Bangladesh J. Bot. **50**(3): 659-669, 2021 (September) DOI: https://doi.org/10.3329/bjb.v50i3.55846

COMBINING ABILITY FOR QUANTITATIVE TRAITS UNDER NORMAL AND HEAT STRESS CONDITIONS IN MAIZE (*ZEA MAYS* L.)

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Keywords: Hybrid maize, Combining ability, Additive and non-additive effects, Quantitative traits, Heat stress

Abstract

Investigation was carried out to ascertain the genetic architecture for heat tolerance and yield components from diallel crosses in maize (*Zea mays* L.). The combining ability in both the normal and heat stress conditions revealed highly significant mean squares due to general combining ability (GCA) and specific combining ability (SCA) in both the direct and reciprocal crosses for all the characters except for anthesis-silking interval in normal condition of the reciprocal crosses. Estimate of components of variance for 13 characters revealed higher SCA variance than that of GCA and reciprocal crosses for all the characters. CML 411 was good general combiner for grain yield in both the conditions, whereas, CML 306 and CML 307 were good general combiners in heat stress condition, and CML 164, CML 304 and CML 305 were average general combiners in normal condition. On the basis of high yield, high SCA and at least high GCA of seed parent, the CML 411 × CML 305 and CML 411 × CML 307 were identified as promising hybrids for normal and heat stress conditions, respectively.

Introduction

Maize (*Zea mays* L.) is considered as a queen of cereals and par excellence in terms of food, feed, fodder, biofuel and industrial raw materials. In India, maize is being grown on an area of 9.22 million hectares with annual production of 28.72 million tonnes and average grain yield of 3115 kg/ha (FAOSTAT 2017). India's population is projected to continue growing for several decades from 1.34 billion in 2017 to around 1.5 billion in 2030 and approaching 1.66 billion in 2050 (Anon. 2017). The increasing food and feed demand, coupled with the fluctuation in temperature and rainfall patterns as a consequence of climate change, a major challenge is to optimize crop production.

Heat in itself is a profitable and natural resource but becomes dangerous and poses harmful effects on plant, when it exceeds, it limits (35ºC) for growth and development. Heat stress in maize results in shortened life cycle (Muchow *et al*. 1990), increased respiration, reduced photosynthesis (Crafts-Brander and Salvucci 2002) and pollen sterility (Schoper *et al*. 1987b), improper pollination and fertilization and ultimately no grain formation (Schoper *et al*. 1987a). The female reproductive tissues of plant have greater tolerance to heat stress in comparison to male reproductive tissues (Dupuis and Dumas 1990). However, the period between silk emergence and pollination, and ovary fertilization in the female reproductive tissues has also recently been highlighted as a critical period controlling grain yield under heat stress (Cicchino *et al*. 2010). To keep pace with climate change effects, especially rising temperature stress, genetic enhancement for heat tolerance in maize has emerged a priority area for maize breeding programme.

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Diallel crosses have been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. These were devised, specifically, to investigate the combining ability of the parental lines for the purpose of identification of superior parents for use in hybrid development programmes. The knowledge of gene effects operative in expression of a trait greatly helps the plant breeder in making correct decisions, about breeding material, selection procedure and type of variety and extent of testing. The objective of this study was to evaluate the performance of maize inbred lines and their hybrids under normal and heat stress conditions.

Materials and Methods

The experiment was conducted at Maize Section, Bihar Agricultural University, Sabour, Bhagalpur, India having longitude (87° 3' 0" E) and latitude (25° 15' 0" N). The seven inbred lines were crossed in a diallel fashion including reciprocal crosses during *kharif*, 2015. Out of seven inbred lines, five were heat stress tolerant [CML 411(P_2), CML 305(P_3), CML 304 (P_4), CML 306 (P_6) and CML 307 (P_7) and two were heat stress susceptible [CML 164 (P_1) and CML 25 (P_5)]. Forty two F_1s and seven inbreds along with two checks (DHM 117 and SHM 2) were evaluated in two environmental conditions in randomized complete block design with three replications each in two rows of five metre length having row to row spacing of 60 cm and plant to plant spacing of 20 cm. Recommended agronomic practices were followed to ensure a healthy crop. One set of experiment was sown on 2nd January, 2016 (normal condition) to avoid high temperature at reproductive stage and second set of experiment was sown on 15th March 2016 (heat stress condition) to coincide heat stress at reproductive stage. The frequent irrigation was given in heat stress condition to avoid drought stress effect during crop period. The average minimum and maximum air temperature at flowering time was 15.9 and 31.8 ºC in normal condition (E_1); and 23.4 and 35.8 ºC in heat stress condition (E_2), respectively.

