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Research Article

Study of gene action in different traits of maize *(Zea mays L.)*

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Abstract
A study was conducted on maize incorporating a total of 28 single crosses, eight parental lines and two standard checks to determine the combining ability and gene action. Among the eleven traits that were studied, the analysis of variance revealed that the mean squares due to genotypes, parents and hybrids were highly significant for all traits, except for 100 grain weight in case of parents, indicating the presence of an adequate amount of genetic variability. On further analysis of variance for combining ability, the mean squares due to GCA and SCA were observed to be highly significant for almost all traits indicating the role of both additive and non additive components of genetic variance in the expression of all the studied traits. The high *gca* effect for grain yield per plant was associated with high or average *gca* for yield component traits for most parents, while the poor combiners for grain yield per plant were also poor combiners for other yield component traits. High *sca* effects were seen in a few cross combinations which were good specific combiners for grain yield per plant and yield component traits. Based on the *gca* effects some inbred lines were identified as good general combiners for various traits. This indicated that these parents could be utilized for developing synthetic variety. The inbred lines with desirable *gca* effects for grain yield and other agro-morphological traits could be inter-crossed to develop an improved base population and subsequent recurrent selection efforts would facilitate the derivation of elite lines excelling in desirable character. All of the cross combinations exhibiting desirable significant *sca* effect were having one parent as a good or average combiner for each of the eleven agro morphological traits studied. It was clear that these hybrids were the combinations of either the parents as good general combiners or one of the parents as a good general combiner for yield and yield related traits. Hence, they can be used as a potential single cross hybrid combination and tested further. The crosses that show high *sca* effects indicate a preponderance of non-additive genes and can be used for heterosis breeding.

Keywords: Maize, Combining ability, GCA and SCA

INTRODUCTION

Maize (*Zea mays* L.) usually called Corn is one among the world's most important cereals having wide adaptability across a range of different agro-climatic conditions. *Zea mays* L. was derived from the Greek word "Zea" (zela) that was the name of a food grass. It is primarily used as an energy crop as the grain is rich in vitamins and fats, but the specialized version for protein, oil, waxy, sweet and pop are found in nature. Maize also finds its use in bio-fuel and bio-ethanol production. With the impacts of rising populations and climate change, there arises a necessity to develop superior hybrids of maize that can counter the growing trend of world hunger. Maize hybrids are created by crossing, or breeding, two different inbred parent lines with desired characteristics to combine into a hybrid. Commercialization of hybrids has now become common and accepted even among farmers because they are high yielding and perform better across different environments than their inbred parental lines or open pollinated varieties

(OPVs). The yield advantage, of these several types of hybrids over the open-pollinated varieties are 46% for single cross, 30% for three way cross, 37% for double top cross, 28% for top cross, and 17% for variety cross (Paliwal, 2000 and Correjado and Magulama,2008). To increase the grain yield of the maize populations and their hybrids several breeding procedures have been established. Maize inbred lines represent a fundamental resource for studies in genetics and breeding and are used extensively in hybrid corn production. In producing superior hybrids a good knowledge of combining ability among the breeding materials is required. Thus, the selection of parents or inbreds based on their combining ability is very important as it helps in identifying potential parents or inbreds and desirable cross combinations. It also helps to know the genetic nature of various traits, their mode of inheritance that enables the breeder to device appropriate breeding methodology to incorporate the traits in question. The recent trend even within the developing and under developed countries is to go forward for single cross hybrid than for double cross because the single cross hybrids show higher uniformity. Information on combining ability implies the gene action and inheritance of associated traits and thereby helps in the formulation of the breeding methodology to be used. It is found to be more reliable than other method of evaluation in deciding the parents to be used in crosses. Diallel technique elaborated by Griffing (1956) is a useful methodology for evaluating parents and crosses for combining ability and also for an understanding of nature and magnitude of gene action and there by breeding methods to be used as well.

MATERIALS AND METHODS

The experiment was carried out at the Experimental Farm of the University of Calcutta at Baruipur, South 24 Parganas during *rabi* season from 1st week of January, 2018 to last week of May, 2018. The experiment was laid out in Randomized Block Design (RBD) with three replications. The inbred lines were sown in the experimental plot in rows of 2 m length and a spacing of 60 cm row to row and 20 cm plant to plant. Normal inter-cultural operations were practised throughout the growing period. A total of 28 single crosses, eight parents with two standard checks were used for the study **(Tables 1 & 2)**.

