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Research Article

Identification of superior drought tolerant maize hybrids based on combining ability and heterosis with Line × Tester mating design

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Abstract
Maize (*Zea mays*) is an important multipurpose cereal crop. Single-cross hybrids play a crucial role in maize cultivation in terms of acreage and production. The combining ability and heterosis are prime criteria for efficacious maize improvement and breeding. This study was focused to access the performances of hybrids, and to estimate heterosis and combining ability for grain yield and yield-related traits. The present study was conducted using 16 parents and 28 F_1 cross combinations of maize hybrids during *rabi* 2019 to identify the best inbred lines and hybrid combinations. The overall study of *gca* effects suggested that the parents CBM-DL-448, CBM-DL- 435, CBM-DL- 360 and UMI1230 were found to be good general combiners for desirable yield-related traits. Among the hybrids, CBM-DL-360 × UMI 1200, CBM-DL-435 × UMI 1230, and CBM-DL-448 × UMI 1230 exhibited positive and significant *sca* effects and standard heterosis for single plant yield.

Keywords
Maize, Combining ability, Heterosis, Hybrids.

INTRODUCTION

Maize (*Zea mays* L.) is a multipurpose crop serving as food, animal feed, and is a new material for bioenergy production. According to the World Food and Agriculture (FAO, 2019), maize had an acreage of 197 million hectares with a production of 1,134 million tonnes in 2017 production season. Hybrid maize play a crucial role in increased maize production (Aslam *et al.*, 2017 and Karim *et al.*, 2018) and food security especially single-cross hybrids. To breed ideal hybrids with the highest grain yield, heterosis and combining ability (CA) of available germplasm have to be exploited. The higher vigour of hybrids compared to their parents was defined as “heterosis” and was first observed by Darwin, 1876. Identification of high-yielding hybrids needs development and careful selection of parents based on their combining ability and genetic structure (Karim *et al.*, 2018). To exploit heterosis in hybrid breeding programme, a genetic mating scheme is usually used to identify elite parental lines and hybrid performance by analyzing general combining ability (gca) and specific combining ability (sca), respectively (Sprague, 1942). Therefore, a better understanding of the genetic basis of combining ability can guide more effectively in maize improvement programs and hybrid performance prediction. Combining ability analysis is a useful genetic means to estimate gca of parents and sca of crosses to select the desired parents and crosses. Griffing, (1956) stated that gca is the average performance of a parent in a series of hybrid combinations. The effect of combining ability, both gca and sca are important indicators of potential value for assessing inbred lines in hybrid combination to develop the hybrid varieties in maize. This information is helpful to plant breeders for formulating hybrid breeding programs. Additive genetic effects in the base population is mainly due to the variability in *gca* effects, while non-additive genetic effects are due to the variability in *sca* effects (Falconer, 1981). Combining ability analysis is useful to assess the potential inbred lines and also helps in identifying the nature of gene action involved in various quantitative characters. Sprague, 1942 emphasized that the general combining ability was relatively more importance than specific combining ability for unselected inbred lines. Line x tester mating design developed by Kempthorne (1957) provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations. The present study was focused on assessing the gene action for yield and yield-related traits and to explore heterotic hybrids in maize.

MATERIAL AND METHODS

The five hundred germplasm obtained from Indian Agricultural Research Institute; New Delhi were screened for drought tolerance during *Rabi* 2018-19 season. The selected drought tolerant inbred lines viz., CBM-DL-38, CBM-DL-80, CBM-DL-111, CBM-DL-157, CBM-DL-164, CBM-DL-200, CBM-DL-238, CBM-DL-289, CBM-DL-313, CBM-DL-322, CBM-DL-333, CBM-DL-360, CBM-DL-435 and CBM-DL-448 were used as female (Lines) and the popular inbreds *viz.,* UMI 1200 and UMI 1230 (TNAU CO 6 Maize hybrid parents) were used as male parents (Testers) .

The selected fourteen drought tolerant inbreds were crossed in a Line×Tester mating design during *Kharif*, 2019 at New Area Farm of Department of millets, TNAU. Plants were raised in four-meter rows with spacing of 60 cm between rows and 25 cm between plants in two staggered sowings to achieve the synchrony in flowering. The resulted hybrids and parents along with the check (CO6) were evaluated during *rabi*, 2019 at Cotton Research Station, Veppanthattai, Tamil Nadu by adopting Randomized Block Design (RBD) with two replications. Recommended agronomic and crop protection measures were carried out to raise a healthy crop.