The data were recorded on ten competitive plants, which were randomly taken from each plot of all replications, for the characters, namely pollen viability, cell membrane thermostability (CMT), days to 50% physiological maturity, plant height, ear height and number of grains per plant. The characters, namely days to 50% anthesis, days to 50% silk, shelling % and grain yield per plant were recorded on the plot basis. The anthesis-silking interval (ASI) was calculated as difference between days to 50% silk and days to 50% anthesis. The 500-seed weight was recorded from the sample of bulk seeds from each plot of each replication. Pollen viability was counted by the method given by Chelong and Sdoodee (2012) and cell membrane thermostability was estimated by the method of Sullivan (1960). INDOSTAT software was used to statistical analyses for combining ability (Griffing 1956) that is method 1 and model 1 (fixed effect model).

Results and Discussion

The analysis of variance for all the traits under study revealed that the mean squares due to genotypes were found to be highly significant in both the normal and heat stress conditions and indicated that the sufficient genotypic variability was present in population in both the conditions. The analysis of variance for combining ability (Tables 1, 2 and 3), in both the conditions, revealed highly significant mean squares due to GCA, SCA and specific combining ability of reciprocal crosses (RSCA) for all the characters except due to RSCA for ASI in normal condition. This indicated that parents differed significantly from each other with respect to the estimates of their GCA effects and hybrids differed from each other for their SCA/RSCA effects. Similar results were also reported by Kaur *et al*. (2010) and Khodarahmpour (2011) for most of the characters studied. Estimates of components of variance (Tables 4 and 5) revealed that variance due to SCA was more than variance due to GCA and reciprocal for all the characters in both the conditions. It indicated that intra-allelic interaction or dominance and inter-allelic interaction or epistasis were more important for expression of above-mentioned characters. The mean performance (Tables 6, 7 and 8) of parents as well as hybrids indicated that there was the effect of heat stress in the expression of the traits in E2 with respect to E1. Similar results were also reported by Kaur *et al*. (2010), Schoper *et al*. (1987a, b) and Makus *et al*. (2000). Thus, identification of superior heat tolerant parents with good general combining ability effects for characters associated with heat tolerance is essential for heat stress condition.

Table 1. Analysis of variance for combining ability under normal and heat stress on days to 50% anthesis and silk, pollen viability and anthesis silking intervals in maize.

Source of variation	df	Mean squares							
		Days to 50% anthesis		Days to 50% silk		Pollen viability (%)		Anthesis-silking interval	
		N	HS	N	HS	N	HS	N	HS
GCA	6	13.86**	21.41**	13.72**	18.59**	61.54**	326.26**	0.26**	0.84**
SCA	21	22.70**	5.85**	19.91**	6.44**	54.39**	177.89**	0.24**	0.62**
Reciprocal	21	4.59**	1.74**	5.10**	2.63**	78.48**	226.16**	0.13	0.54**
Error	96	0.64	0.65	0.71	0.75	1.18	1.64	0.08	0.16

*,** Show significance at 5 and 1% level of probability, respectively.

Table 2. Analysis of variance for combining ability under normal and heat stress on cell membrane thermostability, height of plant and ear and days to 50% physiological maturity in maize.

Source of variation	df	Mean squares							
		Cell membrane thermo stability		Plant height		Ear height		Days to 50% physiological maturity	
		N	HS	N	HS	N	HS	N	HS
GCA	6	50.18**	84.30**	173.96**	108.47**	152.77**	135.73**	152.77**	135.73**
SCA	21	35.88**	62.93**	746.43**	717.28**	160.11**	177.46**	160.11**	177.46**
Reciprocal	21	43.55**	52.89**	51.27**	24.87**	69.19**	37.46**	69.19**	37.46**
Error	96	1.27	1.22	4.63	5.50	4.97	2.28	4.97	2.28

*,** Show significance at 5 and 1% level of probability, respectively.

Table 3. Analysis of variance for combining ability under normal and heat stress on grain per plant, 500-seed weight, shelling and grain yield per cent in maize.

