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Original Research Article

Combining Ability Analysis Using Diallel Mating Design in Inbred Lines of Maize (*Zea mays* L.)

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Diallel, Combining ability, *gca*, *sca*.

A B S T R A C T

Analysis of variance showed that mean squares were highly significant for traits such as grain yield, 100 grain weight, days to 50% tasseling and silking, plant and ear height, ear length, ear girth, cobs/plot etc. High heritability coupled with high genetic advance was recorded for the traits plant height and ear height that depicts the existence of additive gene effects. The analysis of variance for combining ability revealed that mean squares were significant for almost all the characters. Variance due to *sca* was greater than *gca* variance for the traits viz., plant height, ear height, number of kernels row/cob, number of kernels/row, ear length, cob yield and grain yield, which indicated the preponderance of non-additive gene effects in the genetic expression of these traits. The parents/inbred lines DMR 11 R 0144, Z 491-17 and IAMI-85 were found good general combiner. Experimental hybrids obtained with high specific combining ability (SCA) effect were DMR 11 R 0144/Z 491-17, Z 491-17/ IAMI – 85, IAMI-9/ IAMI – 85, IAMI-1/ Z 485-4, IAMI-1/Z 491-3 , IAMI-1/Z 491-17, CAL 1454/Z 485-4. Hybrids Z 491-17/ IAMI- 85, DMR 11 R 0144 / Z 491-17 and IAMI-9/ IAMI- 85 have shown 27.77%, 25.62% and 24.20% standard heterosis respectively against best check in NK-30 in trial.

Introduction

Maize is the third most important cereal crop after wheat and rice in India. Worldwide maize is cultivated on over 185 million hectares in 170 countries with a productivity of 5.62 t/ha. It belongs to the crop family called *Poaceae*. Maize is a vital cereal crop for global food security, as its importance is seen in the wide economic uses ranging from direct human consumption to processing into other food materials, animal feeds, and industrial products. This cereal is referred as “Miracle crop” and “Queen of the Cereals” due to its high productivity potential compared to other poaceae family members. India ranks fourth in area and sixth in the production. The productivity of maize in India (3.1 t/ha) is much lower than the world average. Currently India produces over 28 million MT of maize, of which roughly 60% is used as feed (poultry and animal feed), 14% for industrial purposes, around 13% for food, 7% as processed food and 6% for other purposes including seed. Increasing demand for maize particularly in feed industry has contributed towards increased production. By 2025 India is projected to require about 32 million MT of maize solely in feed industry (Rakshit *et al.,* 2020).

In spite of the significant progress of maize breeding to date, continued investments in this area to enhance productivity, agronomic fitness, and adaptation to climate change continue to be critical for sustaining agricultural growth and food security, improving nutritional quality, and securing harvests. These breeding efforts have led to the generation and supply of diverse maize varieties, parental inbred lines, and hybrids of different maturity groups, grain colors, and types that evidenced both high yield potential and resistance to major diseases that are prevalent in the region. Various types of biometrical techniques are extensively used in crop improvement programmes for evaluating inbred lines in terms of genetic component of variance. Diallel mating design is used to evaluate several inbred lines in terms of combining ability variances and effects. The approach of diallel analysis was developed by Griffing in 1956.

Materials and Methods

The experiment was conducted at Research-cum-instructional farm Ajirma, IGKV, RMD CARS, Ambikapur (C.G.) in Randomized Complete Block Design (RCBD) involving ten inbreds and their forty-five direct crosses with three replications during *Rabi* 2016-17, which is located at a latitude of $20^0$8'N, longitude of $83^0$15'E and altitude of 592.62 m MSL (mean sea level) for estimation of combining ability effects (GCA & SCA) in maize. Each genotype was grown in two rows of 4m length. The spacing of 75 cm X 20 cm was adopted between row and within row, respectively. All the recommended agronomic package of practices was adopted during the entire crop growth period. Observations were recorded following standard procedure. Five plants in each replication were taken randomly for this purpose. 15 quantitative characters *viz.*,days to 50 % tasselling, days to 50 % silking, days to 80 % brown husk maturity, plant height (cm), plant population, ear height (cm), ear length (cm), ear diameter (cm), number of kernel rows per cob, number of kernels per row, number of cobs per plot, test weight (g), shelling percentage and grain yield q/ha were recorded. Data were analyzed for combining ability following approach 2 (Griffings, 1956).

