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Combining ability effects and heterosis estimates in maize (*Zea mays* L.)

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Abstract
Maize is becoming a crop of huge demand day by day due to its multiple uses but its productivity in farmer's fields is generally low due to lack of multiple resistant and wider adaptive improved maize hybrids. For development of improved maize hybrids, heterosis breeding has been recognized as most powerful breeding approach since long time. In this experiment, 54 single cross hybrids were evaluated along with their parental lines and two checks for combining ability and heterotic potential. Highly significant variations were observed within parents and hybrids which indicates a wide genetic variability for the studied characters and the possibility of genetic improvement through utilization of such genetic material of maize. The parents, L1 (D5-1), L6 (D49-2), L14 (D47-1), L17 (D36-1) and L18 (TSK92-3) exhibitted good GCA effects for grain yield and some of the yield contributing traits to emerge as valuable donor parents for further breeding programme. Based on SCA effect and standard heterosis, the hybrid combinations L5xT1 (D2-2xD47), L9xT3 (Azad UttamxTSK32-1-1-3) and L8xT3 (D48xTSK32-1-1-3) were identified as best for grain yield and some of the yield contributing traits.

Keywords: Maize, GCA, SCA, heterotic potential, grain yield

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal crop world wide. In India it is cultivated in an area of 9.57 million hectare with average production of 28.77 million tonnes and productivity of 3.006 tonnes per hectare (DES, 2021). Maize grains contain about 9.9 percent protein, 4 percent oil, 70 percent starch and 2.7 percent crude fiber (Bisen *et al.*, 2017). Globally, maize is becoming very demanding crop day by day due to its multiple uses such as food, feed and a number of industrial products (Bisen *et al.*, 2017). Maize has very high genetic yield potential but its productivity in farmers' fields is generally low due to lack of multiple resistant and wider adaptive improved maize hybrids. The yield advantage, of different types of maize hybrids over the open-pollinated varieties are 46 percent for single cross, 30 percent for three way cross, 37 percent for double top cross, 28 percent for top cross, and 17 percent for variety cross (Diviya *et al.*, 2022). This necessitates the development and commercialization of improved maize hybrids and heterosis breeding is the most powerful tool for this purpose. The present maize breeding programs is also largely based on the exploitation of heterosis (Zhang *et al.,* 2016) and most of the global maize production is provided by hybrid maize (Duvick 2005a, b; Masuka *et al.*, 2017a, b). Taking the above points under consideration the present experiment was carried out.

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MATERIALS AND METHODS

A field experiment was work out to analyze the genetic worth of the studied materials in terms of combining ability and heterotic response. A total of 54 single cross hybrids were produced by crossing of eighteen lines (females) and three testers (males) in line x tester mating design during *kharif*-2018.A field trial was conducted involving all the hybrids, their parents and two checks (Bharat Kaveri and Don 1588) during *Rabi* 2018-19 in Randomized Block Design with three replications at Student Instructional Farm, CS Azad University of Agriculture and Technology, Kanpur (UP) India. The plot length was 4 m and inter and intra row spacing was 60x25cm.The observations were recorded on days to 50% tasseling, days to 50% silking, days to 75% dry husk, 100-grain weight, shelling percentage and grain yield per plant. The mean value of all the observations were used for the Analysis of Variance (ANOVA) as per Panse and Sukhatme, 1985, combining ability analysis as per Kempthorne, 1957, standard heterosis over check-2 (Don-1588) as per Meredith and Bridge, 1972. List of the parental genotypes and standard parents and their source are given in **Table 1.**

RESULTS AND DISCUSSION

The ANOVA for line × tester set comprising 54 single cross hybrids and 21 parents (**Table 2**) revealed that mean squares due to parents, line as well as testers were significant for all the characters. This indicates that the selected parents were more divergent in respect of the studied characters and may be utilized for further heterosis breeding programme in maize. Similar findings have also been reported by Bisen *et al.* (2017) and Diviya *et al.* (2022). The mean squares due to lines *vs.* testers were found significant for all the characters except 100-kernel weight. This indicated that testers were highly divergent from lines and choice of tester was perfect. These results are in full agreement with those of Darshan and Marker, 2019. In case of parents vs crosses, mean squares were found significant for all the characters except days to 50% tasseling. This indicated that the crosses that were made had sufficient level of heterosis for majority of the characters. Significant mean sum of square due to parents vs crosses for different characters has also been reported by Rajitha *et al*. (2014) and Darshan and Marker, 2019.