Source of variation	df	Mean squares							
		Grains per plant		500-seed weight		Shelling per cent		Grain yield per plant	
		N	HS	N	HS	N	HS	N	HS
GCA	6	8716.38**	16573.17**	1423.89**	927.64**	23.67**	231.28**	928.49**	769.70**
SCA	21	11745.70**	9588.05**	333.90**	1005.05**	5.65**	172.78**	1402.39**	997.57**
Reciprocal	21	2771.93**	3032.19**	56.38**	60.28**	7.11**	14.85**	306.42**	221.87**
Error	96	403.56	468.39	5.85	12.15	0.89	3.37	27.83	21.22

*,** Show significance at 5 and 1% level of probability, respectively.

Table 4. Estimates of components of variance under normal and heat stress on days to 50% anthesis and silk, pollen viability, anthesis silking interval, cell membrane thermostability and plant height in maize.

Components	Days to 50% anthesis		Days to 50% silk		Pollen viability (%)		Anthesis-silking interval		Cell membrane thermostability		Plant height	
	N	HS	N	HS	N	HS	N	HS	N	HS	N	HS
$\sigma^2 g$	0.94	1.48	0.93	1.27	4.31	23.19	0.01	0.05	3.49	5.93	12.10	7.36
$\sigma^2 s$	22.06	5.20	19.20	5.69	53.21	176.25	0.16	0.47	34.61	61.71	741.80	711.78
σ^2 reciprocal	1.97	0.55	2.19	0.94	38.65	112.26	0.02	0.19	21.14	25.83	23.32	9.68
$\sigma^2 g/\sigma^2 s$	0.04	0.29	0.05	0.22	0.08	0.13	0.08	0.11	0.10	0.10	0.02	0.01

Table 5. Estimates of components of variance under normal and heat stress on ear height, days to 50% physiological maturity, grains per plant, 500-seed weight, shelling per cent and grain yield per plant in maize.

Components	Ear height		Days to 50% physiological maturity		Grains per plant		500-seed weight		Shelling (%)		Grain yield per plant	
	N	HS	N	HS	N	HS	N	HS	N	HS	N	HS
$\sigma^2 g$	10.56	9.53	3.70	4.22	593.77	1150.34	101.29	65.39	1.63	16.28	64.33	53.46
$\sigma^2 s$	155.14	175.19	7.92	10.56	11342.14	9119.66	328.05	992.89	4.76	169.42	1374.56	976.35
σ^2 reciprocal	32.11	17.59	1.27	2.82	1184.18	1281.90	25.26	24.06	3.11	5.74	139.29	100.33
$\sigma^2 g/\sigma^2 s$	0.07	0.05	0.47	0.40	0.05	0.13	0.31	0.07	0.34	0.10	0.05	0.05

Table 6. Mean performance of significantly superior crosses for grain yield on days to 50% anthesis and silk, pollen viability and anthesis-silking interval in maize crosses and parents under normal and heat stress.

Entry	Days to 50% anthesis		Days to 50% silk		Pollen viability (%)		Anthesis-silking interval (days)	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	77.33	61.00	79.00	65.67	96.00	29.00	1.67	4.67
$P_2 \times P_1$	69.67	56.33	71.00	58.33	91.00	28.33	1.33	2.00
$P_2 \times P_3$	75.00	60.00	77.00	64.00	96.33	72.00	2.00	4.00
$P_2 \times P_6$	71.00	59.00	73.00	62.00	91.33	26.00	2.00	3.00
$P_2 \times P_7$	72.00	62.33	73.33	65.67	96.00	31.00	1.33	3.33
$P_4 \times P_1$	76.67	57.67	79.00	60.33	98.33	32.00	2.33	2.67
DHM-117	76.33	59.33	79.00	65.33	72.33	27.33	2.67	6.00
SHM-2	70.00	60.00	72.00	63.00	90.00	30.00	2.00	3.00
P_1	84.00	63.00	85.00	67.33	95.67	17.67	2.00	4.33
P_2	80.33	62.00	79.33	64.00	91.50	51.00	1.67	2.00
P_3	83.67	68.33	85.00	70.67	98.00	54.00	1.33	2.33
P_4	81.00	65.00	79.00	66.33	97.00	56.00	1.33	1.33
P_5	82.00	65.00	83.67	69.00	92.00	12.33	2.67	4.00
P_6	74.33	63.33	77.33	65.33	92.50	49.33	2.00	2.33
P_7	80.00	68.00	81.67	69.67	94.50	53.00	1.67	2.33
Mean	73.95	61.46	75.43	64.16	89.43	34.69	1.67	2.73
SE ± (m)	0.83	0.82	0.87	0.92	1.08	1.29	0.14	0.22
CD at 5%	2.33	2.31	2.45	2.57	3.02	3.61	0.40	0.63
CV %	1.95	2.32	2.00	2.47	2.09	6.42	14.66	14.18

Table 7. Mean performance of significantly superior crosses for grain yield in maize crosses and parents on cell membrane thermo stability, height of plant and ear and days to 50% physiological maturity under normal and heat stress.