Results and Discussion

Analysis of variance

Analysis of variance (ANOVA) as per the RCBD showed that mean sum of squares were highly significant for all the characters of genotypes (Table – 1). This means the genotypes differ significantly for these traits and also it is a pre-requisite for the ANOVA for combining ability analysis.

Genetic parameters

Genetic parameters such as genetic variability, heritability and genetic advance as percentage of mean were summarized in Table - 2.

Genetic variability

High phenotypic and genotypic coefficient of variation were recorded for traits *viz.*, grain yield in kg per plot (35.21% and 24.44%) followed by cobs yield per plot (kg) (33.66 % and 23.36 %), number of kernels row/cob (28.18% and 10.53%), ear height (cm) (22.38 % and 19.22 %), ear length (cm) (21.18 % and 20.53 %). Moderate phenotypic and genotypic coefficients of variation were recorded for traits *viz.*, No. of kernels/row (18.17% and 16.88%), 100g weight (16.20 % and 16.05 %), plant height (cm) (15.99 % and 14.84 %) and ear girth (cm) (12.09 % and 10.71 %). Low phenotypic and genetic coefficient of variation were recorded for traits *viz.*, final plant stand (9.31 % and 6.73 %), cobs per plot (9.30 % and 6.53 %), shelling percentage (4.58% and 4.14%), Day to 50% tasseling (4.23 % and 3.87 %), Day to 50% silking (3.95 % and 3.56 %) and Day to 50 % maturity (2.94 % and 2.46 %).

Heritability

Among the characters studied, high heritability estimates were recorded for all the characters *viz.*, test weight (98.20), ear length (88.60), days of tasseling (84.00), shelling percentage (81.70) and days of silking (81.00) etc. High heritability indicates the scope of genetic improvement of these characters through selection. This is because of there should be a close correspondence between genotype and phenotype due to relatively smaller contribution of the environment.

Genetic advance

Genetic advance is a measure of genetic gain under selection. The cob yield recorded the highest genetic advance as percentage of mean (86.84 %), grain yield per plot (82.30 %), ear length (52.93%), No. of kernels/row (39.44), 100 grain weight (35.17 %), plant height (33.71) ear height (cm) (30.51%), ear girth (21.98%). Rest of the traits showed low genetic advance as percentage of final plant stand (10.34%), No. of cobs/plot (9.74%), No. of kernels rows/cob (9.24%), shelling percentage (8.27%), day to 50% pollen shed (7.12 %), day to 50% silking (6.38 %) and day to 80% maturity (4.15 %).

The results (Table - 2) revealed that GCV’s were not much differ with their respective PCV’s, indicating the less influence of the environment on the expression of the traits. Relatively higher estimates of GCV for grain yield/plot, cob yield/plot, ear length, ear height number of kernels/row and test weight suggest that the selection can be effective for these traits. Almost all the traits had high heritability estimates indicating to preponderance of additive gene action except number of kernels/row. High heritability coupled with high genetic advance was recorded for the traits plant height, ear height and number of kernels/row that depict the additive gene effects. Thus such characters should be improved through selection. Most of these findings are in harmony with those obtained by Devi *et al.*, (2001), Sofi and Rather (2007), Rafiq *et al.*, (2010) and Wannows *et al.*, (2010).

Combining ability

Data recorded on forty-five hybrids and ten inbred lines was used for combining ability analysis using diallel mating design. The results of the combining ability analysis are summarized in table – 3, 4 & 5.

The GCA and SCA effects are the main criteria used for selection and classification of parents in terms of their potential performance in various cross combinations. The parameter days to 50% tasseling is a very good indicator for earliness. Many crosses are found very good in comparison to check. Inbred lines IAMI 9 (-1.86), IAMI 1 (-1.47), WNC DMR 11 R 0144 (-1.47) and Z 485-4 (-1.19) had significant negative GCA effects. These can be combined to generate early maize synthetic or hybrid varieties.