Ten randomly selected plants of parents and hybrids in each replication were used in the study. Observations were recorded for days to tasseling, days to silking, plant height (cm), leaf length (cm), leaf breadth (cm), cob placement height (cm), tassel length (cm), cob length (cm), the number of kernels per row, the number of kernel rows, cob weight (gm), single plant yield (gm) and 100 kernel weight (gm). The mean values were subjected to line x tester analysis as suggested by Kempthorne (1957) using TNAUSTAT- Statistical package (Manivannan, 2014).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) showed significant variation among the parents and cross combinations for all the traits except cob weight and 100 kernel weight. High significance in variance of parents for all the characters indicates a significant level of average heterosis present in the hybrids. The variance due to lines, testers, and line×tester interaction was significant for all the traits except 100 KW (**Table 1**). Non- significance for 100 KW was reported earlier by Uddin *et al.,* 2008. This indicated that there was a good level of genetic difference present among lines and testers. The gca and sca genetic variances and their relative proportions for all the 13 yield and yield-related traits were shown in Table 1. The study of gca and sca variance reported earlier by Ambikabathy *et al*., 2019; Lal *et al*., 2011; Nandhitha *et al*., 2018 in Maize. The estimate of genetic variance revealed that the σ^2sca was higher in magnitude than the σ^2gca for all the traits *viz.,* plant height, leaf length, leaf breadth, cob placement height, tassel length, days to tasseling, days to silking, cob length, the number of kernels per row, the

Table 1. Analysis of variance for combining ability in yield and yield related traits

Source	df	DT	DS	PH	LL	LB	CPH	TL	CL	NK/R	NKR	CW	SPY	100 KW
CROSS	27	429.59**	1091.96**	15.77**	5.47**	110.59**	31.15**	7.17**	6.06**	31.66**	5.54**	1.3446	234.11**	0.8142
LINE (c)	13	810.42**	2077.31**	12.65**	3.78**	4.28**	33.50**	8.04**	9.55**	40.34**	7.71**	1.3442	317.28**	0.7138
TESTER (c)	1	158.76**	529**	5.92*	0.24	10.05**	5.77*	0.04	4.62*	13.64**	1.38	0.224	187.62**	0.5505
LXT (c)	13	69.60**	149.92**	19.65**	149.92**	16.94**	30.74**	149.92**	2.68*	24.66**	3.68**	1.4312	154.53**	0.9349
error	27	0.0496	0.0179	18.1585	15.5975	0.1345	12.0838	4.9165	2.3772	0.754	1.5681	341.425	1.0307	12.1448
σ^2 gca		0.4305	0.4055	-1.6988	-0.7853	-0.0206	0.1178	0.0382	0.1936	0.1271	0.0701	-0.7127	1.9777	-0.0353
σ^2sca		1.7012	1.3297	169.3722	51.185	1.0716	179.7295	14.3738	2.0038	8.9197	2.104	73.6028	79.1233	-0.3951
σ^2 gca / σ^2sca		0.2531	0.3050	-0.0100	-0.0153	-0.0192	0.0007	0.0027	0.0966	0.0142	0.0333	-0.0097	0.0250	0.0893

* and**Significant at 5 and 1 % level

DT: Days to tasseling, DS: Days to silking, PH: Plant height (cm), LL: Leaf length (cm), LB: Leaf breadth (cm), CPH: Cob placement height (cm), TL: Tassel length, CL: Cob length (cm), NK/R: Number of kernels per row, NKR: Number of kernel rows, CW: Cob weight (gm), SPY: Single plant yield (gm), 100 KW: 100 Kernel weight (gm).

number of kernel rows per cob, cob weight, single plant yield, 100-kernel weight. Table 1 shows the ratios of sca and gca variance were high for all the characters studied revealed the preponderance of non-additive gene action. Similar results are reported in maize by Das *et al.*, 1994; Debnath *et al.*, 1988; Roy *et al.*, 1998 and Sanghi *et al.*, 1983.

Table 2. Mean performance of thirteen yield and yield related traits in parental lines

Parents	DT	DS	PH	LL	LB	CPH	TL	CL	NK/R	NKR	CW	SPY	100 SW
Lines													
CBM-DL-38	54	56	103.0	55	6.3	35.5	24.2	10.4	18	8	53.84	48.92	31.78
CBM-DL-80	53	54	131.5*	66.7	6.7	41.7	30.7	11.8	22	10	68.5	58.43	27.92
CBM-DL-111	56**	57	104.2	73.7	6.5	39.2	31.2	10.3	16	10	55.4	41.71	27.61
CBM-DL-157	54	56	133.5**	84.2**	6.9	42	31.5	12.7	21	8	62.05	54.49	31.12
CBM-DL-164	54	57	111.7	78.3	7.3	46.5	34.5	14.1	26**	12	91.27	80.2**	26.91
CBM-DL-200	52	55	112.5	68.0	6.6	39.7	29.0	9.9	17	10	56.13	46.46	28.78
CBM-DL-238	56**	59**	138.2**	80.5*	5.8	44.5	35.5*	15.7**	25**	8	67.87	56.98	27.85
CBM-DL-289	52	55	114.9	72.5	7.7	37.5	23.7	12.3	20	8	65.13	54.64	33.94
CBM-DL-313	53	56	130.5*	51	5.1	36.5	28.7	11.6	16	12	71.07	63.75	31.38
CBM-DL-322	52	54	121.7	72	7.1	52.5*	29.2	13.6	27**	10	83.01	72.35**	28.48
CBM-DL-333	51	55	130.5*	81.2*	7.4	52.7*	37.7**	11.6	23	10	85.13	76.35**	35.02
CBM-DL-360	56**	58**	124.2	77.9	8.2*	51.2	35.7*	12.1	22	10	72.49	64.49*	30.39
CBM-DL-435	58**	60**	87.2	83.3**	7.8	57.2**	35.3*	11.1	23	10	68.6	62.23	34.55
CBM-DL-448	58**	61**	130.7*	75.4	8.6**	55**	37.5**	11.5	24*	12	89.83	77.58**	29.94
Testers													
UMI 1200	58.5**	61**	100.7	54.2	6.0	50.75	18.75	13	27.5**	10	80.65	72.24**	29.05
UMI 1230	56**	59**	115.5	66.3	8.4*	50.75	29.95	10.4	22.5	10	64.02	51.61	24.10
Mean	54.59	57.06	118.19	71.28	7.05	45.84	30.84	12.00	21.91	9.81	70.93	61.39	29.92

