

COMBINING ABILITY AND HETEROSIS IN MAIZE (*Zea mays* L.) INBRED LINES

Abstract

The present study was framed to determine the combining ability and the extent of heterosis in maize using line \times tester design at maize section, Bihar Agricultural University, Sabour, Bhagalpur (Bihar), India. Crosses were made involving ten lines and three testers in *rabi*, 2019-20 for the study. 30 Crosses along with 13 parents and 2 checks were evaluated in randomized block design with two replications during *kharif*, 2020. The hybrids DHM 117 and SHM 1 were used as checks. Data were recorded on 13 morphological traits. The contribution of lines is found to be greater than that of the testers for most of the characters studied. On the basis of GCA effects, the lines VL109476, VL109475, VL1010848, VL109479 and tester VP15295 were identified as good combiners for grain yield, whereas the line VL1017524 and the tester SML-1 were also identified as good combiner in terms of earliness. These can be used as parents in multiple hybridization programme. On the basis of SCA effects, the crosses VL109476 \times V P15295, VL1010763 \times VP15295, VL1018419 \times VP15295 and VL109475 \times SML-1 were identified as good specific combiners for grain yield, whereas on the basis of standard heterosis VL109476 \times V P15295, VL1010763 \times VP15295, VL109475 \times SML-1 and VL109479 \times SML-1 were superior to the better check in grain yield. The identified hybrids may be tested on large scale multi-location trial and in farmers' field before commercial utilization.

Keywords: Combining ability, Heterosis, GCA, SCA

Introduction

Maize (*Zea mays* L.) is a short duration, high yielding cereal crop and has key importance in assuring food security to the teeming population (Saeed et al. 2000). It possesses somatic chromosome number of 20, a genome size of 2.3 gigabase and more than 32,000 genes (Schnable et al. 2009). It is a member of the grass family Poaceae, tribe Maydeae and one of the oldest cultivated crops (Sleper and Poehlman 2006). The name maize is derived from a South American Indian Arawak-Carib word "Mahiz" and its centre of origin considered to be Central America (Mexico) (Watson and Dallwitz 1992). Maize is grown at latitudes ranging from the equator to approximately 50° North and South, and at altitudes ranging from sea level to over 3,000 meters elevation. This reflects its ability to adapt to a wide range of production environments, under temperatures ranging from extremely cold to very hot, under moisture regimes ranging from extremely wet to semi-arid (Dowswell et al. 1996).

In India, maize is the third most important cereal crop after Rice and Wheat, that provides food, feed, fodder, fuel and also serves as a source of basic raw material for a number of industrial products viz., starch, oil, protein, alcoholic beverages, food sweeteners, cosmetics and bio-fuel etc. It is cultivated in nearly 201 m ha with a production of 1162 m tonnes and productivity of 5754.7 kg/ha all over the world, having wider diversity of soil, climate, biodiversity and management practices (FAOSTAT 2021). India ranks 4th in terms of global maize acreage and 6th in production with 31.51 million tonnes and area of 9.9 million hectares in 2020-21, whereas in *kharif* 2021-22, maize production was 21.24 million

tonnes in an area of 8.15 million hectares (agricoop.nic). United States of America (USA) is the largest producer of maize contributing 30 per cent of the global production and is regarded as the driver of the US economy. Presently, in India maize is attaining high productivity in states like Andhra Pradesh, Tamil Nadu and Karnataka replacing rice. In this context developing high yielding late maturity hybrids which can compete with rice with full productive potentiality and profitability are required. Maize in the tropics is continually exposed to different forms of stresses and variations within the seasons. This may be partly due to global climatic changes, partly due to displacement of maize to more difficult production environments by high value crops, and partly due to declining soil organic matter reducing soil fertility and water holding capacity. Research efforts in the public sector institution has achieved limited success in developing high yielding early maturing hybrids. Choice of germplasm is essential for successful development of high yielding genotypes through suitable breeding programs. Genetic relationship among different genotypes is one of the important parameter which provides essential information regarding choice of germplasm to develop new genotypes from breeding populations.

The hybrid breeding is vital to select the cross combinations with high degree of SCA as well as parents with high GCA. Combining ability is an important tool in identifying the best combiners for hybridization especially, when more numbers of advance inbred lines are available and most promising are to be selected on the basis of their ability to give superior hybrids. GCA & SCA are due to genes which shows additive and dominance or epistatic effects respectively (Sprague and Tatum, 1942). Information on heterotic patterns and combining ability among maize germplasm is basic in improving the effectiveness of hybrid development. Development of commercial maize hybrid generally requires a good knowledge of combining ability of the breeding materials to be used. The result of commercial production of hybrid maize depends up on the availability of productive diverse inbred lines and clear knowledge of gene action for specific traits. Eventually, the present investigation was undertaken to study the combining ability and estimate the extent of heterosis.