Estimates of GCA effects for grain yield showed that out of the 10 inbred lines studied in diallel mating design 06 exhibited positive GCA effects while 04 lines exhibited negative. Among the lines, WNC DMR 11 R 0144 (0.21), Z 491-17 (0.19) and IAMI-85 (0.14) showed positive significant GCA effects. The positive GCA effects indicate their usefulness in breeding for higher grains yield/plot in lines. These lines are also good combiner for many traits.

Table.1 Analysis of variance for grain yield and its component in maize

SN	Characters	Mean Sum of squares		
		Replication	Genotypes	Error
		2	54	108
1	Day to 50% Pollen Shed	9.24	40.24**	3.40
2	Day to 50% Silking	10.67	37.96**	3.64
3	Day to 80% Maturity	9.38	24.55**	5.84
4	Final Plant Stand	5.46	22.27**	3.36
5	No. of Cobs/Plot	2.26	20.71**	5.52
6	Plant height (cm)	200.76	3322.62**	174.26
7	Ear height (cm)	132.23	894.86**	101.17
8	Ear length (cm)	2.26	35.79**	1.42
9	Ear girth (cm)	0.32	9.11**	0.66
10	No. of kernel row/cob	1.63	21.85*	14.75
11	No. of kernels/row	7.33	102.06**	5.09
12	100 grain Weight (gm)	1.23	65.19**	0.44
13	Shelling Percentage (%)	2.49	35.47**	2.33
14	Cob Yield/Plot (kg)	0.66**	10.49**	0.27
15	Grain Yield/Plot (kg)	0.96**	7.04**	0.36

*=significant of p=0.05 level **= significant of p=0.01 level

Table.2 Parameters of Genetic variability for different characters in maize

Characters	Mean	Range		PCV %	GCV %	h^2	GA	GA as % of mean
		Minimum	Maximum					
Days to tasseling	103.71	92.00	110.66	4.23	3.87	84.00	7.34	7.12
Days to silking	107.87	95.00	114.67	3.95	3.56	80.90	6.89	6.38
Days to maturity	149.93	140.67	159.00	2.94	2.46	69.90	6.23	4.15
Final plant stand	35.00	31.67	40.00	9.31	6.73	52.30	3.62	10.34
No. of cobs/plot	34.29	31.00	39.33	9.30	6.53	49.20	3.34	9.74
Plant height	182.42	125.30	258.13	15.99	14.84	86.10	61.51	33.71
Ear height	95.19	39.60	109.80	22.38	19.22	73.80	29.05	30.51
Ear length	12.28	7.80	22.30	21.81	20.53	88.60	6.50	52.93
Ear girth	13.37	11.10	16.30	12.09	10.71	78.40	2.94	21.98
No .of kernels rows/cob	12.33	10.40	14.70	28.18	10.53	14.00	1.14	9.24
No. of kernels/row	26.85	12.50	38.00	18.17	16.88	86.20	10.59	39.44
Test weight	27.35	15.30	39.50	16.20	16.05	98.20	9.62	35.17
Shelling percentage	71.90	66.70	79.13	4.58	4.14	81.70	5.95	8.27
Cob yield	3.04	1.64	6.03	33.66	23.36	69.39	2.64	86.84
Grain yield	2.26	1.10	4.66	35.21	24.44	69.41	1.89	82.30

Table.3 ANOVA for Diallel and Combining Ability Analysis

SOURCE OF VARIANCE	df	DT	DS	DM	FPS	Cobs/Pt	PH	EH	EL	EG	NKRPC	NKPR	100 g wt	SH %	Cob Y/P	GY/Plot
GENOTYPE	54	40.24**	37.96**	24.55**	22.27**	20.71**	3322.62**	894.86**	35.79**	9.11**	21.85*	102.06**	65.19**	35.47**	10.49**	7.04**
REP	2	9.24	10.67	9.38	5.46	2.26	220.76	132.23	2.26	0.32	1.63	7.33	1.23	2.49	0.66	0.96
GCA	9	32.95**	32.20**	17.33**	10.97**	10.82**	861.53**	272.06**	2.02*	6.22**	4.18**	25.98**	57.58**	0.68	0.61	0.36
SCA	45	9.78**	8.78**	6.34**	6.71**	6.12**	1156.76**	303.53**	13.91**	2.39*	7.90**	35.62**	14.56**	14.05**	4.07**	2.74**
ERROR	108	1.00	1.11	1.94	1.78	1.84	58.08	33.72	0.47	0.22	4.90	1.69	0.14	0.77	9.20	5.50
CV%		1.69	1.72	1.61	6.42	6.62	5.96	11.46	7.34	5.61	26.13	6.74	2.19	1.95	9.52	9.43

