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Diallel analyses and heterosis of some agronomic traits in maize (*Zea Mays* L.)

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Abstract

The investigation was carried out on gene action and combining ability in quantitative traits of crosses of 7 diverse maize inbred lines in a full diallel mating design. Forty two F_1 progenies along with their parents and checks were planted in randomized complete block design with three replications in two spring environments (January, 2016 and March, 2016). Pooled analysis of variance revealed that all the genotypes were found to be highly significant mean squares due to GCA, SCA, RSCA and their interactions with environments for all the characters except due to reciprocal x environment for 500-seed weight. Variance due to GCA was more than variance due to SCA and reciprocal for the characters viz., days to 50% silk, pollen viability, anthesis-silking interval, cell membrane thermo stability, days to 50 per cent physiological maturity, grain filling period, grains per plant, 500-seed weight and shelling percentage and it indicated that these characters were controlled by additive gene action. Variance due to SCA was more than variance due to GCA and reciprocal for the characters, namely, days to 50 % anthesis, plant height, ear height, grain yield per plant and it indicated that these characters were controlled by non-additive gene action. The parent CML 411 was found to be good general combiner for grain yield per plant, whereas, parents CML 164, CML 304, CML 306, and CML 307 were found to be average combiners for grain yield. The cross CML 411 (P_2) x CML 307 (P_7) was found to be the best experimental hybrid on the basis of SCA, GCA and standard heterosis for grain yield over the environments.

Keywords: Diallel analysis, Heterosis, *Zea mays* L.

Introduction

Maize (*Zea mays* L.) is considered as a queen of cereals and par excellence in terms of food, feed, fodder, bio-fuel and industrial raw materials. In India and Bihar, maize is third important cereal crop after rice and wheat. In India, maize is being grown on an area of 8.69 million hectares with annual production of 21.81 million tonnes and average grain yield of 2509 kg ha^{-1} (Anonymous, 2016). 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 (Anonymous, 2017). Diets are projected to continue to become more affluent and the need for maize as animal feed is expected to increase as more of the population becomes able to afford eggs, milk and meats (Msangi and Rosegrant, 2011). Hence, the only way to meet this demand is intensification of cropping systems and enhancement in productivity, which will be full fill by obtaining new hybrids with high genetic potential for yield and positive features that exceed the existing commercial hybrids. Diallel crosses have been widely used in plant breeding to investigate combining abilities of the parental lines in order to identify superior parents for use in hybrid development programmes. Heterosis provides information about superiority of cross over the parents. The standard heterosis is of interest to the maize breeder because heterosis can be exploited only, if hybrids are commercially feasible for seed production as well as acceptance of the growers. Besides gene effects, breeders would also like to know how much of the variation in a crop is genetic and to what extent this variation is heritable, because efficiency of selection mainly depends on additive genetic variance, influence of the environment and interaction between genotype and environment (Novoselovic *et al*., 2004). Large genotype × environment effects tend to be viewed as problematic in breeding programme, because the lack of a predictable response hinders progress from selection. The objectives of the present study were to determine general and specific combining ability of inbred lines and crosses, respectively and to estimate heterosis of crosses of inbred lines over two environments in order to determine superior inbred lines and cross combinations.

Materials and Methods

The experiment was conducted at Maize Section of Bihar Agricultural College of Bihar Agricultural University, Sabour, Bhagalpur, Bihar-813210 (India). The seven inbred lines were crossed in a diallel fashion including reciprocal 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 lines [CML 164 (P_1) and CML 25 (P_5)]. The forty two F_1's crosses and seven parental lines along with two checks (DHM-117 and SHM-2) were evaluated in two environments in randomized complete block design with three replications in two rows of five metre length with 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 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. Average minimum and maximum air temperature at flowering time was 15.90 ºC and 31.78 ºC in normal condition; and 23.35ºC and 35.83ºC in heat stress condition, respectively. The data were recorded on ten competitive plants, which were randomly taken from each plot in each replication, for the characters, namely, pollen viability, cell membrane thermo stability, days to 50 per cent physiological maturity, plant height, ear height and number of grains per plant. The characters, namely, days to 50 per cent anthesis, days to 50 per cent silk, period shelling per cent and grain yield per plant were recorded on the plot basis. The anthesis-silking interval was calculated as difference between days to 50 per cent silk and days to 50 per cent anthesis. The 500-seed weight was recorded from the sample of bulk seeds from each plot and each replication. Pollen viability was counted by the method given by Chelong and Sdoodee, 2012 and Cell membrane thermo stability was estimated by the method as given by C.Y. Sullivan (University of Nebraska) in the late 1960's. The mean data of each genotype were subjected to statistical analyses of combining ability analysis as given by Griffing 1956 (b) that is method 1and model 1 (fixed effect model). The statistical t-student test was applied to examine the effects GCA and SCA.