Materials and Methods

In Rabi, 2019-20 the experiment was planned in a line \times tester mating pattern and 30 crosses were made. In Kharif, 2020 all 30 crosses along with their 13 parents (Table 1) and 2 checks (Table 2) were grown in Randomized Block Design with two replications and were evaluated. After land preparation, sowing was done in July 2020. Seeds were sown by hand dibbling with two seeds per hill and afterwards thinned to one plant per hill after emergence to attain an optimum plant population density. Each entry was planted in plot consisting of two rows of 5m length and plot size of 6.0 m². Observations were recorded on plot basis for days to 50 per cent tasseling, days to 50 per cent silking, anthesis – silking interval, days to 75 per cent brown husk, plant height, ear height, cob length, cob girth, number of rows per cob, number of grains per row, test weight, shelling percentage and grain yield at 15% moisture from five randomly selected plants from each plot.

Table 1. Details of the lines

S. No.	Code	Name	Source
1	L ₁	VL1016537	CIMMYT, Hyderabad
2	L ₂	VL109476	CIMMYT, Hyderabad
3	L ₃	VL1010763	CIMMYT, Hyderabad
4	L ₄	VL1018419	CIMMYT, Hyderabad
5	L ₅	VL109475	CIMMYT, Hyderabad
6	L ₆	VL1017055	CIMMYT, Hyderabad
7	L ₇	VL109353	CIMMYT, Hyderabad
8	L ₈	VL1010848	CIMMYT, Hyderabad
9	L ₉	VL109479	CIMMYT, Hyderabad
10	L ₁₀	VL1017524	CIMMYT, Hyderabad

Table 2. Details of the testers

S. No	Code	Name	Source
1	T ₁	VL1016498	CIMMYT, Hyderabad
2	T ₂	VP15295	CIMMYT, Hyderabad
3	T ₃	SML-1	BAU, Sabour

Table 3. Details of the checks

S. No.	Name	Source
1	DHM 117	ANGRAU, Hyderabad
2	SHM 1	BAU, Sabour

Results and Discussion

The analysis of variance displays highly significant difference for all the characters studied (Table 4). The mean square due to parents varied significantly indicating the parents involved in the study were diverse for all the characters except Anthesis – Silking interval, and significant difference was also observed among the crosses for all the characters. The variance due to parents vs crosses differs significantly indicating the presence of high heterosis response in the material studied. The variance due to general and specific combining ability were highly significant for all the characters under study except Anthesis – Silking interval, indicating that the influence of both additive and non-additive effects in the expression of characters. The influence of both type of gene effect was also observed by Singh and Kumar (2008); Verma and Narayan (2008) and Amiruzzaman et al. (2011) in maize. Combining ability analysis revealed that degree of specific combining ability (SCA) variances were higher than general combining ability (GCA) variances for all the characters under study

except Anthesis – Silking interval, suggesting predominance of non-additive geneaction for these characters.

GCA effect

The GCA effects were found to be having both significant positive and significant negative values for various traits studied (Table 5). The high GCA effect observed were attributed to additive effect and additive × additive gene effect (Griffing, 1956 and Sprague, 1966). General combining ability is a good indicator of inbred line performance at hybrid combinations. Parents with high GCA always produce hybrids with high estimate of SCA. However, on the contrary good general combining parents does not always show high SCA effects in their hybrid combination. Kumar and Babu (2016) and Gowharet al. (2009) reported that, the crosses with high SCA effects were found to show result due to all possible parental GCA combinations. The lines VL109476 (464.817), VL109475 (748.317), VL1010848 (541.483) and VL109479 (1424.650) were identified as good combiners for grain yield at 15 % moisture. The line VL1017524 was also found to show good GCA effects for days to 50 per cent tasseling, days to 50 % silking, plant height and ear height. But the line VL109475 showed poor combining ability effects for days to 50 % tasseling and days to 50 % silking. Among the testers, the tester VP15295 (313.517) was identified as good combiner for grain yield at 15 % moisture, cob length, number of grains per row, test weight and shelling percentage, while SML-1is showing good GCA effects for days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk, cob length and also shelling percentage. These observations were in agreement with the works of Elmyhun et al. (2020), Mogesse et al. (2020), Onejeme et al. (2020), Arsodeetal. (2017) and Bisen et al. (2016).