Entry	Cell membrane thermostability (%)		Plant height (cm)		Ear height (cm)		Days to 50% physiological maturity	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	60.33	40.00	169.00	136.63	57.00	48.00	108.00	90.33
$P_2 \times P_1$	68.00	42.00	173.33	128.50	82.00	58.33	110.33	86.00
$P_2 \times P_3$	70.33	35.33	168.33	149.47	73.00	55.00	116.33	96.00
$P_2 \times P_6$	75.67	65.00	174.33	133.63	84.00	53.33	115.00	98.33
$P_2 \times P_7$	72.67	62.00	165.00	136.50	78.00	58.33	113.33	99.33
$P_4 \times P_1$	74.33	64.00	165.33	131.63	57.00	42.67	115.33	91.33
DHM-117	68.00	43.33	180.33	139.53	85.33	55.00	113.00	90.00
SHM-2	70.00	50.00	185.00	155.00	90.00	62.00	106.00	88.00
P_1	62.67	43.33	128.33	92.33	71.67	42.00	111.67	87.33
P_2	68.00	58.00	99.50	73.67	46.00	28.33	112.00	90.33
P_3	68.67	56.33	127.00	98.00	65.00	49.00	117.50	95.00
P_4	69.67	63.00	126.00	96.33	63.67	48.33	109.00	90.33
P_5	66.00	40.33	121.00	79.00	67.00	23.67	108.33	85.67
P_6	67.33	56.67	130.00	97.33	56.00	36.00	116.00	91.67
P_7	70.33	58.00	118.17	89.33	60.00	45.50	115.67	97.33
Mean	63.47	48.22	164.22	131.13	78.32	56.38	111.03	93.27
SE ± (m)	1.14	1.12	2.18	2.43	2.26	1.60	1.26	1.10
CD at 5%	3.19	3.15	6.12	6.82	6.33	4.49	3.52	3.09
CV %	3.11	4.03	2.30	3.21	4.99	4.92	1.96	2.05

Table 8. Mean performance of significantly superior crosses for grain yield on grain per plant, 500-seed weight, shelling and grain yield per cent in maize crosses and parents under normal and heat stress.

Entry	Grains per plant		500-seed weight (g)		Shelling (%)		Grain yield/plant (g)	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	540.00	240.00	157.67	157.00	83.20	69.80	159.67	70.33
$P_2 \times P_1$	526.00	375.00	146.00	134.33	83.70	64.67	152.00	94.00
$P_2 \times P_3$	570.00	277.00	153.33	147.00	86.80	68.47	169.00	76.00
$P_2 \times P_6$	480.00	390.00	146.00	141.00	84.33	69.33	136.33	107.00
$P_2 \times P_7$	485.00	445.00	140.33	133.67	82.27	70.00	132.00	115.00
$P_4 \times P_1$	555.00	425.00	157.33	151.67	86.33	73.67	169.67	123.33
DHM-117	390.00	273.00	153.00	140.67	80.00	60.10	115.00	75.00
SHM-2	450.00	340.00	155.00	145.00	83.00	66.00	130.00	95.00
P_1	278.00	115.00	92.33	37.67	80.33	17.33	48.67	8.00
P_2	271.00	210.00	135.67	103.17	83.53	70.00	68.33	41.00
P_3	265.00	178.00	113.60	97.10	78.00	70.00	56.33	33.00
P_4	275.00	215.00	105.30	83.33	79.67	68.67	54.33	33.67
P_5	235.00	90.00	117.97	63.00	80.33	18.33	52.00	8.67
P_6	300.00	230.00	100.33	86.67	80.67	70.00	57.33	38.33
P_7	296.00	245.00	100.13	88.57	84.33	73.00	56.33	41.33
Mean	427.59	284.75	135.86	125.87	79.95	65.24	109.87	69.75
SE ± (m)	20.42	18.36	2.44	3.49	0.97	1.82	5.24	3.87
CD at 5%	57.30	51.42	6.83	9.79	2.72	5.10	14.70	11.02
CV %	8.27	11.17	3.10	4.80	2.10	4.83	8.26	9.62