*=significant of p=0.05 level **=significant of p=0.01 level

DT - Days to 50% tasseling, DS - Days to 50% silking, DM - Days to 80% maturity, FPS - Final plant stand, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EG - Ear girth (cm), Cobs/Plot - Number of cobs per plot, NKRPC - Number of kernel rows per cob, NKPR - Number of kernels per row, 100 g wt - Test weight , SH %- Shelling percentage (%), Cob Y/Plot- Cob yield (kg/plot),GY/Plot - Grain yield (kg/plot).

Table.4 General Combining Ability effects of Parents for grain yield and its components in maize

Characters	DT	DS	DM	FPS	Cobs/Pt	PH	EH	EL	EG	NKRPC	NKPR	100 g wt	SH %	Cob Y/P	GY/Plot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14.00	15
Parents															
WNC DMR 10RYFWS 8105	2.06**	1.91**	-0.27	-0.99**	-1.02**	-10.58**	-3.92*	0.39*	-0.23	-0.20	-0.97**	-1.38**	0.14	-0.24**	-0.19**
WNC DMR 19 RYDWS 1247	0.56*	0.47	-1.21**	-1.08**	-0.93*	6.74**	4.95**	-0.39*	0.51**	-0.33	-3.05**	0.46**	-0.07	-0.20*	-0.14*
WNC DMR 11 R 0144	-1.47**	-1.23**	0.82*	0.67	0.87*	-7.35**	-3.96*	-0.66**	-0.40**	0.55	-0.94**	-1.38**	0.36	0.25**	0.21**
CAL 1454	-0.66*	-0.56*	-0.57	-1.02**	-1.10**	11.88**	6.45**	0.42*	-0.87**	-0.68	1.78**	-3.43**	-0.04	-0.40**	-0.31**
IAMI-9	-1.86**	-1.95**	-1.41**	-0.19	-0.41	-10.97**	-6.34**	-0.53**	0.31*	-0.23	-0.49	2.09**	-0.26	0.04	0.02
IAMI-1	-1.47**	-1.51**	-0.85*	-0.33	-0.27	-0.59	2.41	0.13	0.15	0.02	1.76**	1.58**	-0.10	0.01	0.01
Z 485-4	-1.19**	-1.39**	-0.77*	1.09**	1.04**	2.33	-0.95	0.08	0.40**	1.16	1.20**	3.80**	-0.30	0.17*	0.11
Z 491-3	-0.24	0.05	0.62	-0.49	-0.38	-6.09**	-5.83**	0.17	-1.03**	-0.74	-0.16	-2.41**	0.35	-0.09	-0.05
Z 491-17	1.28**	1.22**	1.48**	1.53**	1.54**	3.89	3.83*	-0.12	-0.27*	-0.07	0.34	0.18	-0.22	0.26**	0.19**
IAMI - 85	2.98**	2.99**	2.15**	0.81*	0.65	10.74**	3.36*	0.5**	1.42**	0.52	0.53	0.48**	0.14	0.19*	0.14*
SE (Lines)	0.27	0.28	0.37	0.36	0.37	2.08	1.59	0.18	0.12	0.6	0.35	0.10	0.24	0.08	0.06

*=significant of p=0.05 level **=significant of p=0.01 level

DT - Days to 50% tasseling, DS - Days to 50% silking, DM - Days to 80% maturity, FPS - Final plant stand, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EG - Ear girth (cm), Cobs/Plot - Number of cobs per plot, NKRPC - Number of kernel rows per cob, NKPR - Number of kernels per row, 100 g wt - Test weight , SH %- Shelling percentage (%), Cob Y/Plot- Cob yield (kg/plot),GY/Plot - Grain yield (kg/plot).