Table 4. Mean sum of square for quantitative traits in maize (*Zea mays* L.)

Sources	D.f	Mean Sum of Squares (MSS)					
		Days to 50 per cent tasseling (Day)	Days to 50 per cent silking (Day)	Anthesis-silking interval (Day)	Days to 75 per cent brown husk (Day)	Plant height (cm)	Ear height (cm)
Replicates	1	0.94186	1.674	0.186	0.570	1243.360	0.047
Treatments	42	18.81783	18.462***	0.882	10.220*	1337.957***	306.107***
Parents	12	20.05128	18.635***	1.667**	19.571***	1188.782***	352.878***
Parents Vs crosses	1	233.25012	197.847***	1.290	36.076*	26742.470***	5634.467***
Crosses	29	10.91322	12.205***	0.543	5.460	523.667***	103.017
Lines	9	13.09074	17.807**	0.896	8.444***	866.743**	227.128***
Testers	2	68.11667	60.117***	0.217	28.717***	1579.650**	160.117*
Line × tester	18	3.46852	4.080	0.402	1.383	234.798	34.617
Error	42	4.27519	3.960	0.615	5.260	130.837	70.737

*** Significant at 0.1% level ** Significant at 1% level * Significant at 5% level

Contd.

Table 4. Mean sum of square for quantitative traits in maize (*Zea mays* L.)

Sources	D.f	Mean Sum of Squares (MSS)						
		Cob length (cm)	Cob girth (cm)	No. of rows per cob	No. of grains per row	Test weight (g)	Shelling percentage (%)	Grain yield at 15 % moisture (Kg/ha)
Replicates	1	13.442	0.158	2.279	0.890	143.267	17.759	622710.800
Treatments	42	14.247***	0.519***	2.401**	41.316***	3026.800***	49.841***	3308530.000*
Parents	12	9.947***	0.482***	1.205	11.154***	415.282***	36.057***	199571.600*
Parents Vs crosses	1	302.060***	10.026***	15.976***	1024.277***	66440.270**	958.321***	86662500.000**
Crosses	29	6.102**	0.207***	2.428**	19.902***	1920.756***	24.217***	1720721.000***
Lines	9	11.949**	0.186	3.822	34.078*	3247.807	27.771	3539063.000**
Testers	2	8.690	0.373	1.800	30.383	1220.517	103.679**	2065211.000
Line × tester	18	2.891	0.199***	1.800	11.650***	1335.035***	13.611*	773273.800***
Error	42	2.578	0.058	1.041	2.472	37.625	7.261	76723.670

Table 5. Estimates of GCA effects of parents

Parent	Days to 50 per cent tasseling (Day)	Days to 50 per cent silking (Day)	Anthesis-silking interval (Day)	Days to 75 per cent brown husk (Day)	Plant height (cm)	Ear height (cm)
L ₁	0.983	1.200	0.233	-0.500	2.117	0.017
L ₂	-1.017	-1.133	-0.100	-1.667	6.283	5.850
L ₃	0.150	0.200	0.067	-0.333	3.783	0.017
L ₄	0.650	0.367	-0.267	0.500	9.617*	-0.817
L ₅	2.150*	2.033*	-0.267	-0.667	5.950	5.850
L ₆	-0.017	0.367	0.400	1.167	-3.717	4.183
L ₇	0.317	0.867	0.567	0.667	-0.383	2.517
L ₈	-0.017	-0.133	-0.100	0.500	3.783	-0.317
L ₉	0.317	0.533	0.233	2.000*	5.117	-1.650
L ₁₀	-3.517***	-4.300***	-0.767*	-1.667	-32.5***	-15.6***
T ₁	-0.5	-0.517	0.083	-0.667	-7.1**	-2.9
T ₂	2.0***	1.933***	-0.117	1.383*	9.9***	2.7
T ₃	-1.483**	-1.417**	0.033	-0.717	-2.800	0.183
C.D. at 95% (Line)	1.726	1.662	0.655	1.915	9.551	7.022
C.D. at 95% (Tester)	0.946	0.910	0.359	1.049	5.231	3.846

*** Significant at 0.1% level ** Significant at 1% level * Significant at 5% level

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Table 5. Estimates of GCA effects of parents