Table 1.The parental genotypes and their source

Genotypes		Origin/Source
Lines (Females)		
L1	(D5-1)	Winter Nur, Hyderabad (Hyb)
L2	(D13)	Winter Nur, Hyderabad (Hyb)
L3	(D8-1)	Winter Nur, Hyderabad (Hyb)
L4	(D4-1)	Winter Nur, Hyderabad (Hyb)
L5	(D2-2)	Winter Nur, Hyderabad (Hyb)
L6	(D49-2)	Winter Nur, Hyderabad (Hyb)
L7	(Azad Kanti)	Kanpur
L8	(D48)	Winter Nur, Hyderabad (Hyb)
L9	(Azad Uttam)	Kanpur
L10	(D15)	Winter Nur, Hyderabad (Hyb)
L11	(IB3-1/1573/R-17)	Kanpur
L12	(D14)	Winter Nur, Hyderabad (Hyb)
L13	(TSK 36B)	Kanpur
L14	(D47-1)	Winter Nur, Hyderabad (Hyb)
L15	(D12)	Winter Nur, Hyderabad (Hyb)
L16	(JNP white)	Kanpur (CfJaunpur Local)
L17	(D36-1)	Winter Nur, Hyderabad (Hyb)
L18	(TSK92-3)	Kanpur
Testers (Males)		
T1	(D47)	Winter Nur, Hyderabad (Hyb)
T2	(D46)	Winter Nur, Hyderabad (Hyb)
T3	(TSK32-1-1-3)	Kanpur
Checks (Standard Parents)		
C1	(Bharat Kaveri)	Kaveri Seeds Co.Secunderabad (Telangana)
C2	(Don-1588)	Nath Seeds, Jalna (Maharashtra)

L= Line, T= Tester, C= Check

Table 2. ANOVA for six characters in hybrids and parents of maize

Source of Variance	d.f.	Days to 50% tasseling	Days to 50% silking	Days to 75% dry husk	100-Kernel weight (g)	Shelling percentage (%)	Grain yield/ plant (g)
Replicates	2	6.538 *	4.764	5.453	0.699	3.048	1.741
Treatments	74	38.475 **	37.269 **	36.188 **	33.009 **	147.330 **	2484.688 **
Parents	20	51.949 **	44.738 **	34.338 **	36.693 **	204.189 **	847.879 **
Parents (Line)	17	46.676 **	39.539 **	31.853 **	36.403 **	193.428 **	899.742 **
Parents (Testers)	2	96.444 **	80.333 **	66.333 **	56.682 **	283.737 **	669.476 **
Parents (L vs T)	1	52.595 **	61.929 **	12.595 *	1.649	228.029 **	323.001 **
Parents vs Crosses	1	5.531	27.192 **	199.131 **	336.717 **	654.922 **	45061.950 **
Crosses	53	34.013 **	34.641 **	33.811 **	25.888 **	116.297 **	2299.007 **
Line Effect	17	38.392	44.430	54.314 *	29.779	213.604 **	3525.523 *
Tester Effect	2	26.722	14.821	2.241	13.197	73.744	3360.232
Line x Tester Effect	34	32.252 **	30.912 **	25.417 **	24.688 **	70.147 **	1623.324 **
Error	148	2.069	2.107	2.296	0.850	4.436	9.885
Total	224	14.136	13.747	13.520	11.473	51.630	827.381

*, ** significant at 5% and 1% level, respectively

Table 3. Estimates of general combining ability (*gca*) effects of parents (lines and testers)