The estimates of GCA effect (Tables 9, 10 and 11) under normal condition revealed that CML 411 was good general combiner for grain yield, shelling per cent, 500-seed weight, grains per plant, lower ear height, shorter plant height, CMT, pollen viability, early silk and early anthesis, while it was found to be average general combiner for ASI. The similar results were also reported by Ruswandi *et al*. (2015). In heat stress condition, parents, namely, CML 411, CML 306, and CML 307 were found to be good general combiners for grain yield per plant, shelling per cent, grains per plant and pollen viability. In addition, CML 411 was also found to be good general combiner for 500-seed weight, lower ear height, shorter plant height, early silk and early anthesis. CML 306 was also found to be good general combiner for lower ear height, CMT and ASI. CML 307 was also found to be good general combiner for shorter plant height and CMT. Hence, these parents may be rewarding in heat stress condition to get better hybrids.

Table 9. Estimates of GCA effects of parents under normal and heat stress on days to 50% anthesis, days to 50% silk, pollen viability and anthesis-silking interval in maize.

Entry	Days to 50% anthesis		Days to 50 % silk		Pollen viability %		Anthesis-silking interval	
	N	HS	N	HS	N	HS	N	HS
P_1	–0.201	–1.578**	–0.119	–1.418**	0.656*	–6.815**	0.027	0.126
P_2	–0.605**	–1.197**	–0.857**	–0.895**	3.061**	6.185**	0.003	0.269**
P_3	1.347**	1.255**	1.548**	1.344**	0.395	–0.244	0.122	0.102
P_4	0.70**	–0.364	0.001	–0.776**	–3.677**	0.740*	–0.282**	–0.398**
P_5	–0.582**	–0.293	–0.405	–0.037	–0.129	–5.951**	0.122	0.221*
P_6	–1.486**	0.350	–1.214**	0.129	–1.344**	2.495**	–0.020	–0.207*
P_7	0.823**	1.827**	1.048**	1.653**	1.037**	3.590**	0.027	–0.112
SE (gi)	0.197	0.198	0.209	0.213	0.268	0.317	0.070	0.098
CD at 5%	0.484	0.487	0.512	0.523	0.657	0.776	0.173	0.241

*,** Show significance at 5 and 1% level of probability, respectively.

Table 10. Estimates of GCA effects of parents under normal and heat stress on cell membrane thermostability, plant height, ear height and days to 50% physiological maturity in maize.

Entry	Cell membrane thermostability		Plant height		Ear height		Days to 50% physiological maturity	
	N	HS	N	HS	N	HS	N	HS
P_1	1.017**	-0.167	2.561**	–1.920**	1.990**	0.306	–0.925**	–3.282**
P_2	1.350**	0.238	–5.177**	–4.213**	–6.272**	–5.527**	0.980**	0.861**
P_3	–3.173**	–3.095**	1.871**	3.077**	3.990**	1.854**	2.265**	2.027**
P_4	–1.650**	–0.595*	1.799**	2.572**	1.799**	4.092**	–1.663**	–0.949**
P_5	–0.721*	–2.595**	0.252	0.034	0.609	1.401**	–3.116**	–1.949**
P_6	1.207**	3.286**	3.442**	2.330**	–0.605	–2.313**	0.884**	1.527**
P_7	1.969**	2.929**	–4.748**	–1.880**	–1.510**	0.187	1.575**	1.765**
SE (gi)	0.278	0.273	0.532	0.580	0.551	0.373	0.262	0.257
CD at 5%	0.681	0.669	1.303	1.420	1.350	0.913	0.642	0.630

*,** Show significance at 5 and 1% level of probability, respectively.

Table 11. Estimates of GCA effects of parents under normal and heat stress on grains per plant, 500-seed weight, shelling % and grain yield per plant in maize.