Results and Discussion

The results of pooled analysis of variance (Table1) revealed significant mean squares due to general combining ability (GCA), specific combining ability (SCA), reciprocal combining ability (RSCA), environments, GCA x environments, SCA x environments, reciprocal x environment for all the characters studied, except due to reciprocal x environment for 500-seed weight. It indicated that all the genotypes were found to be highly significant mean squares due to GCA, SCA, RSCA and their interactions with environment for all the characters except for 500-seed weight (Devi, 2012, Estakhr *et al.*, 2012 and Haddadi *et al.*, 2014).

Pooled estimates of components of variance (Table2) revealed that variance due to GCA was more than variance due to SCA and reciprocal for the characters viz., days to 50% silk, pollen viability, anthesis-silking interval, cell membrane thermo stability, days to 50 per cent physiological maturity, grain filling period, grains per plant, 500-seed weight and shelling percentage and it indicated that these characters were controlled by additive gene action. Variance due to SCA was more than variance due to GCA and reciprocal for the characters, namely, days to 50 % anthesis, plant height, ear height, grain yield per plant and it indicated that these characters were controlled by non-additive gene action. These findings were supported by Haddadi *et al.* (2014) for days to early silking, plant height, and kernel yield but they contradicted for ear height, where GCA was more important. Hefny (2010) supported the same result for days to 50 per cent tassel, 100-grain weight and yield per plant while, he contradicted for days to 50 per cent silk, number of rows per ear and grains per row, where SCA was more important.

General combining ability

In the estimates of pooled general combining ability analysis (Table3), parent CML 411 was found to be good general combiner for grain yield per plant. It was also found to be good general combiner for shelling per cent, 500-seed weight, grains per plant, grain filling period, short ear height, short plant height, CMT, pollen viability, early silk and anthesis. The parents, namely, CML 164, CML 304, CML 306, and CML 307 were found to be average combiners for grain yield. Parent, CML 164 was also found to be good general combiner for early days to 50 per cent anthesis, early days to per cent silk, early days to 50 per cent physiological maturity and grains per plant. Parent, CML 304 was also found to be good general combiner for early days to50 per cent silk, lower anthesis-silking interval, early days to 50 per cent physiological maturity and 500-seed weight. Parent, CML 306 was also found to be good general combiner for early days to 50 per cent anthesis, early days to 50 per cent silk, cell membrane thermo stability, lower ear height, grain filling period, grains per plant and shelling per cent. Parent CML 307 was also found to be good general combiner for pollen viability per cent, cell membrane thermo stability, lower plant height, lower ear height, grains per plant and shelling per cent. Abuali *et al.* (2012) also found same result for most of the traits.

Specific combining ability

The estimates of pooled specific combining ability effects of crosses over the two environments for the different traits are presented in table 4. In the pooled analysis, crosses, namely, P_1 x P_4, P_2 x P_7, P_2 x P_3, P_5 x P_7 and P_1 x P_7 were found to be top five good specific combinations for grain yield per plant. Cross P_1 x P_4 was also found to be good specific combination for shelling per cent, 500-seed weight, grains per plant, grain filling period, shorter ear height and CMT. Cross P_2 x P_7 was also found to be good specific combination for grains per plant, CMT, early silk and early anthesis. Cross P_2 x P_3 was also found to be good specific combination for grains per plant and grain filling period. Cross P_5 x P_7 was also found to be good specific combination for 500-seed weight and grains per plant. Cross P_1 x P_7 was also found to be good specific combination for grains per plant, early physiological maturity, CMT, early silk and early anthesis. These crosses, namely, P_1 x P_4 involved average x average general combining parents; P_2 x P_7, involved high x average general combining parents;P_2 x P_3 involved high x low general combining parents; P_5 x P_7 involved low x average general combining parents and P_1 x P_7 involved average x average general combining parents. Hence, the crosses, CML 411 (P_2) x CML 307 (P_7) and CML 411 (P_2)x CML 305 (P_3)were identified as the promising experimental hybrids, having high specific combining ability and high general combining ability for at least seed parent for grain yield(Cruz and Regazzi, 1997 and Akbar *et al.*,2009).