Genotype	Days to 50% tasseling	Days to 50% silking	Days to 75% dry husk	100-Kernel weight (g)	Shelling percentage (%)	Grain yield/ plant (g)
L1	-0.556	-0.679	-1.778 **	0.252	4.091 **	35.772 **
L2	0.222	-0.123	0.889	3.454 **	-1.302	7.444 **
L3	-0.667	-1.123 *	-1.222 *	-2.025 **	0.990	6.196 **
L4	-1.000 *	-0.901	0.333	0.221	2.952 **	1.303
L5	1.111 *	0.321	2.444 **	-0.488	-1.027	-6.380 **
L6	-2.444 **	-2.346 **	0.889	1.172 **	6.722 **	25.957 **
L7	-0.778	-0.901	2.333 **	-0.689 *	4.070 **	8.034 **
L8	-2.556 **	-2.790 **	-2.778 **	-1.087 **	1.068	-2.523 *
L9	-1.222 *	-1.123 *	-3.111 **	-1.742 **	-5.448 **	-21.053 **
L10	1.222 *	1.432 **	0.111	1.872 **	-5.491 **	-11.195 **
L11	1.333 **	1.654 **	1.444 **	0.382	-0.183	-12.543 **
L12	1.222 *	1.765 **	2.778 **	1.030 **	-1.949 **	-5.061 **
L13	-2.333 **	-1.235 *	1.222 *	0.338	0.091	3.877 **
L14	3.111 **	3.654 **	2.667 **	2.181 **	4.843 **	13.953 **
L15	-3.444 **	-4.012 **	-4.889 **	\-0.717 *	1.897 **	-5.947 **
L16	0.111	-0.790	-4.000 **	-4.728 **	-14.552 **	-57.512 **
L17	4.000 **	4.099 **	3.000 **	-0.484	2.973 **	10.569 **
L18	2.667 **	3.099 **	-0.333	1.060 **	0.253	9.108 **
T1	0.130	0.302	0.204	-0.450 **	-0.072	2.965 **
T2	0.630 **	0.302		0.529 **	-1.131 **	-8.941 **
T3	-0.759 **	-0.605 **	-0.204	-0.079	1.203 **	5.977 **
CD 95% GCA(Line)	0.951	0.959	1.001	0.609	1.392	2.078
CD 95% GCA(Tester)	0.388	0.392	0.409	0.249	0.568	0.848

*, ** significant at 5% and 1% level, respectively

Table 4. Estimates of specific combining ability (*sca*) effects and percentage standard heterosis (SH %) of different cross combination for six characters