Parent	Cob length (cm)	Cob girth (cm)	No. of rows per cob	No. of grains per row	Test weight (g)	Shelling percentage (%)	Grain yield at 15 % moisture (Kg/ha)
L ₁	1.264	-0.136	-1.067*	0.396	-30.867***	-3.942**	-784.850***
L ₂	1.154	0.206*	-0.067	1.513*	11.467***	1.190	464.817***
L ₃	-0.130	-0.007	-0.400	0.612	-0.367	1.373	-38.350
L ₄	0.442	-0.179	-0.733	2.438***	-25.700***	1.285	-353.183**
L ₅	0.060	-0.012	0.267	-0.438	42.133***	-2.387*	748.317***
L ₆	-0.835	0.013	0.267	-1.604*	-15.867***	1.345	-514.850***
L ₇	-1.503*	0.231*	-0.733	0.229	-20.200***	0.845	-525.683***
L ₈	1.195	0.225*	1.267**	-0.771	15.633***	1.108	541.483***
L ₉	1.302	-0.062	1.267**	3.063***	20.967***	1.977	1424.650***
L ₁₀	-2.950**	-0.279**	-0.067	-5.438***	2.800	-2.795*	-962.350***
T ₁	-0.407	-0.056	-0.300	-0.538	-9.017***	0.904	-328.633***
T ₂	0.761*	-0.099	0.000	1.410***	4.283**	-2.590***	313.517***
T ₃	-0.354	0.156**	0.300	-0.873*	4.733**	1.686**	15.117
C.D. at 95 % (Line)	1.341	0.201	0.852	1.313	5.122	2.250	231.276
C.D. at 95 % (Tester)	0.734	0.110	0.467	0.719	2.805	1.232	126.675

*** Significant at 0.1% level ** Significant at 1% level * Significant at 5% level

SCA effect

The SCA effect was also found to be having both significant positive and significant negative values for various traits studied (Table 6). The crosses VL109476 x V P15295 (502.483), VL1010763 x VP15295 (521.650), VL1018419 x VP15295 (470.483), VL109475 x SML-1 (747.383), VL109353 x SML-1 (651.383) and VL1010848 x VL1016498 were identified as good specific combiners for grain yield at 15% moisture and none of the crosses were identified as good specific combiners for earliness. These observations were in agreement with the works of Elmyhun et al. (2020), Mogesse et al. (2020), Nandan et al. (2020), Onejeme et al. (2020), Darshan and Marker (2019), Dar et al. (2018), and Kumar et al. (2015).

Table 6. Estimates of SCA effects of crosses

Crosses	Days to 50 per cent tasseling (Day)	Days to 50 per cent silking (Day)	Anthesis-silking interval (Day)	Days to 75 per cent brown husk (Day)	Plant height (cm)	Ear height (cm)
L ₁ × T ₁	-0.583	-0.150	0.417	1.000	-17.017 *	-5.417
L ₁ × T ₂	0.267	0.400	0.117	-1.050	5.883	1.433
L ₁ × T ₃	0.317	-0.250	-0.533	0.050	11.133	3.983
L ₂ × T ₁	-0.583	-0.817	-0.250	-0.333	-1.183	1.250
L ₂ × T ₂	0.767	1.233	0.450	0.617	-0.783	0.600
L ₂ × T ₃	-0.183	-0.417	-0.200	-0.283	1.967	-1.850
L ₃ × T ₁	-1.250	-1.150	0.083	-0.667	-1.183	-5.417
L ₃ × T ₂	1.100	1.400	0.283	-0.217	-0.783	1.433
L ₃ × T ₃	0.150	-0.250	-0.367	0.883	1.967	3.983
L ₄ × T ₁	-0.750	-0.817	-0.083	-0.500	0.483	2.917
L ₄ × T ₂	1.100	1.233	0.117	0.450	8.383	-0.233
L ₄ × T ₃	-0.350	-0.417	-0.033	0.050	-8.867	-2.683
L ₅ × T ₁	1.750	2.017	0.417	0.167	13.150	-3.750
L ₅ × T ₂	-0.400	-0.933	-0.383	0.617	-2.950	8.100
L ₅ × T ₃	-1.350	-1.083	-0.033	-0.783	-10.200	-4.350
L ₆ × T ₁	0.917	0.683	-0.250	0.833	8.817	2.917
L ₆ × T ₂	-0.733	-0.267	0.450	-0.717	6.717	-2.733
L ₆ × T ₃	-0.183	-0.417	-0.200	-0.117	-15.533	-0.183
L ₇ × T ₁	0.583	0.183	-0.417	0.333	-7.017	4.583
L ₇ × T ₂	-0.067	0.233	0.283	-1.217	-4.117	-3.567
L ₇ × T ₃	-0.517	-0.417	0.133	0.883	11.133	-1.017
L ₈ × T ₁	1.417	1.183	-0.250	0.000	-6.183	-1.083
L ₈ × T ₂	-0.233	-0.267	-0.050	-0.050	9.217	-0.733
L ₈ × T ₃	-1.183	-0.917	0.300	0.050	-3.033	1.817
L ₉ × T ₁	0.583	0.517	-0.083	-1.000	-0.017	1.250
L ₉ × T ₂	-1.067	-1.433	-0.383	1.450	-3.117	0.600
L ₉ × T ₃	0.483	0.917	0.467	-0.450	3.133	-1.850
L ₁₀ × T ₁	-2.083	-1.650	0.417	0.167	10.150	2.750
L ₁₀ × T ₂	-0.733	-1.600	-0.883	0.117	-18.450 *	-4.900
L ₁₀ × T ₃	2.817	3.250 *	0.467	-0.283	8.300	2.150
C.D at 95%	2.990	2.878	1.134	3.317	16.542	12.163