* and**significant at 5 and 1 % level

Table 3. Mean performance of thirteen yield and yield related traits in Hybrids

Hybrids	DT	DS	PH	LL	LB	CPH	TL	CL	NK/R	NKR	CW	SPY	100 KW
CBM-DL-38 × UMI 1200	55	58	185.0	73.9	8.0	78.0	37.7	17.6	37	16	203.35	160.04	26.24
CBM-DL-38 × UMI 1230	56	59	175.0	67.0	8.2	77.5	33.5	16.6	34	18	189.25	160.76	28.81
CBM-DL-80 × UMI 1200	58**	62**	176.5	66.2	6.4	58.0	30.5	14.0	41**	16	242.22	184.55**	25.80
CBM-DL-80 × UMI 1230	60**	63**	179.2	78.7	8.2	75.5	33.5	11.9	36	14	193.93	165.79	30.18
CBM-DL-111 × UMI 1200	59**	62**	193.5	71.0	8.0	86.2**	31.7	14.4	37	16	190.74	165.89	31.78
CBM-DL-111 × UMI 1230	61**	64**	183.5	77.0	7.2	63.5	33.5	13.7	39	12	214.60	166.09	26.88
CBM-DL-157 × UMI 1200	57	60	199.0*	74.7	7.5	86.5**	35.7	15.2	39	16	192.72	166.49	28.39
CBM-DL-157 × UMI 1230	55	58	182.0	64.7	7.9	53.0	29.2	12.6	40**	16	208.65	166.61	30.40
CBM-DL-164 × UMI 1200	60**	63**	165.6	77.5	6.6	70.5	36.2	18.2	36	16	204.66	167.00	30.53
CBM-DL-164 × UMI 1230	57	61**	211.7**	81.5	8.4	83.7**	40.7**	15.9	36	14	252.35*	167.30	32.01
CBM-DL-200 × UMI 1200	54	56	180.2	75.0	8.5	69.5	35.5	19.0	37	18	210.26	167.71	31.06
CBM-DL-200 × UMI 1230	52	56	195.5	66.2	7.9	78.5	35.0	13.7	36	18	206.32	195.10**	25.67
CBM-DL-238 × UMI 1200	59**	62**	185.0	78.7	7.7	74.2	38.0	20.3**	43**	16	206.15	162.08	26.38
CBM-DL-238 × UMI 1230	56	59	176.0	64.4	7.5	78.2	33.0	19.8*	37	18	200.51	169.72	27.30
CBM-DL-289 × UMI 1200	54	58	186.6	77.7	7.9	62.2	30.0	18.9	38	18	205.07	170.03	27.59
CBM-DL-289 × UMI 1230	53	56	185.2	71.6	7.1	68.7	36.7	15.7	37	18	203.72	170.31	25.20
CBM-DL-313 × UMI 1200	55	59	190.5	75.7	8.3	56.7	29.0	16.1	37	12	225.64	170.53	32.66
CBM-DL-313 × UMI 1230	54	58	194.2	63.7	6.1	46.2	25.0	14.3	40**	16	210.72	177.31*	27.60
CBM-DL-322 × UMI 1200	55	58	215.5**	74.7	7.7	86**	32.5	16.0	41**	16	208.25	180.15**	27.61
CBM-DL-322 × UMI 1230	52	55	191.2	67.2	7.2	76.2	32.5	19.4*	35	16	214.99	171.34	30.49
CBM-DL-333 × UMI 1200	54	58	178.5	72.7	6.9	54.5	28.5	16.0	42**	14	203.87	173.11	33.30
CBM-DL-333 × UMI 1230	53	57	182.5	85.0*	8.4	68.5	31.5	17.0	37	18	216.80	174.97	28.72
CBM-DL-360 × UMI 1200	61**	64**	190.0	79.2	8.0	82.2**	43.5**	20.5**	29	20**	218.56	183.89**	30.82
CBM-DL-360 × UMI 1230	62**	65**	190.5	83.3*	9.3**	99.5**	33.5	22.3**	30	21**	210.22	176.28	29.88
CBM-DL-435 × UMI 1200	63**	66**	180.0	62.5	5.9	57.5	27.0	13.4	34	20*	218.64	177.29*	29.64
CBM-DL-435 × UMI 1230	61**	64**	214.2**	84.6*	9.4**	99**	39.2*	16.8	44**	16	228.80	202.69**	27.49
CBM-DL-448 × UMI 1200	59**	63**	174.5	78	8.4	92.7**	36.0	20.2*	41**	16	225.79	182.44**	28.86
CBM-DL-448 × UMI 1230	61**	63**	179.2	75.35	7.35	78	36.75	17.7	38	18	237.76	198.96**	30.36
Mean	57.05	60.27	187.13	73.88	7.72	73.62	33.78	16.7	37.79	16.27	212.31	174.09	28.99