Entry	Grains per plant		500-seed weight		Shelling (%)		Grain yield per plant	
	N	HS	N	HS	N	HS	N	HS
P_1	23.959**	22.214**	–5.973**	–8.299**	0.287	–5.643**	1.241	0.020
P_2	16.245**	18.143**	14.051**	13.058**	2.280**	2.248**	17.051**	10.592**
P_3	–3.184	–33.214**	–2.316**	–0.999	–0.091	1.498**	–2.139	–9.051**
P_4	–16.755**	–28.929**	5.284**	4.986**	–1.329**	0.645	0.980	–5.337**
P_5	–47.327**	–45.071**	10.522**	5.463**	–1.701**	–5.855**	–4.711**	–7.384**
P_6	12.888*	39.500**	–10.282**	–6.228**	0.130	3.683**	–6.830**	6.354**
P_7	14.173**	27.357**	–11.287**	–7.980**	0.423	3.424**	–5.592**	4.806**
SE (gi)	4.970	5.355	0.598	0.862	0.233	0.453	1.305	1.140
CD at 5%	12.163	13.103	1.465	2.111	0.571	1.111	3.194	2.789

*,** Show significance at 5 and 1% level of probability, respectively.

The estimates of SCA effects (Tables 12, 13 and 14) in normal condition revealed that twelve crosses were found to be significant for higher yield per plant. Out of them crosses, namely $P_1 \times P_4$, $P_2 \times P_3$, $P_1 \times P_2$, $P_6 \times P_7$ and $P_5 \times P_7$ were found to be top five in terms of high SCA for grain yield per plant. $P_1 \times P_4$ was also found to be good specific combination for shelling per cent, 500-seed weight, grains per plant, lower ear height, CMT and ASI. $P_2 \times P_3$ was also found to be good

Table 12. Estimates of SCA effects of top five crosses for grain yield under normal and heat stress on days to 50 % anthesis, days to 50% silk, pollen viability % and anthesis-silking interval in maize.

Entry	Days to 50% anthesis		Days to 50 % silk		Pollen viability %		Anthesis-silking interval	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	0.320	–0.088	0.548	0.156	0.010	–5.637**	–0.170	0.279
$P_1 \times P_4$	–0.156	–1.255*	0.857	–1.296*	–0.918	1.141	0.449*	–0.054
$P_1 \times P_7$	–2.109**	–1.612**	–2.024**	–1.724**	–5.633**	-0.542	0.139	–0.173
$P_2 \times P_3$	–1.061*	–0.588	–0.452	–0.439	–3.061**	9.791**	0.235	0.136
$P_2 \times P_7$	–1.704**	–0.827	–1.786**	–0.248	–1.704*	–14.042**	–0.337	0.517*
$P_3 \times P_6$	–0.180	–0.969	–0.762	–0.963	–4.656**	–9.518**	–0.075	–0.054
$P_4 \times P_6$	–1.037*	0.483	–0.881	1.156*	–4.585**	–8.002**	–0.170	0.612*
$P_5 \times P_6$	–0.252	–0.755	–0.476	-0.582	3.367**	–3.978**	–0.075	0.160
$P_6 \times P_7$	1.344**	0.959	0.571	0.228	2.534*	5.482**	–0.480**	–0.840**
SE (sij)	0.491	0.494	0.519	0.530	0.666	0.787	0.175	0.244
CD at 5%	1.025	1.031	1.083	1.106	1.390	1.643	0.367	0.510

*,** Show significance at 5 and 1% level of probability, respectively.

specific combination for shelling per cent, grains per plant, CMT and early anthesis. $P_1 \times P_2$ was also found to be good specific combination for 500-seed weight, grains per plant, physiological maturity and lower ear height. $P_6 \times P_7$ was also found to be good specific combination for grains per plant, ASI and pollen viability. $P_5 \times P_7$ was also found to be good specific combination for 500-seed weight, grains per plant, physiological maturity, early silk and early anthesis. The cross,

Table 13. Estimates of SCA effects of top five crosses for grain yield under normal and heat stress conditions on cell membrane thermostability, plant height, ear height and days to 50% physiological maturity in maize.

Entry	Cell membrane thermo stability		Plant height		Ear height		Days to 50% physiological maturity	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	–1.446*	–7.357**	10.320**	8.232**	-4.156**	2.099*	–1.980**	–2.861**
$P_1 \times P_4$	6.554**	5.810**	1.510	0.197	-8.228**	–5.687**	5.663**	3.116**
$P_1 \times P_7$	1.602*	4.452**	15.224**	12.832**	8.415**	7.718**	–1.575*	–2.599**
$P_2 \times P_3$	2.912**	–5.429**	10.677**	14.201**	1.844	1.384	1.497*	1.830**
$P_2 \times P_7$	0.935	3.381**	13.129**	11.875**	7.344**	6.384**	–0.313	1.592*
$P_3 \times P_6$	–3.612**	–1.143	5.391**	7.625**	0.677	3.503**	0.092	0.830
$P_4 \times P_6$	–3.136**	–2.810**	8.463**	13.880**	7.034**	8.599**	–1.037*	0.483
$P_5 \times P_6$	3.935**	4.024**	10.510**	7.918**	–1.609	3.956**	–0.252	–0.755
$P_6 \times P_7$	–3.755**	–7.833**	1.344	–3.118*	0.177	–1.663	1.344**	0.959
SE (sij)	0.691	0.679	1.322	1.441	1.369	0.926	0.491	0.494
CD at 5%	1.442	1.417	2.758	3.007	2.857	1.934	1.025	1.031