Reciprocal specific combining ability effects

In the pooled estimates of reciprocal specific combining effects (Table5), crosses, namely, P_4 x P_1 and P_3 x P_2 were found to be top good reciprocal specific combinations for grain yield per plant. Cross P_4 x P_1 was also found to be good reciprocal specific combination for grains per plant, lower anthesis-silking interval and early silk. Cross P_3 x P_2 was also found to be good reciprocal specific combination for 500-seed weight. These crosses, namely, P_4 x P_1 involved average x average general combining parents andP_3 x P_2 involved low x high general combining parents. Hence, none of the cross was identified as the promising experimental hybrids due to average/low general combining ability for seed parent(Cruz and Regazzi, 1997 and Akbar *et al.*,2009).

Heterosis

The pooled standard heterosis was estimated over the best check SHM-2 for grain yield per plant. In the pooled heterosis (Table 6), cross P_2 x P_7 was found to be the first rank for standard heterotic combinations for grain yield per plant, whereas, P_2 x P_7 was found to be second rank for shelling per cent and CMT, third rank for early physiological maturity and seventh rank for grain filling period and short ear height. These results were supported by Rashmi (2012) for most of the characters. In pooled heterosis of reciprocal crosses (Table 7), cross P_4 x P_1 was found to be the first rank for standard heterotic combinations of reciprocal crosses for grain yield per plant. P_4 x P_1 was also found to be first rank for short ear height and CMT, second rank for shelling per cent, sixth rank for short plant height and seventh rank for grain filling period.

Table 1: Pooled analysis of variance for combining ability for days to 50 per cent anthesis, days to 50 per cent silk, pollen viability, anthesis-silking interval, cell membrane thermo stability, plant height and ear height in maize over two environments

Source of variation	d.f.	Mean Squares						
		Days to 50 per centanthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silkinginterval	Cell membrane thermo stability	Plant height	Ear height
GCA	6	13.05**	13.45**	111.87**	0.46**	59.94**	122.21**	132.80**
SCA	21	12.27**	11.51**	75.12**	0.32**	42.33**	724.69**	149.68**
Reciprocal	21	2.23**	2.98**	87.56**	0.21**	38.72**	29.29**	46.91**
Environments	1	3801.09**	3112.98**	73676.81**	25.51**	5482.54**	26671.70**	11483.34**
GCA*Environments	6	4.59**	2.71**	82.03**	0.12*	7.30**	19.00**	11.45**
SCA*Environments	21	2.01**	1.67**	41.01**	0.11*	7.07**	7.16**	19.11**
Reciprocal*Environments	21	0.93**	0.89**	64.76**	0.12**	9.49**	8.78**	6.41**
Error	192	0.32	0.36	0.70	0.06	0.62	2.53	1.81

*, ** Significant at 5 % & 1 % level of probability, respectively.

Contd. table 1: Pooled analysis of variance for combining ability for days to 50 per cent physiological maturity, grain filling period, grains per plant, 500-seed weight, shelling per cent and grain yield per plant in maize over two environments

Source of variation	d.f.	Mean Squares					
		Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
GCA	6	51.89**	34.03**	11510.90**	1140.07**	80.53**	634.29**
SCA	21	6.42**	18.74**	9172.80**	614.72**	42.30**	1083.88**
Reciprocal	21	3.10**	4.68**	1376.46**	54.42**	8.58**	171.34**
Environments	1	7626.13**	979.56**	508320.03**	2418.44**	5192.29**	39654.64**
GCA*Environments	6	4.64**	2.88**	1133.87**	35.70**	46.94**	214.81**
SCA*Environments	21	3.93**	1.71**	1494.08**	54.76**	46.91**	116.10**
Reciprocal*Environments	21	2.09**	1.01**	1525.60**	3.91	2.40**	92.80**
Error	192	0.55	0.56	217.99	4.50	1.06	12.26

*, ** Significant at 5 % & 1 % level of probability, respectively.