* and **significant at 5 and 1 % level

The key condition for the selection of desirable parents was based on the performance of inbreds for their high expression of gca along with their mean. Among the lines, higher *per se* performance values were exhibited by CBM-DL-238 for cob length, CBM-DL-164, CBM-DL-238, CBM-DL-322, CBM-DL-448 for the number of kernels per row, CBM-DL-164, CBM-DL-322, CBM-DL-333, CBM-DL-360 and CBM-DL-448 for single plant yield. Among the testers, higher *per se* value was recorded by UMI 1200 for the number kernels per row and single plant yield (Ambikabathy *et al.*, 2019) and the crosses involving them are anticipated to produce hybrids with high yield potential. The cross combinations of CBM-DL-80 × UMI 1200, CBM-DL-200 × UMI 1230, CBM-DL-322 × UMI 1200, CBM-DL-360 × UMI 1200, CBM-DL-435 × UMI 1200, CBM-DL-448 × UMI 1200, CBM-DL-448 × UMI 1230 were considered as outstanding ones for improving the single plant yield based on the *per se* performance (**Table 3**) (Ambikabathy*et al.*, 2019).

From a statistical point of view, Kulembeka *et al.*, 2012 explained that the gca is a main effect and the sca is an interaction effect. The higher *gca* of the parents denoted that the parents are well combiners for the characters under study (Sprague, 1942). Based on Sprague and Tatum, (1942) gca is owing to the activity of genes which are largely additive in their effects as well as additive × additive interactions. Among the lines, the inbreds CBM-DL-360, CBM-DL-435 and CBM-DL-448 recorded positive and highly significant effect for the trait single plant yield. The inbreds CBM-DL- 360 and CBM-DL- 448 showed positive and high significant effects for the trait cob length. The inbred CBM-DL- 435 recorded positive and significant value for the trait cob weight. Inbreds *viz.,* CBM-DL- 157, CBM-DL- 238, and CBM-DL- 435 showed highly significant and positive *gca* for the number of kernels per row. For the number of kernel rows per cob, the inbreds CBM-DL-360 and CBM-DL- 200 recorded significant and positive *gca* effect. Negatively significant *gca* effect was seen in CBM-DL- 157 and CBM-DL- 200 for days to tasseling. Overall performance of the general combining ability showed that the inbred CBM-DL- 448 recorded significant positive *gca* for single plant yield and cob length. The inbred CBM-DL- 435 recorded significant positive gca for single plant yield, the number of kernels per row and cob weight. CBM-DL- 360 recorded positive significant *gca* for single plant yield, cob length and the number of kernel rows per cob. The inbreds CBM-DL- 200, CBM-DL- 322, CBM-DL- 360 and CBM-DL- 238 had desirable gca for more than two yield and yield attributing trait. Similar kind of studies were reported by Karim *et al.*, 2018 on gca effects of single plant yield, days to tasseling, the number of kernels per row, the number of kernel rows per cob, cob length and cob weight. The tester UMI1230 showed positive and significant gca effect for single plant yield and negative significance gca effect for days to tasseling . Ambikabathy *et al.*, 2019 also reported similar kind of finding in UMI1230 inbred. For the trait number of kernels per row, the inbred UMI1200 recorded positive significant gca effect. Hence the lines *viz.,* CBM-DL- 448, CBM-DL- 435and CBM-DL- 360 and the testers *viz.,* UMI1230 (**Table 4**) could be effectively utilized for a single cross hybrid program to have high yield potential and earliness. High general combining ability effect for a particular trait

