2.50	-16.67	112.65	-12.06	291.10	-19.05	27.10*	28.65**	58.22	20.04
VL1011× ZL11953	2.00	-33.33	113.50	-11.40	326.50	-9.20	27.05*	28.41**	65.30	34.64
VL062609× VL1110175	3.50	16.67	113.65	-11.28	372.00	3.45	27.40*	30.05**	74.40	53.40
VL062609×VL107	2.00	-33.33	154.15	20.34	226.60	-36.99	26.62*	26.37*	45.32	-6.56
VL062609× ZL132102	5.00	66.67	108.95	-14.95	194.00*	-46.05*	23.80	13.01	38.80	-20
VL062609v ZL11959	3.00	0.00	114.30	-10.77	215.00*	-40.21*	24.51	16.33	43.00*	-11.34
VL062609× ZL11953	2.50	-16.67	104.80	-18.19	282.90	-21.33	27.84*	32.14**	56.58	16.66
BIO9544 (Check)	3.00	-	128.50	-	359.60	-	21.06	-	71.92	-
C.D. at 5%	3.18	-	35.66	-	136.46	-	4.26	-	27.29	-
C.D. at 1%	4.14	-	49.49	-	189.40	-	5.91	-	37.88	-

*& ** significant at 0.05 and 0.01 level of probability respectively

The hybrid combinations of experiment-I (NCD-II), ZL126643 × VL1010877 registered significant sca effects for days to 50% anthesis and test weight; VL107578 × VL1010877 for plant height; VL107578×VL1018816, ZL126643×VL0556 for shelling % ; VL107578 × VL1018816, ZL134971 × VL0556 for grain yield per plant in desirable direction (Table 4). In experiment-II (Line × Tester), the hybrids *viz.,* VL108868 × VL1110175 for days to 50% anthesis and VL108868 × ZL11959 for ear length recorded significant *sca* effects in desirable direction under heat stress condition (Table 5). Similarly, Dinesh *et al.* (2016) and Jodage *et al.* (2017) identified good general combiners and specific combiners for grain yield and its contributing traits under heat stress condition. With respect to the tassel blast and leaf firing, neither parental lines nor test hybrids registered significant *gca* and *sca* effects, respectively in either of the experiments.

Heterosis

Among three checks *viz.,* 31Y45 (DuPont Pioneer), BIO9544 (Bio seed) and D2244 (Dow Agro Sciences), BIO9544 was the best performing in both the sets of experiments and was used to calculate standard heterosis of the test hybrids. The standard heterosis of test hybrids for ASI ranged from -50 to 75 %, but none of the hybrids recorded significant standard heterosis over best performing check.

The standard heterosis for plant height ranged from -25.62 to 20.34 % over best check and the test hybrids *viz.,* VL109126 × VL0556 (14.05 %), VL145313 × VL0556 (15.70 %) and ZL134971 × VL0556 (13.22 %) exhibited significant standard heterosis in desirable direction over best check for plant height (Table 6). The standard heterosis for tassel blast and leaf firing ranged from -50 to 1085.17 % and -50 to 751.33 %, respectively, and none of the test hybrids exhibited significant standard heterosis. None of the hybrids exhibited significant standard heterosis for number of kernels per cob. The hybrid, VL1011 × VL1110175 (40.33%) exhibited highest significant standard heterosis for test weight followed by VL1011 × VL107 (34.16%) and VL 062609 × ZL11953 (32.14 %).

The standard heterosis for grain yield per plant ranged from -13.01 to 67.13 %. The hybrids *viz.,* VL107578 × VL1018816 (39.29 %), ZL126643 × VL1010877 (40.82 %), ZL126643 × VL0556 (40.21 %) and ZL134971 × VL0556 (38.15 %) exhibited significant standard heterosis in desirable direction over best check for grain yield per plant in experiment-I (NCD-II). In experiment-II (Line × Tester) only one hybrid, VL1011 ×

VL1110175 (67.13 %) exhibited significant heterosis over best check for grain yield per plant. Similarly, Jodage (2016) identified hybrids exhibiting desirable standard heterosis over best check for plant height, test weight and grain yield per plant under heat stress condition.

Conclusion

The present investigation revealed that non-additive gene action was predominant in governing most of the traits of tropical maize under heat stress condition irrespective of mating designs. The parental lines, which recorded significant gca effects in desirable direction for different traits under heat stress condition could be exploited for development of new synthetic varieties. The superior hybrids identified could be commercially exploited in high temperature areas after retesting. Further, the promising hybrids could be evaluated in multilocation trials over seasons to assess their stability and potentiality for commercial cultivation besides their use in isolation of second cycle inbred lines.

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