For eleven yield traits, data were collected on five randomly selected plants from each replication. For days devoted to tasseling (50 %), the plant was tasselled when the inflorescence was exposed by the leaf, exposing the spikelets, and the number of days from planting to when 50% of the plant produced tassel was calculated. Countdown to silking (50 %) was calculated as the amount of days between planting and the appearance of silk on 50% of the plants. Plant height (cm) before harvesting was measured in cm from the base to the flag leaf, and the mean was computed. Before harvesting, the ear height of the selected plants was measured in cm from ground level to the node carrying the topmost ear, and the mean was computed. Cob Length (cm) was determined by measuring the distance between the first and last group of grains on the base and tip of the cob, respectively. Cob Diameter (cm) was calculated by measuring the width of the cob without the husk in the centre. The number of grain rows per cob, the number of grain rows in a cob and the number of grains per row were counted and an average was calculated. For the weight of 100 grains (g), for each genotype, 100 grains were counted, their weight was measured in grams, and the mean was computed. The mean grain yield obtained from the five randomly selected plants in each replication was used to estimate grain yield per plant.

Analysis was done according to the half diallel mating design (Method II and Model I) proposed by Griffing (1956 a) to partition the mean square due to crosses into lines, tester and line by tester effects using Windostat Version 9.2 from indostat services, HYDERABAD Licensed to Dept of Genetics and Plant Physiology Palli Shiksha Bhavana Shanti Niketan.

Table 1. List of parents and checks

Number	GENOTYPES	TYPE	CATEGORY	SOURCE
P1	DMR QPM 102	QPM	INBRED LINE	DMR
P2	CML 170	QPM	INBRED LINE	DMR
P3	DMR QPM 03-121	QPM	INBRED LINE	DMR
P4	DMR QPM 103	QPM	INBRED LINE	DMR
P5	CML 509	QPM	INBRED LINE	CIMMYT
P6	CML 511	QPM	INBRED LINE	CIMMYT
P7	CML 539	Non QPM	INBRED LINE	CIMMYT
P8	CML 167	QPM	INBRED LINE	DMR
SC1	900 M GOLD (C)	NORMAL	HYBRID	MONSANTO
SC2	HQPM 1 (c)	QPM	HYBRID	LOCAL

Table 2. List of genotypes for half diallel crosses

Number	Parents/ hybrids	Cross	Cross name
P1	DMR QPM 102	P2 x P7	CML 170 x CML 539
P2	CML 170	P2 x P8	CML 170 x CML 167
P3	DMR QPM 03-121	P3 x P4	DMR QPM 03-121 x DMR QPM 103
P4	DMR QPM 103	P3 x P5	DMR QPM 03-121 x CML 509
P5	CML 509	P3 x P6	DMR QPM 03-121 x CML 511
P6	CML 511	P3 x P7	DMR QPM 03-121 x CML 539
P7	CML 539	P3 x P8	DMR QPM 03-121 x CML 167
P8	CML 167	P4 x P5	DMR QPM 103 x CML 509
P1 x P2	DMR QPM 102 x CML 170	P4 x P6	DMR QPM 103 x CML 511
P1 x P3	DMR QPM 102 x DMR QPM O3-121	P4 x P7	DMR QPM 103 x CML 539
P1 x P4	DMR QPM 102 x DMR QPM 103	P4 x P8	DMR QPM 103 x CML 167
P1 x P5	DMR QPM 102 x CML 509	P5 x P6	CML 509 x CML 511
P1 x P6	DMR QPM 102 x CML 511	P5 x P7	CML 509 x CML 539
P1 x P7	DMR QPM 102 x CML 539	P5 x P8	CML 509 x CML 167
P1 x P8	DMR QPM 102 x CML 167	P6 x P7	CML 511 x CML 539
P2 x P3	CML 170 x DMR QPM 03-121	P6 x P8	CML 511 x CML 167
P2 x P4	CML 170 x DMR QPM 103	P7 x P8	CML 539 x CML 167
P2 x P5	CML 170 x CML 509	SC1	900 M GOLD
P2 x P6	CML 170 x CML 511	SC2	HQPM 1

Combining ability analysis was performed with the data obtained for parents and hybrids according to Model – I, Method – II proposed by Griffing (1956). This includes portioning of variation among sources attributable to general combining ability (*gca*) and specific combining ability (*sca*) components. The analysis of variances for the combining ability is based on the following statistical model:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + (1/b)\, e_{ijk}$$

RESULTS AND DISCUSSION

Half diallel analysis (Griffing's method II and model I) of 28 F1 hybrids developed by crossing eight inbred lines was carried out to detect the combining ability effects for yield and its attributing traits in maize.