Table.5 Specific Combining Ability Effects of crosses for grain yield and its components in maize

Characters	**DT**	**DS**	**DM**	**FPS**	**Cobs/Pt**	**PH**	**EH**	**EL**	**EG**	**NKRPC**	**NKPR**	**100 g wt**	**SH %**	**Cob Y/P**	**GY/Plot**
Line	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P_1 x P_2	-1.71*	-2.66**	2.34*	2.08	1.96	13.16*	8.57	0.94	-0.48	1.07	3.81**	-2.61**	2.81**	1.24**	1.07**
P_1 x P_3	-1.68*	-1.96*	-2.02	-0.34	-0.18	11.85	1.09	2.80**	0.64	-1.01	4.03**	1.06**	1.65*	1.29**	1.07**
P_1 x P_4	-1.15	-0.96	-1.30	-3.31**	-3.20**	15.76*	0.47	1.99**	0.37	0.88	0.02	1.94**	2.08**	0.47	0.43*
P_1 x P_5	0.04	-0.57	-1.80	2.86*	2.10	26.61**	19.33**	2.21**	0.39	-0.23	2.26*	2.58**	0.83	1.24**	0.95**
P_1 x P_6	-1.35	-0.68	-0.36*	-0.34	-0.70	9.10	5.31	2.15**	1.29**	0.18	4.34**	-1.57**	1.58*	0.39	0.34
P_1 x P_7	0.38	0.54	-2.44	-6.76**	-6.01**	-3.69	3.67	0.93	0.44	-0.50	1.23	3.71**	0.88	-1.33**	-1.04**
P_1 x P_8	0.10	0.43	0.51	1.49	1.41	18.93**	10.42*	1.58**	2.47**	1.88	4.26**	-0.58	1.79*	1.00**	0.83**
P_1 x P_9	-1.76*	-2.41**	-1.36	-1.20	0.84	13.75*	2.96	2.40**	0.98*	0.00	3.42**	2.17**	0.56	1.31**	0.99**
P_1 x P_{10}	-1.12	-0.18	-1.69	-0.48	-0.62	30.77**	22.36**	1.51**	0.68	0.34	3.23**	0.19	0.67	0.65*	0.50**
P_2 x P_3	-3.51**	-3.85**	-2.41*	0.74	0.74	21.40**	10.09*	2.59**	0.32	-0.88	5.12**	6.06**	1.39	0.78**	0.61**
P_2 x P_4	-1.98*	-1.85*	0.31	0.77	1.05	6.50	5.47	1.78**	0.56	0.74	3.06**	0.61*	2.25**	1.10**	0.91**
P_2 x P_5	0.21	0.20	0.14	-0.73	-0.98	22.08**	12.46*	2.70**	1.38**	1.90	4.34**	4.58**	-0.22	0.53*	0.30
P_2 x P_6	0.49	-0.24	0.26	0.41	0.55	7.77	8.31	0.87	0.95*	0.72	3.09**	-0.40	1.89**	0.55*	0.45*
P_2 x P_7	1.88*	1.32	-1.16	-1.01	-1.09	7.79	11.67*	2.12**	1.76**	1.30	-0.36	1.04**	1.29	0.80**	0.61**
P_2 x P_8	-1.40	-1.13	-4.55**	0.91	0.32	21.21**	10.15*	0.37	-1.54**	0.14	3.01**	9.42**	2.47**	0.59*	0.81**
P_2 x P_9	-0.93	-0.63	-4.08**	-3.12**	-2.59*	15.76*	9.36	0.98	0.30	1.73	1.51	-5.50**	0.84	0.17	0.11
P_2x P_{10}	-3.29**	-3.41**	-2.08	0.94	0.96	10.51	11.83*	0.29	2.34**	1.28	5.31**	0.36	0.91	0.84**	0.65**
P_3 x P_4	-3.29**	-3.49**	-3.05**	-1.64	-1.43	6.59	7.91	1.57**	0.34	-0.13	-0.38	2.11**	2.39**	-0.02	0.06
P_3 x P_5	-0.43	-0.77	0.45	-2.14*	-2.12	13.84*	9.77*	0.86	0.69	-0.71	3.89**	-0.25	2.48**	-0.02	0.05
P_3 x P_6	-0.48	-0.55	0.56	-0.67	-0.59	14.60*	5.09	2.33**	0.66	-1.10	2.31*	5.26**	1.09	0.77**	0.60**
P_3 x P_7	-1.10	-0.99	2.81*	0.91	1.10	3.75	7.45	0.91	0.80*	1.38	0.20	1.87**	2.15**	1.09**	0.93**
P_3 x P_8	-2.37**	-2.10*	2.42*	3.49**	3.85**	13.03*	11.86*	1.43*	-0.03	-0.73	4.56**	0.42	0.70	1.55**	1.19**