Contd.

Table 6. Estimates of SCA effects of crosses

Crosses	Cob length (cm)	Cob girth (cm)	No. of rows per cob	No. of grains per row	Test weight (g)	Shelling percentage (%)	Grain yield at 15% moisture (Kg/ha)
L ₁ × T ₁	-1.695	-0.022	-0.033	-4.296 ***	4.017	0.658	-476.700 *
L ₁ × T ₂	1.948	0.351 *	-0.333	2.757 *	-4.283	-5.123 *	141.150
L ₁ × T ₃	-0.253	-0.329	0.367	1.539	0.267	4.466 *	335.550
L ₂ × T ₁	-1.335	-0.409 *	-1.033	-0.412	-12.317 **	1.626	-674.367 **
L ₂ × T ₂	1.033	-0.011	-0.333	0.340	27.383 ***	-1.245	502.483 *
L ₂ × T ₃	0.302	0.419 *	1.367	0.072	-15.067 **	-0.381	171.883
L ₃ × T ₁	-0.196	-0.220	-0.700	-1.013	-10.983 *	0.058	-541.200 **
L ₃ × T ₂	0.356	-0.062	0.000	3.190 **	-1.783	0.822	521.650 *
L ₃ × T ₃	-0.160	0.283	0.700	-2.178	12.767 **	-0.879	19.550
L ₄ × T ₁	0.762	0.216	0.633	3.663 **	-30.150 ***	0.851	58.133
L ₄ × T ₂	-0.461	-0.091	0.333	-1.660	31.550 ***	-1.425	470.483 *
L ₄ × T ₃	-0.301	-0.126	-0.967	-2.003	-1.400	0.574	-528.617 *
L ₅ × T ₁	-1.496	-0.255	0.633	0.538	-29.983 ***	-0.882	-288.367
L ₅ × T ₂	-0.504	-0.052	-0.667	-1.410	0.717	0.817	-459.017 *
L ₅ × T ₃	2.000	0.308	0.033	0.873	29.267 ***	0.066	747.383 ***
L ₆ × T ₁	0.699	-0.015	-1.367	-1.296	31.017 ***	-0.604	-41.200
L ₆ × T ₂	-0.009	0.293	1.333	2.757 *	-25.283 ***	2.115	343.150
L ₆ × T ₃	-0.690	-0.277	0.033	-1.461	-5.733	-1.511	-301.950
L ₇ × T ₁	-0.178	-0.214	0.633	-0.129	-4.150	1.446	76.133
L ₇ × T ₂	-0.505	-0.131	-0.667	-2.577 *	-7.450	-4.005 *	-727.517 ***
L ₇ × T ₃	0.683	0.344	0.033	2.706 *	11.600 *	2.559	651.383 **
L ₈ × T ₁	1.184	0.248	0.633	0.871	45.017 ***	-0.692	1223.967 ***
L ₈ × T ₂	-0.834	-0.119	-0.667	-0.077	-9.283 *	2.447	-393.183
L ₈ × T ₃	-0.350	-0.129	0.033	-0.794	-	-1.754	-830.783 ***
L ₉ × T ₁	0.547	0.255	-0.367	0.538	35.733 ***	-1.516	339.300
L ₉ × T ₂	-0.191	0.043	0.333	-0.910	22.683 ***	2.648	-50.850
L ₉ × T ₃	-0.357	-0.297	0.033	0.373	-	-1.133	-288.450
L ₁₀ × T ₁	1.709	0.416 *	0.967	1.538	18.567 ***	-0.944	324.300
L ₁₀ × T ₂	-0.834	-0.221	0.667	-2.410 *	-15.150 **	2.950	-348.350
L ₁₀ × T ₃	-0.875	-0.196	-1.633 *	0.873	-7.450	-2.006	24.050
C.D@95%	2.322	0.348	1.476	2.274	22.600 ***	3.897	400.582