The analysis of variance revealed that the mean squares due to genotypes, parents and hybrids were highly significant for all traits, except for 100 grain weight in case of parents, indicating the presence of the adequate amount of genetic variability **(Table 3).** The further analysis of variance for combining ability showed that the mean squares due to GCA and SCA were highly significant for almost all traits. This indicated the role of both additive and non additive components of genetic variance in the expression of all the studied traits. The importance of both additive and non-additive gene effects in maize was also reported by Kamara (2015). A higher magnitude of SCA variance in relation to GCA implied the preponderance of non-additive gene action in the inheritance of traits *viz.*, plant height, ear height, cob length, the number of grain rows per cob, the number of grains per cob and 100 grain weight while the higher magnitude of GCA indicated the predominant role of additive gene action in the inheritance of days to 50% tasseling, days to 50% silking, cob diameter, the number of grains per row and grain yield per plant. A preponderance of additive component for these traits have been reported in earlier studies by Kamara (2015) and Aung *et al.* (2016) and non-additive component has been reported by Rovaris *et al.* (2014) and Talukder *et al.* (2016). The variance due to SCA **(σ^{2s})** were higher in magnitude than their corresponding GCA variance (σ2**g)** for all the traits indicating the preponderance of non-additive gene action in the inheritance of these traits **(Table 4).** The estimates of σ2g and σ2s were translated into genetic components of variance viz. additive genetic variance (σ2A) and dominance genetic variance (σ2D) as per the methodology suggested by Griffin (1956 b). It was observed from the results that the σ2D values were higher in magnitude over their corresponding σ2A values for all traits, except for days to 50% silking strongly suggesting the major role of dominant gene action in the expression of these traits. Involvement of both additive (fixable) and non-additive (non-fixable) components of genetic variances with a greater role of non-additive gene actions in governing the inheritance of yield and it's component traits have been reported by several researchers (Moradi, 2014). The estimates of the average degree of dominance were more than unity for all assessed traits, except for days to 50% silking. Thus the average degree of dominance was in the range of over dominance for grain

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Table 3. Analysis of variance for various agro-morphological traits in maize

Sources of variation	df	Mean Squares										
		DT 50%	DS 50%	PH	EH	CL	CD	GR/C	G/R	G/C	GW	GY/P
Replication	2	1166.4***	1510.6***	8551.3***	8575.4***	12.1*	9.4***	6.2*	376.9***	85443.6***	48.5*	6981.7***
Genotypes	35	28.7***	26.1***	1739.9***	619.7***	9.3***	3.3***	4.1***	67.5***	19644.3***	38.6***	2095.2***
Parents	7	76.9***	60.4***	1900.4***	673.8***	3.8**	3.2**	5.4**	73.3***	18061.0***	15.8	1243.1*
Hybrids	27	15.6**	17.6**	1666.8***	611.9***	9.3***	3.1***	3.2***	68.0***	20598.6***	40.7***	2241.5***
Parent Vs Hybrids	1	43.7*	16.0	2588.9**	452.3	14.8*	7.4**	0.1	13.1	4961.4	143.0***	4110.5**
Error	70	7.4	7.9	308.8	148.2	2.7	0.8	1.4	17.0	3300.0	10.8	459.6
GCA	7	20.9***	23.9***	566.9***	180.4**	3.0**	1.7***	1.3*	29.6***	5384.8***	9.2*	835.6***
SCA	28	6.7***	4.9*	583.2***	213.1***	3.1***	0.9***	1.4***	20.7***	6838.9***	13.8***	664.1***
Error	70	2.50	2.6	102.9	49.4	0.9	0.3	0.5	5.7	1100.0	3.6	153.2
GCA/SCA		0.44	0.94	0.10	0.08	0.10	0.20	0.09	0.16	0.08	0.06	0.13

*, ** and *** Significant at 0.05, 0.01 and 0.001 levels of probability, respectively

Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

Table 4. Estimates of components of genetic variance for various agro-morphological traits in Maize

Sources of variation	DT 50%	DS 50%	PH	EH	CL	CD	GR/C	G/R	G/C	GW	GY/P
σ^2 g	1.8	2.1	46.4	13.1	0.2	0.1	0.1	2.4	428.5	0.6	68.2
σ^2 s	4.2	2.3	480.3	163.7	2.2	0.7	0.9	15.0	5738.9	10.2	510.9
σ^2 A	3.7	4.3	92.8	26.2	0.4	0.3	0.2	4.8	857.0	1.1	136.5
σ^2 D	4.2	2.3	480.3	163.7	2.2	0.7	0.9	15.0	5738.9	10.2	510.9
$[\sigma^2 D/ \sigma^2 A]^{1/2}$ (Average degree of dominance)	1.07	0.73	2.28	2.50	2.35	1.53	2.12	1.77	2.59	3.05	1.93
$2 \sigma^2 g /(2 \sigma^2 g + \sigma^2 s)$ (Predictability ratio)	0.46	0.65	0.16	0.14	0.16	0.29	0.16	0.24	0.13	0.10	0.21
Heritability (NS)*	35.5	46.5	13.7	10.9	12.0	22.8	10.9	18.8	11.1	7.6	17.0

Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

*Heritability (NS) = Heritability Narrow Sense (Range: Low= <30%, Moderate= 30-60%, High= > 60%)

yield and cob traits while for days to 50% silking it was in the range of partial dominance indicating the role of non additive gene action in the inheritance of these traits. The average degree of dominance in over dominance range indicated that the inbreds contained contrasting alleles in most of the cases in the dispersion phase, which on combination through hybridization increased heterozygosity. The anverage degree of dominance in the over-dominance range for grain yield and cob traits in maize has been reported by Dawod *et al.* (2012) and Wani *et al.* (2017). Narrow-sense heritabilities were calculated from the estimated components of variance. Narrow sense heritability estimates ranged from 7.6 to 47.6 per cent. The low estimates of narrow sense heritability for plant height, ear height, cob length, cob diameter, the number of grains per cob, the number of grains per row, the number of grains per cob, 100 grain weight and grain yield per plant are indicative of non additive gene effects in these phenotypes. The magnitude of narrow sense heritability was moderate for days to 50% tasseling (35.50) and days to 50% silking (46.30) suggesting the involvement of both gene actions *viz*., additive and non additive in their expression. The involvement of both the gene actions was earlier reported by Amiruzzamman *et al.* (2013) and Rajitha and Reddy (2013).

The findings of the present study suggested the significant role of non-additive gene action in the inheritance of yield and yield related traits which resulted from dominance or various epistatic interaction effects. In case of days to 50% silking and to some extent for days to 50% tasseling it was seen that the genetic control of these traits was largely due to additive gene action though some degree of dominance gene action also existed. The preponderance of non additive gene action indicated the presence of heterozygosity in the population and as it is not fixable, selection for the traits grain yield per plant, plant height, ear height, cob length, cob diameter, the number of grain rows per cob, the number of grains per row, the number of grains per cob and 100 grain weight would not be effective. Non additive genetic variance governing the inheritance of yield and the majority of yield related traits is more often evident in maize as compared to components of additive genetic variance (Wright *et al.,* 1971). Therefore, hybridization followed by selection at advanced segregating generations is suggested for exploiting non additive gene effects. Breeding methods such as heterosis breeding followed by recurrent selection might not only break the undesirable linkages but also increase the frequency of favourable alleles governing quantitatively inherited traits like grain yield (Tiwari *et al*., 2011).

The present study demonstrates that on all accounts the inbreds namely, CML 509, CML167, CML 511, DMR QPM 102 and the hybrids namely, DMR QPM 103 x CML 539, DMR QPM 103 x CML 509, DMR QPM 102 x CML 167 were the best performers (**Table 5**). However, the inbreds and the hybrids with high yield potentiality maintained more or less better performance in a majority of the cob characters indicating the importance of cob size, grain rows per cob, grains per row and grains per cob in determining the grain yield. This by and large supports the earlier observations of Abrha *et al*. (2013) and Iqbal *et al*. (2007) who observed better cob characters are desirable for realizing high yielding hybrids in maize. It is to be emphasized that these are functionally related characters and they will show correlated responses during selection. Significantly these hybrids attained a tall stature (good plant height) suggesting the significance of improved growth in hybrids for realizing desirable yield.