	Days to 50% tasseling		Days to 50% silking		Days to 75% dry husk		100-kernel weight (g)		Shelling percentage (%)		Grain yield/plant (g)	
	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %
L1xT1	-0.907	-3.94 **	-0.969	-3.57 **	-7.093 **	-5.79 **	0.875	7.70 *	-0.647	0.04	20.723 **	51.26 **
L1xT2	1.593	-1.57	1.364	-1.79	1.778 *	-0.6	-0.191	7.36 *	1.139	0.92	-7.681 **	13.46 **
L1xT3	-0.685	-4.46 **	-0.395	-3.83 **	5.315 **	1.4	-0.683	2.93	-0.492	1.77	-13.042 **	22.42 **
L2xT1	0.981	-1.84 *	1.475	-1.28	-0.426	-0.2	0.029	17.19 **	5.723 **	1.22	29.451 **	32.88 **
L2xT2	0.815	-1.57	0.809	-1.79	3.444 **	2.00 **	1.483 **	26.99 **	-1.391	-8.64 **	-30.587 **	-34.58 **
L2xT3	-1.796 *	-4.72 **	-2.284 **	-4.85 **	-3.019 **	-2.00 **	-1.512 **	12.48 **	-4.332 **	-9.37 **	1.136	9.16 **
L3xT1	2.204 **	-1.57	2.142 *	-1.53	0.685	-0.8	6.731 **	22.12 **	1.344	-1.3	17.452 **	20.46 **
L3xT2	0.370	-2.62 **	0.475	-2.81 **	-0.111	-1.4	-3.381 **	-14.66 **	-1.050	-5.46 **	-4.192 *	-11.00 **
L3xT3	-2.574 **	-6.04 **	-2.617 **	-5.87 **	-0.574	-1.80 *	-3.350 **	-16.98 **	-0.294	-1.73	-13.260 **	-5.51 *
L4xT1	-1.130	-4.46 **	-1.080	-3.83 **	-1.204	-1	0.879	7.60 *	-5.235 **	-6.87 **	-14.548 **	-14.13 **
L4xT2	-4.296 **	-6.56 **	-3.747 **	-5.87 **	-2.333 **	-1.80 *	-2.453 **	-1.88	3.244 **	2.09	12.975 **	0.51
L4xT3	5.426 **	0	4.827 **	0	3.537 **	1.60 *	1.574 **	11.89 **	1.990	3.39	1.573	3.81
L5xT1	-1.241	-2.89 **	-0.969	-2.81 **	1.352	1.80 *	-0.862	-2.27	5.121 **	0.83	41.384 **	31.11 **
L5xT2	0.926	-0.79	0.698	-1.53	1.556	1.80 *	0.555	7.38 *	0.637	-5.86 **	-22.367 **	-39.83 **
L5xT3	0.315	-2.36 *	0.272	-2.55 **	-2.907 **	-1	0.307	3.93	-5.757 **	-10.76 **	-19.018 **	-22.70 **
L6xT1	-0.685	-5.25 **	-1.636	-5.36 **	-2.426 **	-1.4	-0.422	6.19 *	-0.052	3.94	4.844 **	27.17 **
L6xT2	2.481 **	-2.36 *	3.031 **	-1.79	2.111 *	1.2	0.445	13.62 **	0.788	3.67	20.243 **	30.44 **
L6xT3	-1.796 *	-6.82 **	-1.395	-5.87 **	0.315	0	-0.023	9.29 **	-0.736	4.65 *	-25.088 **	1.93
L7xT1	-1.685 *	-4.72 **	-2.414 **	-4.85 **	-0.537	0.6	0.029	0.51	4.064 **	5.70 **	20.928 **	25.44 **
L7xT2	1.481	-1.84 *	1.586	-1.79	0.000	0.8	4.617 **	22.93 **	2.557 *	2.61	13.017 **	6.86 **
L7xT3	0.204	-3.94 **	0.827	-3.06 **	0.537	1	-4.646 **	-16.82 **	-6.621 **	-5.65 **	-33.944 **	-23.19 **
L8xT1	0.759	-4.20 **	1.142	-3.57 **	1.241	-1.4	1.174 *	3.52	0.523	-2.19	3.484	-0.81
L8xT2	-1.741 *	-5.77 **	-1.525	-5.61 **	-1.889 *	-3.39 **	-1.856 **	-4.74	1.052	-2.83	-36.470 **	-49.44 **
L8xT3	0.981	-4.72 **	0.383	-4.85 **	0.648	-2.00 **	0.682	3.03	-1.575	-3.19	32.986 **	29.68 **
L9xT1	6.426 **	1.31	5.475 **	1.02	6.241 **	1.4	-0.402	-5.46	-7.082 **	-19.23 **	-31.762 **	-51.24 **
L9xT2	-0.407	-3.67 **	-0.858	-3.83 **	-2.222 *	-3.79 **	-3.958 **	-15.84 **	3.381 **	-7.89 **	-7.833 **	-39.96 **

Table 4. Continued..