Table 4. The gca effects of parents for thirteen yield and yield related traits

Parent	PH	LL	LB	CPH	TL	DT	DS	CL	NK/R	NKR	CW	SPY	100 KW
						Lines							
CBM-DL-38	-7.13**	-3.43	0.40*	4.13*	1.85	-1.55 **	-1.77 **	0.4	-2.29**	0.23	-16.01	-13.69**	-1.46
CBM-DL-80	-9.38**	-1.38	-0.42*	-6.87**	-1.77	1.95 **	2.23 **	-3.72 **	1.21**	-1.02	5.77	1.08 *	-1
CBM-DL-111	1.37	0.15	-0.12	1.26	-1.15	3.20 **	2.73 **	-2.62 **	0.46	-2.27**	-9.64	-8.10**	0.34
CBM-DL-157	3.37	-4.13*	-0.02	-3.87*	-1.27	-1.05 **	-1.27 **	-2.80 **	2.21**	-0.77	-11.62	-7.53**	0.41
CBM-DL-164	1.54	5.62 **	-0.2	3.51	4.72 **	1.45 **	1.73 **	0.38	-1.79**	-1.77**	16.2	-6.94**	2.28
CBM-DL-200	0.74	-3.25	0.48*	0.38	1.48	-4.05 **	-4.27 **	-0.32	-1.04*	1.73 *	-4.01	7.32**	-0.62
CBM-DL-238	-6.63**	-2.28	-0.1	2.63	1.73	0.45 **	0.23 **	3.35 **	2.46**	-0.27	-8.97	-8.19**	-2.15
CBM-DL-289	-1.21	0.82	-0.22	-8.12**	-0.4	-3.55 **	-3.27 **	0.6	-0.04	1.23	-7.91	-3.92**	-2.59
CBM-DL-313	5.24*	-4.13*	-0.47*	-22.12**	-6.78 **	-2.30 **	-1.77 **	-1.45	1.21**	-2.27**	5.88	-0.17	1.15
CBM-DL-322	16.12**	-2.88	-0.27	7.51 **	-1.27	-3.30 **	-3.77 **	1	0.21	-0.27	-0.69	1.66**	0.06
CBM-DL-333	-6.63**	5.00 *	-0.07	-12.12**	-3.78 **	-3.55 **	-2.52 **	-0.2	1.96**	-0.27	-1.97	-0.05	2.02
CBM-DL-360	3.12	7.42**	0.93**	17.26**	4.72 **	4.45 **	4.23 **	4.73 **	-8.04**	4.23**	2.08	6.00**	1.36
CBM-DL-435	9.87**	-0.33	-0.05	4.63 *	-0.67	4.95 **	4.73 **	-1.60 *	1.46**	1.23	11.41	15.90**	-0.42
CBM-DL-448	-10.38**	2.8	0.15	11.76 **	2.60 *	2.95 **	2.73 **	2.27 **	1.96**	0.23	19.47 *	16.62**	0.63
SE	2.1306	1.9747	0.1833	1.7381	1.1087	0.1114	0.0668	0.7709	0.4342	0.6261	9.2388	0.5076	1.7425
						Tester							
UMI 1200	-1.39	0.26	-0.16 *	-1.12	-0.06	0.38 **	0.41 **	0.44	0.43 *	-0.2	-1.17	-1.86**	0.35
UMI 1230	1.39	-0.26	0.16 *	1.12	0.06	-0.38 **	-0.41 **	-0.44	-0.43 *	0.2	1.17	1.86**	-0.35
SE	0.8053	0.7464	0.0693	0.6569	0.419	0.0421	0.0253	0.2914	0.1641	0.2367	3.492	0.1919	0.6586