*,** Shows significance at 5 and 1% level of probability, respectively.

Table 14. Estimates of SCA effects of top five crosses for grain yield under normal and heat stress conditions on grains per plant, 500-seed weight, shelling % and grain yield per plant in maize.

Entry	Grains per plant		500-seed weight		Shelling %		Grain yield per plant	
	N	HS	N	HS	N	HS	N	HS
$P_1 \times P_2$	64.898**	–16.714**	8.639**	15.728**	0.991	5.295**	28.187**	–0.568
$P_1 \times P_4$	69.898**	95.357**	12.906**	19.633**	3.367**	7.998**	31.425**	18.051**
$P_1 \times P_7$	36.969**	96.571**	1.311	5.099*	–2.118**	2.719*	7.330*	25.980**
$P_2 \times P_3$	111.541**	74.714**	–2.184	–1.572	2.103**	–2.512*	30.401**	15.503**
$P_2 \times P_7$	21.684**	85.643**	1.120	3.242	0.205	–1.505	8.187*	33.527**
$P_3 \times P_6$	11.898**	57.357**	3.982**	3.547	0.820	0.319	9.116**	20.075**
$P_4 \times P_6$	4.969	23.071**	2.382	4.061	–0.959	–1.495	4.997	22.194*
$P_5 \times P_6$	16.541**	56.714**	–0.189	6.418**	–0.071	3.388**	8.187*	17.075**
$P_6 \times P_7$	76.041**	-35.714**	–0.380	–2.639	0.389	–1.757	19.401**	–11.949**
SE (sij)	3.226	3.580	1.486	2.142	0.579	1.127	3.241	2.830
CD at 5%	6.710	7.446	3.100	4.468	1.208	2.352	6.762	5.904

*,** Shows significance at 5 and 1% level of probability, respectively.

CML 411 (P_2) × CML 305 (P_3) was identified as the promising experimental hybrid, having high yield, high SCA and high GCA for one parent (CML 411) for grain yield. Similar result was also reported by Akbar *et al*. (2009). In heat stress, eleven crosses were found to be significant for higher yield per plant out of them crosses, namely $P_2 \times P_7$, $P_1 \times P_7$, $P_4 \times P_6$, $P_3 \times P_6$ and $P_1 \times P_4$ were found to be top five good specific combinations for grain yield per plant. $P_2 \times P_7$ was also found to be good specific combination for grains per plant and CMT. $P_1 \times P_7$ was also found to be good specific combination for shelling per cent, 500-seed weight, grains per plant, physiological maturity, CMT, early silk and early anthesis. $P_4 \times P_6$ was also found to be good specific combination for grains per plant. $P_3 \times P_6$ was also found to be good specific combination for grains per plant. $P_1 \times P_4$ was found to be good specific combination for shelling per cent, 500-seed weight, grains per plant, lower ear height, CMT, early anthesis and early silk. The cross, CML 411 (P_2) × CML 307 (P_7) was identified as the promising experimental hybrids, having high yield, high SCA and high GCA for both the parents for grain yield.

The estimates of RSCA effects in normal condition revealed that crosses, namely, $P_4 \times P_1$, $P_3 \times P_2$ and $P_6 \times P_2$ were significant reciprocal specific combinations for grain yield per plant (Tables 15, 16 and 17). $P_4 \times P_1$ was found to be good reciprocal specific combination for grains per plant, early anthesis, early silk and ASI. $P_3 \times P_2$ was also found to be good reciprocal specific combination for shelling per cent, 500-seed weight, lower ear height, CMT and pollen viability. $P_6 \times P_2$ was found to be good reciprocal specific combination for CMT. None of cross was identified as the best experimental hybrids due to average/low GCA for seed parent. In heat stress condition,

Table 15. Estimates of RSCA effects of top three crosses for grain yield under normal and heat stress on days to 50% anthesis, days to 50% silk, pollen viability % and anthesis-silking interval in maize.