Table 2: Pooled estimates of components of variance for thirteen quantitative characters in maize over two environments

Components	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
$\sigma^2 g$	2.73	2.80	23.82	0.09	12.71	25.65	28.07	11.00	7.17	2419.91	243.34	17.03	133.29
$\sigma^2 s$	2.91	2.69	18.43	0.05	10.27	179.91	36.51	1.33	4.40	2184.21	151.43	10.04	264.84
σ^2 reciprocal	0.09	0.12	4.14	0.01	1.81	1.27	2.15	0.12	0.20	55.17	2.38	0.36	7.58
$\sigma^2 g / \sigma^2 s$	0.94	1.04	1.29	1.71	1.24	0.14	0.77	8.28	1.63	1.11	1.61	1.70	0.50

Table 3: Pooled estimates of GCA effects of parents for thirteen quantitative characters in maize over two environments

Sl No.	Entry	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
1.	CML-164(P1)	-0.889**	-0.769**	-3.079**	0.077	0.425	0.320	1.148*	-2.104**	-1.359**	23.087**	-7.136**	-2.678**	2.131
2.	CML-411(P2)	-0.901**	-0.876**	4.623**	0.136*	0.794*	-4.695**	-5.900**	0.920**	1.772**	17.194**	13.554**	2.264**	13.821**
3.	CML-305(P3)	1.301**	1.446**	0.076	0.112	-3.134**	2.474**	2.922**	2.146**	0.760**	-18.199**	-1.657*	0.703	-5.595**
4.	CML-304(P4)	0.704**	-0.388*	-1.469	-0.340**	-1.122**	2.186**	2.946**	-1.306**	-0.942**	-22.842**	5.135**	-0.342	-2.179
5.	CML-25(P5)	-0.437*	-0.221	-3.040**	0.172**	-1.658**	0.143	1.005*	-2.532**	-2.252**	-46.199**	7.993**	-3.778**	-6.048**
6.	CML-306(P6)	-0.568**	-0.543**	0.576	-0.114	2.247**	2.886**	-1.459**	1.206**	1.724**	26.194**	-8.255**	1.907**	-0.238
7.	CML-307(P7)	1.325**	1.350**	2.314**	-0.043	2.449**	-3.314**	-0.662	1.670**	0.296	20.765**	-9.634**	1.923**	-1.893
	S.E. (gi)	0.196	0.189	0.852	0.065	0.361	0.488	0.492	0.257	0.215	5.346	0.767	0.623	1.431
	C.D. at 5 %	0.480	0.462	2.086	0.161	0.884	1.195	1.206	0.630	0.528	13.083	1.879	1.524	3.502

*, ** Significant at 5 % & 1 % level of probability, respectively.

Table 4: Pooled estimates of SCA effects for thirteen quantitative characters in maize of positive significant crosses for grain yield per plant over two environments

Sl No.	Entry	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
1	P_1 x P_2	0.116	0.352	-2.814	0.054	-4.401 **	9.276 **	-1.029	-2.420 **	-2.748 **	24.092 **	12.184 **	3.143*	13.810 **
2	P_1 x P_4	-0.706	-0.219	0.111	0.197	6.182 **	0.853	-6.957 **	4.389**	4.633 **	82.628 **	16.269 **	5.682**	32.476 **
3	P_1 x P_7	-1.861 **	-1.874 **	-3.087	-0.017	3.027 **	14.028 **	8.066 **	-2.087**	-0.189	66.770 **	3.205	0.300	14.190*
4	P_2 x P_3	-0.825	-0.446	3.365	0.185	-1.259	12.439 **	1.614	1.663*	2.049 **	93.128 **	-1.878	-0.204	17.083 **
5	P_2 x P_6	-1.039*	-0.457	5.198*	0.495**	3.694 **	11.211 **	7.412 **	2.520 **	3.002 **	20.735 **	5.469 **	-0.516	10.262 **
6	P_2 x P_7	-1.265*	-1.017*	-7.873 **	0.090	2.158*	12.502 **	6.864**	0.639	1.680	53.663 **	2.181	-0.650	22.952 **
7	P_3 x P_5	-1.789 **	-1.600 **	0.528	0.150	-3.306 **	10.876 **	5.043 **	0.116	2.156 **	10.270 **	10.600 **	1.704	8.321*
8	P_3 x P_6	-0.575	-0.862	-7.087 **	-0.065	-2.378 **	6.508 **	2.090	0.461	1.264	34.628 **	3.765 **	0.569	12.595 **
9	P_4 x P_5	-0.408	-0.434	-5.403*	-0.315	-2.735 **	13.289 **	7.352 **	-1.682**	-1.308	41.163 **	8.807 **	3.591*	7.655*