* and**significant at 5 and1 % level

Table 5 The sca effects of hybrids for thirteen yield and yield related traits

Hybrid	DT	DS	PH	LL	LB	CPH	TL	CL	NK/R	NKR	CW	SPY	100 KW
CBM-DL-38 × UMI 1200	-0.87 **	-0.91 **	6.39 *	3.19	0.03	1.37	2.19	0.06	1.07	-1.3	8.22	1.50 *	-1.63
CBM-DL-38 × UMI 1230	0.88 **	0.91 **	-6.39 *	-3.19	-0.03	-1.37	-2.19	-0.06	-1.07	1.3	-8.22	-1.50 *	1.63
CBM-DL-80 × UMI 1200	-1.38 **	-0.91 **	0.14	-6.51 *	-0.74 **	-7.63 **	-1.44	0.58	2.07 **	0.95	25.32	11.24 **	-2.53
CBM-DL-80 × UMI 1230	1.38 **	0.91 **	-0.14	6.51 *	0.74 **	7.63 **	1.44	-0.58	-2.07 **	-0.95	-25.32	-11.24 **	2.53
CBM-DL-111 × UMI 1200	-1.13 **	-1.41 **	6.39 *	-3.28	0.56 *	12.49 **	-0.81	-0.07	-1.18	2.20 *	-10.76	1.76 *	2.1
CBM-DL-111 × UMI 1230	1.13 **	1.41 **	-6.39 *	3.28	-0.56 *	-12.49 **	0.81	0.07	1.18	-2.20 *	10.76	-1.76 *	-2.1
CBM-DL-157 × UMI 1200	0.63 **	0.59 **	9.89 **	4.74	-0.04	17.87 **	3.31 *	0.86	-0.93	0.7	-6.8	1.80 *	-1.35
CBM-DL-157 × UMI 1230	-0.62 **	-0.59 **	-9.89 **	-4.74	0.04	-17.87 **	-3.31 *	-0.86	0.93	-0.7	6.8	-1.80 *	1.35
CBM-DL-164 × UMI 1200	1.13 **	0.59 **	-21.69 **	-2.26	-0.72 **	-5.51 *	-2.19	0.68	-0.43	0.7	-22.68	1.71 *	-1.08
CBM-DL-164 × UMI 1230	-1.13 **	-0.59 **	21.69 **	2.26	0.72 **	5.51 *	2.19	-0.68	0.43	-0.7	22.68	-1.71 *	1.08
CBM-DL-200 × UMI 1200	0.62 **	-0.41 **	-6.24 *	4.12	0.46	-3.38	0.31	2.23	0.32	0.2	3.14	-11.84 **	2.35
CBM-DL-200 × UMI 1230	-0.63 **	0.41 **	6.24 *	-4.12	-0.46	3.38	-0.31	-2.23	-0.32	-0.2	-3.14	11.84 **	-2.35
CBM-DL-238 × UMI 1200	1.13 **	1.09 **	5.89	6.89 *	0.28	-0.88	2.56	-0.19	2.32 **	-0.8	3.99	-1.97 *	-0.81
CBM-DL-238 × UMI 1230	-1.13 **	-1.09 **	-5.89	-6.89 *	-0.28	0.88	-2.56	0.19	-2.32 **	0.8	-3.99	1.97 *	0.81
CBM-DL-289 × UMI 1200	0.13	0.59 **	2.06	2.79	0.56 *	-2.13	-3.31 *	1.16	-0.18	-0.3	1.84	1.72 *	0.85
CBM-DL-289 × UMI 1230	-0.12	-0.59 **	-2.06	-2.79	-0.56 *	2.13	3.31 *	-1.16	0.18	0.3	-1.84	-1.72 *	-0.85
CBM-DL-313 × UMI 1200	0.38 *	0.09	-0.49	5.74 *	1.26 **	6.37 *	2.06	0.46	-1.93 **	-1.8	8.63	-1.53 *	2.19
CBM-DL-313 × UMI 1230	-0.37 *	-0.09	0.49	-5.74 *	-1.26 **	-6.37 *	-2.06	-0.46	1.93 **	1.8	-8.63	1.53 *	-2.19
CBM-DL-322 × UMI 1200	0.88 **	1.09 **	13.64 **	3.49	0.41	5.99 *	0.06	-2.14	2.57 **	0.2	-2.2	6.27 **	-1.79
CBM-DL-322 × UMI 1230	-0.87 **	-1.09 **	-13.64 **	-3.49	-0.41	-5.99 *	-0.06	2.14	-2.57 **	-0.2	2.2	-6.27 **	1.79
CBM-DL-333 × UMI 1200	0.13	0.34 **	-0.61	-6.38 *	-0.59 *	-5.88 *	-1.44	-0.94	1.82 **	-1.8	-5.3	0.93	1.94
CBM-DL-333 × UMI 1230	-0.12	-0.34 **	0.61	6.38 *	0.59 *	5.88 *	1.44	0.94	-1.82 **	1.8	5.3	-0.93	-1.94
CBM-DL-360 × UMI 1200	-0.88 **	-0.91 **	1.14	-2.31	-0.49	-7.51 **	5.06 **	-1.37	-0.68	-0.3	5.33	5.66 **	0.12
CBM-DL-360 × UMI 1230	0.87 **	0.91 **	-1.14	2.31	0.49	7.51 **	-5.06 **	1.37	0.68	0.3	-5.33	-5.66 **	-0.12
CBM-DL-435 × UMI 1200	0.62 **	0.59 **	-15.61 **	-11.31 **	-1.62 **	-19.63 **	-6.04 **	-2.14	-5.68 **	1.7	-3.91	-10.84 **	0.73
CBM-DL-435 × UMI 1230	-0.63 **	-0.59 **	15.61 **	11.31 **	1.62 **	19.63 **	6.04 **	2.14	5.68 **	-1.7	3.91	10.84 **	-0.73
CBM-DL-448 × UMI 1200	-1.38 **	-0.41 **	-0.86	1.07	0.68 *	8.49 **	-0.31	0.83	0.82	-0.3	-4.82	-6.40 **	-1.1
CBM-DL-448 × UMI 1230	1.38 **	0.41 **	0.86	-1.07	-0.68 *	-8.49 **	0.31	-0.83	-0.82	0.3	4.82	6.40 **	1.1
SE	0.1575	0.0945	3.0132	2.7926	0.2593	2.458	1.5679	1.0902	0.614	0.8855	13.0657	0.7179	2.4642

* and**significant at 5 and1 % level

in a parent specifies the existence of additive gene effects for that trait in the respective parent and this specifies gca has an important role in choice of parents for hybridization programme (Muntean *et al.*, 2014).