	Days to 50% tasseling		Days to 50% silking		Days to 75% dry husk		100-kernel weight (g)		Shelling percentage (%)		Grain yield/plant (g)	
	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %	Sca effects	SH %
L9xT3	-6.019 **	-9.19 **	-4.617 **	-7.40 **	-4.019 **	-4.99 **	4.360 **	15.21 **	3.700 **	-4.68 *	39.596 **	18.50 **
L10xT1	-3.019 **	-4.20 **	-4.080 **	-4.34 **	-0.315	-0.6	-4.019 **	-5.48	-4.305 **	-15.94 **	-24.903 **	-35.56 **
L10xT2	0.148	-1.31	0.586	-0.77	-0.444	-0.8	2.382 **	24.24 **	-1.249	-13.53 **	8.986 **	-14.95 **
L10xT3	2.870 **	-0.26	3.494 **	0.77	0.759	-0.2	1.637 **	18.79 **	5.554 **	-2.5	15.918 **	5.54 *
L11xT1	0.537	-1.31	1.031	-0.26	0.352	0.6	0.591	7.09 *	-1.949	-6.69 **	-12.279 **	-24.99 **
L11xT2	3.037 **	1.05	2.364 **	0.77	-1.444	-0.6	-0.148	8.05 **	1.293	-4.05	14.183 **	-11.34 **
L11xT3	-3.574 **	-5.25 **	-3.395 **	-4.34 **	1.093	0.8	-0.443	4.42	0.656	-2	-1.904	-12.44 **
L12xT1	1.648 *	-0.52	1.586	0.26	-0.981	0.6	-2.663 **	-3.41	0.750	-5.56 **	-3.655 *	-9.89 **
L12xT2	-1.852 *	-2.89 **	-2.747 **	-3.06 **	0.556	1.4	1.261 *	16.34 **	-1.281	-9.29 **	0.671	-16.99 **
L12xT3	0.204	-2.36 *	1.160	-0.77	0.426	1.2	1.402 **	14.46 **	0.532	-4.28 *	2.983	-0.84
L13xT1	2.870 **	-2.36 *	3.253 **	-0.77	0.907	0.8	1.488 **	10.52 **	-1.257	-5.52 **	-5.032 **	-2.8
L13xT2	-2.630 **	-6.30 **	-2.747 **	-5.36 **	-1.222	-0.6	-2.471 **	-1.48	6.335 **	2.37	13.070 **	3.01
L13xT3	-0.241	-5.51 **	-0.506	-4.34 **	0.315	0.2	0.983	9.99 **	-5.078 **	-8.59 **	-8.038 **	-2.79
L14xT1	-0.574	-0.79	0.031	0.51	0.796	1.60 *	-4.241 **	-5.13	2.031	4.18 *	-10.808 **	1.23
L14xT2	1.259	1.05	2.364 **	2.30 *	-0.333	0.8	-0.030	15.77 **	1.703	2.51	3.761 *	3.73
L14xT3	-0.685	-1.57	-2.395 **	-2.04 *	-0.463	0.6	4.271 **	30.64 **	-3.734 **	-1.24	7.047 **	20.80 **
L15xT1	-0.685	-6.04 **	-0.969	-6.12 **	0.019	-3.39 **	0.027	0.39	6.791 **	6.37 **	6.829 **	-0.89
L15xT2	-5.519 **	-9.45 **	-4.969 **	-9.18 **	-3.111 **	-5.39 **	0.484	6.17 *	-9.327 **	-14.36 **	-7.965 **	-25.92 **
L15xT3	6.204 **	-1.31	5.938 **	-1.53	3.093 **	-1.80 *	-0.511	-0.28	2.536 *	2.78	1.137	-3.4
L16xT1	0.093	-2.62 **	1.475	-1.79	-1.870 *	-3.99 **	2.528 **	-5.69	-5.230 **	-27.99 **	-14.597 **	-69.33 **
L16xT2	-3.074 **	-4.72 **	-3.525 **	-5.61 **	1.333	-2.20 **	-0.215	-12.79 **	-3.675 **	-27.39 **	-2.138	-68.81 **
L16xT3	2.981 **	-1.05	2.049 *	-2.04 *	0.537	-2.79 **	-2.313 **	-23.69 **	8.905 **	-9.39 **	16.735 **	-37.13 **
L17xT1	-2.796 **	-1.84 *	-2.080 *	-0.77	-0.204	1.2	-1.326 *	-4.12	-4.659 **	-6.15 **	-33.665 **	-23.37 **
L17xT2	3.370 **	3.41 **	2.920 **	3.06 **	0.667	1.60 *	3.471 **	19.14 **	0.973	-0.63	31.235 **	26.32 **
L17xT3	-0.574	-0.79	-0.840	-0.51	-0.463	0.8	-2.145 **	-5.92	3.686 **	5.46 **	2.430	13.30 **
L18xT1	-2.796 **	-2.89 **	-3.414 **	-2.55 **	3.463 **	1.4	-0.416	5.76	4.071 **	1.11	6.153 **	12.60 **
L18xT2	4.037 **	2.89 **	3.920 **	3.06 **	1.667	0.2	0.004	11.40 **	-5.130 **	-11.28 **	1.092	-3.31
L18xT3	-1.241	-2.36 *	-0.506	-1.02	-5.130 **	-3.99 **	0.412	10.59 **	1.059	-0.99	-7.245 **	2.86
CD 95%	1.647	2.3286	1.661	2.3496	1.734	2.4527	1.056	1.4928	2.411	3.4096	3.599	5.0895