*** Significant at 0.1% level ** Significant at 1% level * Significant at 5% level

Table 7. Magnitude of heterosis for grain yield at 15 % moisture (Kg ha⁻¹)

Crosses	Heterosis (%) over			
	RH	BP	Check1	Check2
L ₁ × T ₁	27.75	22.39	-49.64**	-50.78**
L ₁ × T ₂	65.13 **	45.36 **	-21.36**	-23.15
L ₁ × T ₃	120.53 **	85.44 **	-23.69**	-25.43*
L ₂ × T ₁	97.16 **	96.25 **	-26.03**	-27.71
L ₂ × T ₂	151.07 **	112.20 **	14.78**	12.17**
L ₂ × T ₃	107.89 **	109.59 **	0.67**	-1.62
L ₃ × T ₁	55.29 **	40.07 **	-34.33**	-35.83***
L ₃ × T ₂	105.85 **	92.12 **	3.92**	1.55**
L ₃ × T ₃	129.44 **	83.37 **	-14.04**	-16.00
L ₄ × T ₁	92.22 **	91.16 **	-27.96	-29.60
L ₄ × T ₂	109.51 **	76.93 **	-4.28	-6.43*
L ₄ × T ₃	103.88 **	78.66 **	-33.41*	-34.93
L ₅ × T ₁	159.52 **	136.11 **	-11.01	-13.04*
L ₅ × T ₂	134.33 **	84.07 **	-0.42**	-2.69
L ₅ × T ₃	107.01 **	88.30 **	19.95**	17.21***
L ₆ × T ₁	87.27 **	75.62 **	-33.81	-35.32
L ₆ × T ₂	104.90 **	64.95 **	-10.77*	-12.80
L ₆ × T ₃	122.94 **	106.22 **	-31.95	-33.50
L ₇ × T ₁	91.09 **	81.96 **	-31.41	-32.98
L ₇ × T ₂	47.32 **	20.08	-35.05*	-36.53
L ₇ × T ₃	187.11 **	161.69 **	-10.79	-12.82
L ₈ × T ₁	225.27 **	113.84 **	18.25*	15.51**
L ₈ × T ₂	116.31 **	78.22 **	-3.59	-5.78
L ₈ × T ₃	153.25 **	127.99 **	-20.10	-21.92
L ₉ × T ₁	224.38 **	103.75 **	18.24**	15.55**
L ₉ × T ₂	177.46 **	129.06 **	25.02*	22.15*
L ₉ × T ₃	253.64 **	117.65 **	11.87**	9.375*
L ₁₀ × T ₁	89.62 **	70.74 **	-35.65	-37.72
L ₁₀ × T ₂	51.09 **	17.69	-36.33*	-37.51*
L ₁₀ × T ₃	124.35 **	116.43 **	-34.67***	-36.23

*** Significant at 0.1% level ** Significant at 1% level * Significant at 5% level

Estimates of heterosis

Negative and significant heterosis is desirable for days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk, anthesis-silking interval, plant height and ear height as it implies that these crosses may mature earlier.

In Maize shorter plants are taken in to consideration over taller types, so significant negative heterosis is considered desirable for plant height for the development of shorter hybrids that could avoid lodging.

Positive and significant heterosis for cob length, cob girth, number of grains per row, number of rows per cob, test weight, shelling % and grain yield at 15% moisture is desired. In the present study several crosses were showing desirable significant heterosis for these traits. On the basis of standard heterosis VL109476 x V P15295, VL1010763 x VP15295, VL109475 x SML-1 and VL109479 x SML-1 were superior to the better check in grain yield. The identified hybrids may be tested on large scale multi-location trial and in farmers' field before commercial utilization.

These finding also agree with, Ali et al. (2014), Shushay (2014), Amiruzzaman et al. (2010), Sumalini and Rani (2010), Singhal et al. (2006), Mohanraj and Gopalan (2005), Reddy and Ahuja (2004), Sinha *etal.* (2004), Dubey *etal.* (2001), Iqbal et al. (2001), Pandey and Kumar (2001), Kabdal (2000), Pradhan (1999) and Sinha and Mishra (1977) who also reported positive and significant heterosis for yield and related traits.