Entry	Days to 50% anthesis		Days to 50% silk		Pollen viability %		Anthesis-silking interval	
	N	HS	N	HS	N	HS	N	HS
$P_3 \times P_2$	1.333*	–1.000	1.333*	–0.167	6.167**	21.333**	0.003	0.833**
$P_4 \times P_1$	–2.333**	0.667	–2.833**	0.333	–12.500**	–2.000*	–0.500*	–0.333
$P_4 \times P_2$	–0.500	0.002	–0.333	–0.333	–1.333	0.001	0.333	–0.333
$P_6 \times P_2$	0.167	–0.667	0.003	–0.833	–2.500**	–25.667**	–0.167	–0.167
SE (rij)	0.565	0.568	0.597	0.610	0.767	0.906	0.202	0.281
CD at 5%	1.179	1.185	1.246	1.273	1.600	1.890	0.422	0.586

*,** Show significance at 5 and 1% level of probability, respectively

Table 16. Estimates of RSCA effects of top three crosses for grain yield under normal and heat stress conditions on cell membrane thermostability, plant height, ear height and days to 50% physiological maturity in maize.

Entry	Cell membrane thermo stability		Plant height		Ear height		Days to 50% physiological maturity	
	N	HS	N	HS	N	HS	N	HS
$P_3 \times P_2$	6.000**	–4.667**	–2.500	5.933**	–4.500**	1.000	0.500	–2.167**
$P_4 \times P_1$	–5.167**	–10.667**	4.000**	–0.317	16.500**	12.333**	–1.167	1.000
$P_4 \times P_2$	5.667**	3.833**	2.333	3.750*	1.500	1.500	1.500*	0.001
$P_6 \times P_2$	7.500**	8.167**	–0.833	–3.933	1.833	1.167	–0.167	–0.333
SE (rij)	0.795	0.781	1.521	1.658	1.576	1.066	0.749	0.735
CD at 5%	1.659	1.630	3.173	3.460	3.288	2.225	1.563	1.534

*,** Show significance at 5 and 1% level of probability, respectively.

four crosses were found to be significant for higher yield per plant, out of them, crosses, namely, $P_4 \times P_1$, $P_4 \times P_2$ and $P_6 \times P_2$ were found to be top three in terms of RSCA for grain yield per plant. $P_4 \times P_1$ was also found to be good RSCA for grains per plant and shelling per cent. $P_4 \times P_2$ was also found to be good RSCA for grains per plant and CMT. $P_6 \times P_2$ was also found to be good RSCA for grains per plant and CMT. The cross, CML 306 (P_6) × CML 411 (P_2) had high RSCA and high GCA but had low yield. Thus, it was not identified as promising experimental hybrids. These results are in agreement the findings of Akbar *et al.* (2008).

Table 17. Estimates of RSCA effects of top three crosses for grain yield under normal and heat stress on grains per plant, 500-seed weight, shelling % and grain yield per plant in maize.

Entry	Grains per plant		500-seed weight		Shelling %		Grain yield per plant	
	N	HS	N	HS	N	HS	N	HS
$P_3 \times P_2$	17.500	–66.500**	8.667**	11.333**	2.617**	1.900	14.333**	–10.167**
$P_4 \times P_1$	50.000**	52.500**	–10.000**	–10.167**	–4.117**	5.333**	26.667**	23.000**
$P_4 \times P_2$	–32.500**	56.500**	1.000	4.333	–0.117	0.400	–11.000**	20.000**
$P_6 \times P_2$	–4.000	34.000**	3.000	2.167	1.133	0.002	7.500*	9.667**
SE (rij)	3.710	4.125	1.710	2.465	0.666	1.297	3.730	3.257
CD at 5%	7.716	8.580	3.567	5.142	1.390	2.706	7.781	6.794

*,** Show significance at 5 and 1% level of probability, respectively.

Parent CML 411 was found to be good general combiner for grain yield per plant and other related traits in both the normal and heat stress conditions, whereas, CML 306 and CML 307 were considered as good general combiners in heat stress condition for grain yield per plant and other related traits. The experimental hybrid, CML 411 × CML 305 was identified as the best hybrid for normal condition, whereas, the experimental hybrid, CML 411 × CML 307 was identified for heat stress condition.

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(Manuscript received on 30 June, 2019; revised on 15 June, 2020)