Table 6 Standard heterosis for thirteen yield and yield related traits in maize hybrids

Hybrid	DT	DS	PH	LL	LB	CPH	TL	CL	NK/R	NKR	CW	SPY	100 KW
CBM-DL-38 × UMI 1200	0	0	0.54	-17.66 **	-5.88	12.23 *	12.69	24.82 *	67.81 **	-53.33 **	-15.78 *	-18.41 **	-7.83
CBM-DL-38 × UMI 1230	1.82 **	1.72 **	-4.89 *	-25.35 **	-2.94	11.51 *	0	17.73	-10.96	13.33	-21.62 **	-18.04 **	1.19
CBM-DL-80 × UMI 1200	5.45 **	6.90 **	-4.08	-26.18 **	-24.71 **	-16.55 **	-8.96	-0.71	-6.58	6.67	0.32	-5.91 **	-9.38
CBM-DL-80 × UMI 1230	9.09 **	8.62 **	-2.72	-12.26 **	-3.53	8.63	0	-15.25	-3.65	6.67	-19.68 *	-15.48 **	5.99
CBM-DL-111 × UMI 1200	8.18 **	6.90 **	5.16 *	-20.89 **	-5.88	24.10 **	-5.22	2.48	-8.77	3.33	-21.00 **	-15.43 **	11.63
CBM-DL-111 × UMI 1230	10.91 **	10.34 **	-0.27	-14.15 **	-15.29 **	-8.63	0	-2.84	-4.38	-6.67	-11.12	-15.33 **	-5.58
CBM-DL-157 × UMI 1200	3.64 **	3.45 **	8.15 **	-16.71 **	-11.76 **	24.46 **	6.72	7.8	-5.11	-6.67	-20.19 *	-15.12 **	-0.26
CBM-DL-157 × UMI 1230	0	0	-1.09	-27.86 **	-7.06	-23.74 **	-12.69	-10.64	-0.73	0	-13.58	-15.06 **	6.8
CBM-DL-164 × UMI 1200	9.09 **	8.62 **	-10.00 **	-13.65 **	-21.76 **	1.44	8.21	29.08 *	-5.84	6.67	-15.24	-14.86 **	7.24
CBM-DL-164 × UMI 1230	3.64 **	5.17 **	15.08 **	-9.19 *	-1.18	20.50 **	21.64 **	13.12	-13.15	-6.67	4.51	-14.71 **	12.42
CBM-DL-200 × UMI 1200	-1.82 **	-3.45 **	-2.04	-16.43 **	0	0	5.97	35.11 **	-6.58	6.67	-12.92	-14.50 **	9.1
CBM-DL-200 × UMI 1230	-5.45 **	-3.45 **	6.25 **	-26.18 **	-7.06	12.95 *	4.48	-2.84	-10.96	20	-14.55	-0.54	-9.83
CBM-DL-238 × UMI 1200	7.27 **	6.90 **	0.54	-12.26 **	-8.82 *	6.83	13.43 *	43.97 **	-2.19	6.67	-14.62	-17.37 **	-7.36
CBM-DL-238 × UMI 1230	1.82 **	1.72 **	-4.35	-28.19 **	-11.76 **	12.59 *	-1.49	40.43 **	1.46	6.67	-16.96 *	-13.47 **	-4.13
CBM-DL-289 × UMI 1200	-1.82 **	0	1.41	-13.37 **	-7.06	-10.43 *	-10.45	34.04 **	-6.58	20	-15.07	-13.32 **	-3.09
CBM-DL-289 × UMI 1230	-3.64 **	-3.45 **	0.68	-20.17 **	-16.47 **	-1.08	9.7	11.35	-8.04	13.33	-15.63 *	-13.17 **	-11.49
CBM-DL-313 × UMI 1200	0.91 *	1.72 **	3.53	-15.60 **	-1.76	-18.35 **	-13.43 *	14.54	-8.04	0	-6.55	-13.06 **	14.73
CBM-DL-313 × UMI 1230	-1.82 **	0	5.57 *	-28.97 **	-27.65 **	-33.45 **	-25.37 **	1.77	-2.92	0	-12.73	-9.61 **	-3.06
CBM-DL-322 × UMI 1200	0	0	17.12 **	-16.71 **	-9.41 *	23.74 **	-2.99	13.48	2.19	0	-13.75	-8.15 **	-3.04
CBM-DL-322 × UMI 1230	-4.55 **	-5.17 **	3.8	-25.07 **	-15.29 **	9.71	-2.99	37.59 **	-6.58	6.67	-10.96	-12.65 **	7.11
CBM-DL-333 × UMI 1200	-1.82 **	0.86 **	-2.99	-18.94 **	-18.82 **	-21.58 **	-14.93 *	13.48	-5.11	0	-15.57 *	-11.74 **	16.95
CBM-DL-333 × UMI 1230	-3.64 **	-1.72 **	-0.82	-5.29	-1.18	-1.44	-5.97	20.57	-1.46	13.33	-10.21	-10.80 **	0.88
CBM-DL-360 × UMI 1200	10.91 **	10.34 **	3.26	-11.70 **	-5.88	18.35 **	29.85 **	45.39 **	-17.53	20	-9.48	-6.25 **	8.24
CBM-DL-360 × UMI 1230	12.73 **	12.07 **	3.53	-7.13	9.41 *	43.17 **	0	58.51 **	-27.03	33.33	-12.93	-10.13 **	4.94
CBM-DL-435 × UMI 1200	14.55 **	13.79 **	-2.17	-30.36 **	-30.59 **	-17.27 **	-19.40 **	-4.96	-21.92	40.00 *	-9.45	-9.61 **	4.13
CBM-DL-435 × UMI 1230	10.91 **	10.34 **	16.30 **	-5.74	11.18 *	42.45 **	17.01 *	19.15	-3.65	13.33	-5.24	3.33 **	-3.44
CBM-DL-448 × UMI 1200	7.27 **	8.62 **	-5.16 *	-13.09 **	-1.18	33.45 **	7.46	43.62 **	6.58	6.67	-6.49	-6.99 **	1.39
CBM-DL-448 × UMI 1230	10.91 **	8.62 **	-2.72	-16.04 **	-13.53 **	12.23 *	9.7	25.53 *	-2.19	6.67	-1.53	1.44 *	6.66
SE	0.2125	0.127	4.055	3.8023	0.3485	3.4186	2.1241	1.5875	8.5295	2.8389	18.0497	1.1311	3.3319