Information about combining ability is crucial for exploitation of heterosis. The estimates of general combining ability (GCA) effects in respect of 21 parents for different characters are presented in **Table 3**. Parents, L15, L8 and L9 showed significant desirable negative GCA effects for all the three maturity parameters *i.e.*, days to 50% tasseling days to 50% silking and days to 75% dry husk to emerge as good general combiner for early maturity and to serve as valuable donor parents for earliness in further breeding programme. Many workers such as Talukder *et al.* (2016), Darshan and Marker (2019), Sabitha *et al.* (2021) have also reported similar findings.

The best general combiner having desirable highly significant positive GCA effects for grain yield per plant (g), L1 (35.772), L6 (25.957), L14 (13.953), L17 (10.569) and L18 (9.108) may serve as donor parents in further breeding programme for grain yield improvement in maize. Similar findings have also been reported by Singh *et al*. (2019), Bhusal and Lal, (2020) and Sabitha *et al.* (2021).

The estimates of SCA effects and standard heterosis for all the studied characters are presented in **Table 4.** The top five hybrids having desirable negative and highly significant SCA effects for days to 75% dry husk were L1xT1 (-7.093), L18xT3 (-5.130), L9xT3 (- 4.019), L15xT2 (-3.111) and L2xT3 (-3.019).This suggested that the parents involved in the above cross combinations may be utilized for complete exploitation of heterosis and development of best heterotic hybrids for early maturity. Similar findings have also been reported by Talukdar *et al.* (2016), Bhusal and Lal, (2020).

The top five hybrids having desirable positive and highly significant SCA effects for grain yield per plant were L5xT1 (41.384), L9xT3 (39.596), L8xT3 (32.986), L17xT2 (31.235) and L2xT1 (29.451). This suggested that the parents involved in the above specific cross combinations may be utilized in heterosis breeding for development of high yielding single cross hybrids. Earlier workers such as Ejigu *et al.* (2017), Singh *et al.* (2019) and Ali *et al.* (2019) have also reported similar results.

In the present study standard heterosis was studied with respect to superiority or inferiority of hybrids over the better check Don 1588 . Top five hybrids that showed highly significant standard heterosis in desirable direction for days to 75% dry husk were L1xT1 (-5.79 %), L15xT2 (-5.39 %), L9xT3 (-4.99 %), L18xT3 (-3.99 %) and L16xT1 (-3.99 %). These hybrids may be commercialized as early maturing maize hybrids after confirmation of their suitability for commercial cultivation. Good level of negative heterosis for maturity traits in maize genotypes have also been reported by Rajitha *et al.* (2014), Talukdar *et al.* (2016), Bhusal and Lal, (2020). The top five hybrids that showed highly significant standard heterosis in desirable direction for grain yield per plant were L1xT1 (51.26 %), L2xT1 (32.88 %), L5xT1 (31.11 %), L6xT2 (30.44 %) and L8xT3 (29.68 %). Among these hybrids, L2xT1 L6xT2 L1xT1 had significant standard heterosis in desirable direction for 100-kernel weight also, indicating that these hybrids may be commercialized as high yielding and bold seeded maize hybrids after confirmation of their suitability for commercial cultivation. Good heterotic potential for grain yield and related traits in maize genotypes has also been reported by Rajitha *et al.* (2014), Singh *et al.* (2019), Ali *et al*. (2019) and Sabitha *et al.* (2021).

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