The variation in *gca* effects calculated from data pertaining to pooled over years for each parent for eleven traits are shown in **Table 6**. Highly significant positive values of *gca* effects were desirable for all traits except for days to 50% tasseling, days to 50% silking, plant height and ear height where negative values would be useful from breeders' point of view. In the present investigation, none of the inbred lines (parents) showed significant *gca* effects in the desired direction simultaneously for all the assessed traits. The high *gca* effect for grain yield per plant was associated with high or average *gca* for yield component traits *viz*, cob length, cob diameter, the number of grain rows per cob, the number of grains per row, the number of grains per cob, 100 grain weight for most parents, while poor combiners for grain yield per plant were also poor combiners for other yield component traits.

Both negative and positive *gca* effects were observed for days to 50% tasseling and 50% silking. DMR QPM 102 and CML 170 showed negative and significant *gca* effects for days to 50% tasseling as well as for days to 50% silking. The negative value implies that the inbred lines are good combiners as it indicates the tendency of earliness and the reverse is true for those with positive *gca* effects. Thus, DMR QPM 102 and CML 170 were good general combines for early flowering. The rest of the parents were considered as average combiners for earliness as they recorded non significant *gca* effects. The current results are in general agreement with the findings of researchers Abrha *et al*. (2013) and Aung *et al.* (2016). A shorter plant height with a lower ear position is usually preferred in maize for resistance to root and stem lodging. Thus, negative estimates of *gca* are desirable since they indicate shorter plant and ear height. For plant height, CML 511 and CML 539 were found to be good general combiners as they displayed highly significant and positive *gca* effects For ear height, only one line *viz*., CML 539 showed negative and significant *gca* effects. CML 539 was a good combiner for both plant and ear height as it recorded significant negative *gca* effects for both the traits. This result is in conformity with the findings of Abrha *et al*. (2013) and Talukder *et al.* (2016). Inbred line DMR QPM 102 was the

Table 5. Mean performance of parents, F1 hybrids and standard checks of maize for yield and it's attributing traits