* and**Significant 5 and1 % level

The hybrids *viz.,* CBM-DL- 360 × UMI1200, CBM-DL- 435 × UMI1230, and CBM-DL- 448 × UMI1230 recorded positive *sca* effect for single plant yield (**Table 5**). Similar kind of observations were made in Maize by Choudhary *et al.*, 2000; Kuselan *et al.*, 2017; and Prakash *et al.*, 2004. For the trait number of kernels per row, the hybrids CBM-DL- 322 × UMI1200, and CBM-DL- 435 × UMI1230 scored positive sca effect as like Iqbal *et al.*, 2007. The negatively significant sca effect had been scored by CBM-DL- 360 × UMI1200, CBM-DL- 435 × UMI1230 and CBM-DL- 448 × UMI1200 for days to tasseling which could be utilized for earliness to reduce the duration of crop as similar kind of report earlier by Bharti *et al.,* 2017. The hybrids *viz.,* CBM-DL- 322 × UMI1200 and CBM-DL- 435 × UMI1230 scored positive and significant sca effect for single plant yield and the number of kernels per row which could be used to increase the productivity through a single cross-hybridization programme. Similar kind of report made earlier in maize by Iqbal *et al.*, 2007.

The standard heterosis expressed by 28 crosses for all quantitative traits is presented in Table 6. The Standard Heterosis ranged from -21.62 to 4.51, -11.49 to 16.95 and -18.41 to 3.33 for cob weight, 100 kernel weight, and single plant yield, respectively with wide range of variability. Similar kind of observations were made in maize by Amiruzzaman *et al.*, 2010; Mohammad *et al.*, 2016 and Uddin *et al.*, 2006. In common, significant heterosis over the standard check, CO 6 was observed for two yield related traits in cross combinations namely, DL-435 × UMI 1230 and CBM-DL-448 × UMI 1230. Hence, these hybrids were judged as the best crosses suited for heterosis breeding. The hybrids *viz.,* CBM-DL- 435 × UMI1230 and CBM-DL- 448 × UMI1230 recorded a significant positive heterosis for single plant yield . Significant positive hetererosis for yield is reported earlier by Bharti *et al.,* 2017 while using UMI1200 and UMI1230 inbred lines. For the trait cob length CBM-CBM-DL- 360 × UMI1230, CBM-DL- 448 × UMI1200 and CBM-DL- 448 × UMI1230 hybrids recorded significant and positive standard heterosis. Negatively significant heterosis was recorded in CBM-DL- 200 × UMI1230 and CBM-DL- 322 × UMI1230 for days to tasseling. Overall performance of the standard heterosis showed a positive significant standard heterosis for single plant yield in CBM-DL- 435 × UMI 1230, and CBM-DL- 448 × UMI1230 hybrids and negative significant standard heterosis for days to tasseling in the hybrids I CBM-DL- 200 × UMI1230 and CBM-DL- 322 × UMI1230 over its standard check. Thus, these hybrid combinations could be effectively utilized for heterosis breeding. The importance of identification of heterotic combinations in maize hybrid programme is emphasized by Nandhitha *et al.,* 2018.

Overall performance of the parents implies that the lines *viz.,* CBM-DL-448, CBM-DL- 435 and CBM-DL- 360 and the tester UMI1230 are the good combiners based on *per se* performance and single plant yield which could be used as a potential genetic material for hybridization breeding programme. The hybrids *viz.,* CBM-DL- 435 × UMI1230, CBM-DL- 448 × UMI1230 and CBM-DL- 360 × UMI1200 are well recommended for producing the hybrids with a higher yield based on mean performance, positive significant standard heterosis and high significant positive sca effect which is useful to exploit high yield potential.

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