P_3 x P_9	-2.23**	-1.27	1.89	2.47*	2.93**	-4.75	-10.46*	1.05	0.27	-0.75	3.73**	4.00**	1.94**	1.42**	1.19**
P_3x P_{10}	-1.26	-2.05*	-4.44**	1.19	1.16	8.47	-1.59	0.49	0.18	0.67	3.87**	1.36**	1.31	1.39**	1.13**
P_4 x P_5	4.10**	3.90**	2.17	0.55	0.18	16.68**	4.96	-0.55	0.63	0.91	-0.49	-2.19**	1.51*	0.63*	0.51**
P_4 x P_6	-1.29	-0.88	1.28	0.02	-0.29	28.23**	20.27**	1.12*	-0.01	-0.27	0.92	2.15**	2.18**	0.39	0.36
P_4 x P_7	-0.90	0.34	0.53	5.27**	4.74**	28.38**	21.10**	2.37**	0.01	-1.28	0.48	-1.24**	3.28**	1.80**	1.55**
P_4 x P_8	-3.18**	-2.77**	1.81	-1.48	-0.84	-6.73	-8.22	0.55	0.04	0.09	0.17	3.31**	1.20	0.79**	0.62**
P_4 x P_9	-4.71**	-3.93**	-2.05	-0.84	-2.09	-6.73	4.92	1.57**	0.41	0.61	2.01	-0.11	0.00	0.44	0.28
P_4x P_{10}	-1.40	-1.38	-3.05**	-1.45	-0.54	13.35*	1.46	0.35	0.45	1.09	1.81	-0.92**	0.94	0.07	0.06
P_5 x P_6	0.57	0.51	-1.22	-1.81*	-1.32	18.22**	6.06	1.27*	0.48	0.35	1.87	1.79**	2.14**	0.35	0.32
P_5 x P_7	-3.37**	-3.27**	4.37**	0.44	1.05	13.23*	4.96	0.72	-0.11	-1.73	1.42	0.57	3.17**	0.93**	-3.19**
P_5 x P_8	-0.65	0.62	1.64	3.69**	3.46**	4.58	1.04	2.17**	1.19**	0.31	3.12**	1.28**	1.12	1.39**	1.40**
P_5 x P_9	-2.85**	-2.21*	1.12	3.99**	3.55**	6.80	-4.61	1.45*	0.37	0.03	3.95**	1.19**	3.16**	1.17**	0.99**
P_5x P_{10}	-1.54	-0.99	-0.88	1.72	1.77	26.36**	10.52*	2.50**	1.14**	1.84	4.76**	2.89**	2.03**	1.64**	1.33**
P_6 x P_7	-1.43	-1.71*	-0.52	2.91**	2.91*	20.46**	19.94**	1.99**	1.13**	-0.38	-0.16	-1.92**	1.68*	1.76**	1.40**
P_6 x P_8	-0.71	-0.49	0.76	1.83	2.32*	20.47**	0.75	1.97**	0.43	0.46	2.87**	-2.04**	2.20**	1.18**	0.99**
P_6 x P_9	-1.57	-1.66	1.23	1.80	1.74	1.42	0.96	3.39**	1.27**	-0.08	1.03	4.71**	1.93**	1.63**	1.33**
P_6x P_{10}	-1.26	-1.10	-1.11	-1.48	-1.70	19.38**	1.23	0.77	0.77*	2.86	1.17	-2.26**	1.08	0.76**	0.60**
P_7 x P_8	-0.98	-0.60	-0.66	0.08	0.02	22.16**	6.51	2.09**	0.57	-0.95	2.42*	1.07**	0.07	1.06**	0.75**
P_7 x P_9	-1.85*	-1.10	-0.86	-0.62	-0.23	24.44**	-16.27**	1.44*	0.28	0.24	-1.08	-0.35	1.63*	0.84**	0.69**
P_7x P_{10}	-0.54	-0.88	0.48	0.44	-0.34	6.53	0.68	2.82**	0.18	-0.35	1.73	-2.49**	0.41	0.98**	0.73**
P_8 x P_9	3.88**	3.12**	-1.91	-6.03**	-5.82**	9.72	-5.69	1.56**	-0.69	-0.26	3.62**	-1.81**	0.42	-0.53*	-0.45**
P_8x P_{10}	2.52**	2.34**	4.09**	-4.64**	-4.26**	26.55**	5.61	2.00**	0.48	2.35	1.09	-1.28**	1.33	-0.03	-0.01
P_9x P_{10}	-1.35	-1.16	2.56*	2.33*	2.16	4.43	5.22	1.02	0.92*	1.81	1.59	4.47**	2.43**	1.58**	1.36**
Overall Average	**-1.03**	**-0.95**	**-0.25**	**0.07**	**0.13**	**13.39**	**5.89**	**1.54**	**0.57**	**0.63**	**2.31**	**0.99**	**1.55**	**0.81**	**0.59**