10	P_5 x P_6	-0.503	-0.529	-0.305	0.043	3.980**	9.214**	1.173	0.389	0.859	36.628**	3.115	1.659	12.631**
11	P_5 x P_7	-0.730	-0.672	-3.543	0.054	0.611	7.822**	3.543**	-0.158	0.454	35.306**	8.493**	1.717	14.619**
	S.E. (sij)	0.487	0.469	2.116	0.163	0.896	1.212	1.224	0.639	0.536	3.630	1.906	1.547	3.554
	C.D. at 5 %	1.017	0.979	4.416	0.341	1.871	2.530	2.553	1.334	1.119	7.550	3.977	3.227	7.414

*, ** Significant at 5 % & 1 % level of probability, respectively.

Table 5: Pooled estimates of reciprocal SCA effects for thirteen quantitative characters in maize of positive significant crosses for grain yield per plant over two environments

Sl No.	Entry	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
1	P_3 x P_2	0.167	0.583	-13.750**	0.417*	0.667	1.717	-1.750	-0.833	-1.417*	-24.500**	10.000**	2.258	2.083**
2	P_4 x P_1	-0.833	-1.250*	-7.250**	-0.417*	-7.917**	1.842	14.417**	-0.083	1.167	51.250**	-10.083	-4.725**	24.833**
	S.E. (Rij)	0.560	0.540	2.436	0.188	1.031	1.395	1.408	0.736	0.617	4.175	2.193	1.780	4.090
	C.D at 5 %	1.169	1.126	5.081	0.392	2.152	2.911	2.938	1.535	1.287	8.684	4.576	3.713	8.531

*, ** Significant at 5 % & 1 % level of probability, respectively.

Table 6: Pooled standard heterosis of crosses for thirteen quantitative characters in maize of positive significant crosses for grain yield per plant over two environments

Sl No.	Entry	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
1	P_2x P_7	3.33**	2.96**	5.83	-6.67**	12.22**	-11.32**	-10.31**	9.62**	24.86**	17.72*	-8.67*	2.19	10.13*
	S.E. (d)	1.12	1.08	4.87	0.37	2.06	2.79	2.81	1.47	1.23	8.35	4.38	1.45	4.95
	C.D. at 5 %	2.33	2.25	10.16	0.78	4.30	5.82	5.87	3.07	2.57	17.36	9.15	2.87	17.06
	C.D. at 1 %	2.91	2.80	12.65	0.97	5.35	7.24	7.31	3.82	3.20	23.63	11.39	3.79	21.23

*, ** Significant at 5 % & 1 % level of probability, respectively.

Table 7: Pooled standard heterosis of reciprocal crosses for thirteen quantitative characters in maize of positive significant crosses for grain yield per plant over two environments

Sl No.	Entry	Days to 50 per cent anthesis	Days to 50 per cent silk	Pollen viability per cent	Anthesis-silking interval	Cell membrane thermo stability	Plant height	Ear height	Days to 50 per cent physiological maturity	Grain filling period	Grains per plant	500-seed weight	Shelling per cent	Grain yield per plant
1.	P_4 x P_1	3.33**	3.21**	8.61	0.00	15.28**	-12.66**	-34.43**	6.53**	14.12**	24.05**	-3.00	7.38**	30.22**
	S.E. (d)	1.12	1.08	4.87	0.37	2.06	2.79	2.81	1.47	1.23	8.35	4.38	1.45	4.95
	C.D. at 5 %	2.33	2.25	10.16	0.78	4.30	5.82	5.87	3.07	2.57	17.36	9.15	2.87	9.76
	C.D. at 1 %	2.91	2.80	12.65	0.97	5.35	7.24	7.31	3.82	3.20	23.63	11.39	3.79	12.88

*, ** Significant at 5 % & 1 % level of probability, respectively

Conclusion

In present investigation, Parents CML 411 was found to be good general combiner for grain yield per plant, whereas, CML 164, CML 304, CML 306 and CML 307were found to be average general combiners for grain yield in pooled analysis. The best experimental hybrid was identified on the basis of SCA, GCA and standard heterosis for grain yield in pooled analysis was CML 411(P2) x CML 307(P7) .

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