Conclusion

1. The good general combiner for yield lines L₂, L₅, L₈ and L₉ and tester T₂ observed in the study, may be used in hybridization programmes for greater yield..
2. The best cross combinations for greater yield L₂×T₂, L₃×T₂, L₄×T₂, L₅×T₃, L₇×T₃ and L₈×T₁ in the study, may be forwarded for multi-location testing and Front Line Demonstration (FLD), and then promising crosses may be released as hybrid.
3. As a future breeding strategy, improvement of the traits showing preponderance of non-additive gene action could be achieved by recurrent selection, or by way of inter-mating the most desirable segregants, followed by selection or the use of multiple crosses or biparental mating.

References

- Ali Q, Ali A, Ahsan, M, Nasir, IA, Abbas HG, Ashraf MA (2014) Line \times Tester analysis for morpho-physiological traits of *Zea mays* L. seedlings. *Advancements in Life Sciences*, 1(4), 242-253.
- Ali Q, Ali, A, Awan, MF, Tariq, M, Ali, S, Samiullah, TR, Hussain T (2014) Combining ability analysis for various physiological, grain yield and quality traits of *Zea mays* L. *Life Science Journal*, 11(8s), 540-551.
- Amiruzzaman M, Islam MA, Hasan L, Rohman, MM (2010) Combining ability and heterosis for yield and component characters in maize. *Academic journal of plant sciences* 3(2): 79-84.
- Arsode K Murali Krishna N, Sunil Vani Sree, A Ravi Charan (2017) Combining Ability and Heterosis Studies for Grain Yield and Its Components in Hybrids of Quality Protein Maize (*Zea mays* L.). *International Journal of Current Microbiology and Applied Sciences* ISSN: 2319-7706 Volume 6 Number 12 (2017) pp. 2538-2545
- Bisen, Amit Dadheech, Namrata, Omprakash Nagar, Ram Kunwar Meena (2017) Exploitation of Heterosis in Single Cross Hybrids of Quality Protein Maize (*Zea mays* L.) for Yield and Quality Traits. *International Journal of Bio-resource and Stress Management*, 8(1):012-019
- Darshan, S Marker (2019) Heterosis and combining ability for grain yield and its component characters in quality protein maize (*Zea mays* L.) hybrids. *Electronic Journal of Plant Breeding*, 10 (1): 111 – 118 (Mar 2019)
- Dar ZA, Lone AA, Alie BA, Ahangar, MA, Ali G, Abidi I, Gazal A, Lone RA (2018) Combining ability analysis for yield and yield contributing traits in popcorn (*Zea mays* L.) under temperate conditions. *Journal of Pharmacognosy and Phytochemistry* 7(1):361-366.
- Dowswell CR, Paliwal RL and Cantrell RP. (1996) Maize in third world. West View Press, Colorado, USA.
- Dubey R B, Joshi V N , Pandiya N K (2001) Heterosis and combining ability for quality, yield and maturity traits in conventional and non-conventional hybrids of maize. *Indian Journal of Genetics*. 61(4): 353-355.
- Elmyhun M, Liyew C, Shita A, Andualem M (2020) Combining ability performance and heterotic grouping of maize (*Zea mays*) inbred lines in testcross formation in Western Amhara, North West Ethiopia. *Cogent Food & Agriculture*. 6: 1727625