P_1- DMR 10RYFWS 8105, **P_2**-DMR 19 RYDWS 1247, **P_3**- DMR 11 R 0144, **P_4**-CAL 1454,
P_5-IAMI-9, **P_6**-IAMI-1, **P_7**-Z 485-4, **P_8**-Z 491-3,
P_9-Z 491-17, **P_{10}**-IAMI-85

Table.6 Standard heterosis for grain yield in maize

Cross combination	NK 30(%)	Hishell (%)	Pro-4212(%)	JK-502(%)	IAHM-15-45(%)
P_1 x P_2	7.07	25.00**	31.58**	15.47*	11.11
P_1 x P_3	14.92*	34.17**	41.23**	23.94**	19.26**
P_1 x P_4	-10.06	5.00	10.53	-3.00	-6.67
P_1 x P_5	8.49	26.67**	33.33**	17.01*	12.59
P_1 x P_6	-5.78	10.00	15.79	1.62	-2.22
P_1 x P_7	-32.19**	-20.83*	-16.67	-26.87**	-29.63**
P_1 x P_8	4.21	21.67**	28.07**	12.39	8.15
P_1 x P_9	12.78	31.67**	38.60**	21.63**	17.04*
P_1 x P_{10}	1.36	18.33*	24.56**	9.31	5.19
P_2 x P_3	6.35	24.17**	30.70**	14.70	10.37
P_2 x P_4	1.36	18.33*	24.56**	9.31	5.19
P_2 x P_5	-4.35	11.67	17.54*	3.16	-0.74
P_2 x P_6	-1.50	15.00	21.05*	6.24	2.22
P_2 x P_7	4.21	21.67**	28.07**	12.39	8.15
P_2 x P_8	-1.50	15.00	21.05*	6.24	2.22
P_2 x P_9	-5.07	10.83	16.67	2.39	-1.48
P_2 x P_{10}	5.64	23.33**	29.82**	13.93	9.63
P_3 x P_4	-9.35	5.83	11.40	-2.23	-5.93
P_3 x P_5	-2.21	14.17	20.18*	5.47	1.48
P_3 x P_6	9.21	27.50**	34.21**	17.78*	13.33
P_3 x P_7	18.49**	38.33**	45.61**	27.79**	22.96**
P_3 x P_8	20.63**	40.83**	48.25**	30.10**	25.19**
P_3 x P_9	25.62**	46.67**	54.39**	35.49**	30.37**
P_3 x P_{10}	23.48**	44.17**	51.75**	33.18**	28.15**
P_4 x P_5	-3.64	12.50	18.42*	3.93	0.00
P_4 x P_6	-7.21	8.33	14.04	0.08	-3.70
P_4 x P_7	20.63**	40.83**	48.25**	30.10**	25.19**
P_4 x P_8	-2.93	13.33	19.30*	4.70	0.74
P_4 x P_9	-5.07	10.83	16.67	2.39	-1.48
P_4 x P_{10}	-10.78	4.17	9.65	-3.77	-7.41
P_5 x P_6	-0.79	15.83	21.93*	7.01	2.96
P_5 x P_7	12.78	31.67**	38.60**	21.63**	17.04*
P_5 x P_8	14.20*	33.33**	40.35**	23.17**	18.52*
P_5 x P_9	18.49**	38.33**	45.61**	27.79**	22.96**
P_5 x P_{10}	24.20**	45.00**	52.63**	33.95**	28.89**
P_6 x P_7	24.20**	45.00**	52.63**	33.95**	28.89*
P_6 x P_8	12.06	30.83**	37.72**	20.86**	16.30*
P_6 x P_9	24.20**	45.00**	52.63**	33.95**	28.89**
P_6 x P_{10}	7.78	25.83**	32.46**	16.24*	11.85
P_7 x P_8	9.21	27.50**	34.21**	17.78*	13.33
P_7 x P_9	12.78	31.67**	38.60**	21.63**	17.04*
P_7 x P_{10}	12.78	31.67**	38.60**	21.63**	17.04*
P_8 x P_9	-15.06*	-0.83	4.39	-8.39	-11.85
P_8 x P_{10}	-6.50	9.17	14.91	0.85	-2.96
P_9 x P_{10}	27.77**	49.17**	57.02**	37.80**	32.59**