- Gowhar A, Rather AG, Ishfaq A, Gulzaffar, Imran S, Dar SA (2009) Combining ability and gene action studies for yield and its related traits in maize (*Zea mays* L.). *Journal of Environment and Ecology*. Vol.27 No.2 pp.699-703 ref.8.
- Griffing B. (1956) Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Science* 9: 463-493
- Iqbal AM, Nehvi FA, Wani SA, Qadir R, Dar, ZA (2007) Combining ability analysis for yield and yield related traits in maize (*Zeamays* L.). *International Journal of Plant Breeding and Genetics*. 1(2):101-105.
- Iqbal M, Salum M, Rasid O (2001) Inter-raceal heterosis in maize hybrids. *Pakistan Journal of Scientific and Industrial Research*. 44 (4): 239-343.
- Kabdal MK (2000) Combining ability and heterosis analysis for grain yield and its components in maize (*Zea mays* L.). Thesis, M.Sc. (Ag.) GBPUA&T, Pantnagar, India. 115p.
- Kemphorne O (1957) An introduction to statistics. John Wiley and Sons. Inc. New York. pp: 468- 471.
- Kumar P S (2008) Combining ability studies in maize (*Zea mays* L.). *Advances in Plant Sciences*. 21 (1): 15-19.
- Kumar R, Mandal SS, Mishra AK, Smriti, Singh R, Kumar P (2015) Heterosis and combining ability for yield and its contributing traits of *kharif* maize (*Zeamays* L.). *The Bioscan*. 10(4): 2049-2056.
- Kumar SVVP, Babu DR (2016) Combining ability and heterosis in maize (*Zea mays* L.) for grain yield and yield components. *International Journal of Agriculture, Environment and Biotechnology*. 9(5): 763-772.
- Mogesse, Habtamu Zelleke, Mandefro Nigussie (2020) General and Specific Combining Ability of Maize (*Zea mays* L.) Inbred Line for Grain Yield and Yield Related Traits Using 8×8 Diallel Crosses. *American Journal of BioScience* 2020; 8(3): 45-56
- Mohanraj K and Gopalan A (2005) Heterosis across several characters in maize (*Zea mays* L.). *Plant Archive*. 5(1): 311-312.
- Nandan G, Mandal SS, Prasad BD, Zareen U, Rani, J. (2020) Combining ability for yield and its attributes in response to arsenic absorption in maize (*Zea mays* L.). *International Journal of Current Microbiology and Applied Sciences*. 9(6): 1007-1021.
- Onejeme, Emmanuel Ogbonna Okporie, Chinedu Emmanuel Eze (2020) Combining Ability and Heterosis in Diallel Analysis of Maize (*Zea mays* L.) Lines. *International Annals of Science*. ISSN: 2456-7132 Volume 9, Issue 1, pp. 188-200, 2020

- Pandey BP, Kumar, P. (2001). Heterosis in varietal crosses of maize. Diamond Jubilee Symposium, Indian Society of Genetics and Plant Breeding. New Delhi, Nov. 6-9, pp. 129.
- Pradhan (1999) Classification and characterization of inbred lines of maize (*Zea mays* L.). Ph.D. Thesis, G.B.P.U.A. & T., Pantnagar, India, 137 p.
- Reddy DM, Ahuja VP (2004). Phenotypic stability in recycled inbreds of maize. *National Journal Plant Improvement*. 6 (1): 29-30.
- Saeed MT, Saleem M and Afzal M. (2000) Genetic analysis of yield and its components in maize diallel crosses (*Zea mays* L.). *International Journal of Agriculture and Biology* 2: 376-378
- Schnable PS, Ware D and Fulton RS. (2009) The B73 maize genome: complexity, diversity and dynamics. *Science* 326: 1112-1115
- Shushay WA (2014) Standard Heterosis of Maize (*Zeamays* L.) Inbred Lines for Grain Yield and Yield Related Traits in Central Rift Valley of Ethiopia. *Journal of Biology, Agriculture and Healthcare*. Vol.4 No.23 pp.31-37 ref.19.
- Singh PK and Kumar N. (2008) Selection of tester for evaluation of inbred lines in hybrid maize (*Zea mays* L.). *Environment and Ecology* 27: 895-897
- Singhal N, Verma SS, Baskheti DC, Kumar A (2006) Heterosis and combining ability analysis in quality protein maize inbred lines. *Journal of Biological Sciences*. 1 (2): 54-56, 85-88.
- Sinha A, Mishra SN (1996) Combining ability analysis in varietal crosses of maize. *Indian Journal of Genetics*. 57(2): 149-153.
- Sinha SS, Dubey RB, Lakshyadeep, Punia SS (2004) Heterosis for quality traits in single cross hybrids of maize. (*Zea mays* L.). *Indian Journal of Agricultural Biochemistry*. 17 (1): 37-39.
- Sleper DA and Poehlman JM. (2006) Breeding corn (Maize). Chapter 17. In: *Breeding Field Crops*, Edition 5. Blackwell Publishing pp 277-296
- Sprague GF and Tatum LA. (1942) General v/s specific combining ability in single crosses in corn. *Journal of American Society of Agronomy* 30: 923-932
- Sumalini K, Rani TS (2010) Heterosis and combining ability for polygenic traits in late maturity hybrids of maize, *Zea mays* (L.). *Madras Agricultural Journal*, 97(10/12), 340-343.

Verma R, Kumar SS, Reddy VN and Sankar AS. (2008) Heterosis studies for grain yield and its component traits in single cross hybrids of maize (*Zea mays* L.). *International Journal of Plant, Animal and Environmental Science* 4: 304 -306

Watson L and Dallwitz MJ. (1992)The grass genera of the World. CAB International, Oxon, pp 1038

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