P_1- DMR 10RYFWS 8105, **P_2**-DMR 19 RYDWS 1247,
P_3- DMR 11 R 0144, **P_4**- CAL 1454,
P_5- IAMI-9, **P_6**- IAMI-1,
P_7- Z 485-4, **P_8**- Z 491-3,
P_9- Z 491-17, **P_{10}**- IAMI-85

Both positive and negative and significant estimates of SCA effects were observed among the crosses for grain yield Among the 45 hybrids, thirty-four hybrids have shown significant SCA effects. Among these hybrids, thirty-two hybrids have shown the positive significant SCA effects and two hybrids have shown the negative significant SCA effects. The hybrid CAL 1454 x Z 485-4 (1.55) showed highest positive significant effect followed by IAMI 9 x Z 491-3 & IAMI 1 x Z 485-4 (1.40), Z 491-17 x IAMI 85 (1.36). These crosses with highly positive and significant estimates of SCA effect could be selected for their specific combining ability to use in maize improvement program. Inbred line WNC DMR 11 R 0144 exhibited the maximum positive GCA effect, whereas IAMI-1 exhibited the lowest GCA effect, indicating the existence of best and poorest general combiners in the group of inbred lines studied. Inbred lines identified for good general combining ability could be utilized in maize grain improvement programs for improvement of the traits of interest as these lines have high potential to transfer desirable traits to their cross progenies. The findings of the present study are in agreement with the findings of Pal *et al.,* (1986), Vasal *et al.,* (1992), Satyanarayana *et al.,* (1994), Srivastava and Singh (2002), Todkar and Navale (2006), Kanagarasu *et al.,* (2010), Pavan *et al.,* (2011), Abrha *et al.,* (2013) and Kachapur *et al.,* (2018).

Heterosis

Investigation on heterosis provides fundamental information regarding the utility of the cross combination and its use for commercial exploitation. Standard heterosis was estimated for grain yield in all 45 hybrids and is presented in table-6. Five checks were taken to work out standard heterosis. The standard heterosis over the best check NK-30 ranged from -32.19% (DMR 10RYFWS 8105 x Z 485-4) to 27.77% (Z 491-17 x IAMI-85). Over NK-30, fourteen hybrids have shown significant standard heterosis effects. Among them, 12 hybrids have shown the positive significant effects while 2 hybrids have shown the negative significant effects.

Heterosis increases yield potential and improves adaptation to stress in maize; however, the underlying mechanisms of heterosis and combining ability remain elusive (Araus *et al.,* 2010). Many hybrids gave negative values of heterosis in desirable direction for earlier tasseling, silking and plant height. Many hybrids exposed positive values of heterosis in desirable direction for cobs/plot, grain yield, cob yield, ear girth, ear length and 100 grain weight. These findings are in confirmatory with the results of Mohammed (2005), Muraya *et al*., (2006), Hussain *et al*., (2011) and Ali *et al.,* (2014). Heterosis was observed for several combination and the lines with high values of combining ability will be further selfed to generate stable inbred lines that will be evaluated in commercial breeding programs.

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