Parents/hybrids	TRAITS										
	DT 50	DS 50	PH	EH	CL	CD	GR/C	G/R	G/C	GW	GYP
Parents											
DMR QPM 102	86.7	89.3	216.7	123.5	18.7	12.9	12.6	34.8	451.7	26.9	125.2
CML 170	86.0	88.7	206.2	94.8	13.8	14.0	13.6	27.8	358.5	25.0	80.4
DMR QPM 03-121	88.7	92.3	166.5	92.6	14.4	12.0	12.4	27.6	347.6	30.2	83.1
DMR QPM 103	89.0	91.3	176.0	118.4	13.7	13.7	12.8	31.7	408.4	25.8	112.5
CML 509	88.0	93.0	229.3	130.3	18.6	14.9	12.7	32.5	414.4	33.7	136.8
CML 511	89.7	91.3	237.2	135.4	16.2	14.2	12.6	32.4	409.9	33.8	129.3
CML 539	91.0	96.7	164.5	78.8	11.2	13.5	12.0	19.1	229.2	30.1	60.7
CML 167	90.0	92.3	243.5	131.5	15.3	15.3	15.5	33.5	515.7	24.3	134.6
Mean	88.6	91.9	205.0	113.2	15.2	13.8	13.0	29.9	391.9	28.7	107.8
Hybrids											
DMR QPM 102 x CML 170	80.7	84.0	187.2	89.1	15.8	14.0	13.4	31.0	411.1	27.7	110.6
DMR QPM 102 x DMR QPM 03-121	83.0	86.3	180.1	101.5	14.3	13.5	13.1	28.6	372.3	28.0	101.9
DMR QPM 102 x DMR QPM 103	83.3	87.0	218.4	118.1	15.7	14.2	13.1	32.8	425.0	30.7	124.0
DMR QPM 102*CML 509	88.3	89.3	223.3	112.2	17.5	14.0	13.6	33.4	458.7	30.2	146.1
DMR QPM 102 x CML 511	87.3	90.3	227.2	118.5	15.9	15.4	14.0	34.3	465.5	29.2	133.6
DMR QPM 102 x CML 539	88.0	90.3	223.8	119.3	17.2	14.2	13.1	32.5	427.8	34.0	142.5
DMR QPM 102*CML 167	88.7	90.7	226.8	123.1	16.6	15.1	13.6	33.7	457.4	28.3	155.0
CML 170 x DMR QPM 03-121	91.7	93.7	242.1	132.7	17.6	14.9	15.3	35.3	534.9	28.0	149.0
CML 170 x DMR QPM 103	80.3	83.3	199.5	99.7	14.5	14.7	14.0	36.2	507.1	26.5	122.9
CML 170 x CML 509	91.7	93.7	224.1	105.4	14.7	15.0	13.2	29.3	380.9	32.0	115.0
CML 170 x CML 511	88.0	90.7	207.5	100.7	15.2	14.6	13.9	33.2	484.6	27.7	135.2
CML 170 x CML 539	81.3	83.7	192.5	93.9	14.8	13.6	12.8	33.9	437.4	24.8	104.7
CML 170 x CML 167	90.7	92.3	223.3	119.5	17.0	14.9	15.3	36.9	554.4	20.3	106.8
DMR QPM 03-121 x DMR QPM 103	84.3	88.0	195.5	100.2	13.4	12.7	13.2	29.6	416.1	22.7	98.0
DMR QPM 03-121 x CML 509	86.3	89.0	200.1	106.2	14.9	14.0	14.0	30.4	424.6	26.7	108.6
DMR QPM 03-121 x CML 511	88.3	90.7	190.2	102.9	13.2	13.6	13.6	28.3	386.3	24.3	113.4
DMR QPM 03-121 x CML 539	91.0	93.7	186.3	99.7	15.0	14.4	13.7	30.1	408.0	29.0	118.1
DMR QPM 03-121 x CML 167	89.7	91.7	200.7	106.7	14.0	13.7	16.0	28.8	424.8	19.7	110.6
DMR QPM 103 x CML 509	86.7	89.0	200.3	105.5	16.7	16.1	14.2	35.0	497.2	31.0	157.1
DMR QPM 103 x CML 511	94.0	96.3	207.5	107.2	14.3	14.1	13.0	31.7	406.7	28.3	122.8
DMR QPM 103 x CML 539	90.3	92.7	221.2	118.1	15.1	14.7	13.4	34.7	526.6	31.3	175.1
DMR QPM 103 x CML 167	94.0	96.0	206.5	107.9	13.2	13.2	13.3	29.1	398.4	25.5	101.8
CML 509 x CML 511	90.7	94.3	243.9	134.9	14.7	14.8	13.1	29.3	383.1	32.5	131.6
CML 509 x CML 539	92.3	94.7	229.4	131.3	16.3	14.7	12.6	32.0	401.3	39.0	124.5
CML 509 x CML 167	90.3	93.0	229.3	129.5	15.7	15.3	15.1	30.6	458.0	27.7	120.8
CML 511 x CML 539	89.0	91.7	226.9	115.7	14.8	15.2	13.2	28.6	410.6	31.0	131.7
CML 511 x CML 167	94.7	94.7	231.9	129.3	16.2	15.1	12.9	32.3	418.1	36.3	123.1
CML 539 x CML 167	90.7	92.7	217.6	115.1	14.6	14.0	14.7	32.0	471.3	23.0	103.3
Mean	88.4	90.8	213.0	112.3	15.3	14.4	13.7	31.9	441.0	28.4	124.6
Checks											
900 M Gold (SC 1)	97.00	98.00	238.87	140.47	14.91	15.76	14.50	31.11	449.72	24.00	150.69
HQPM1 (SC 2)	95.33	96.67	238.60	126.13	16.12	15.83	15.69	33.38	522.89	22.50	145.90
Mean	96.2	97.3	238.7	133.3	15.5	15.8	15.1	32.2	486.3	23.3	148.3
Overall											
Mean	91.1	93.3	218.9	119.6	15.4	14.7	14.0	31.4	439.7	26.8	126.9
CV %	3.75	3.48	12.66	16.29	23.09	5.54	7.48	16.24	23.77	11.98	24.30

Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height (cm) = PH, Ear height = EH, Cob length (cm) = CL, Cob diameter (cm) = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight (g) = GW and Grain yield/plant (g) = GY/P

Table 6. Estimates of general combining ability effects for various agro-morphological traits in Maize

Parents	DT 50%	DS 50%	PH	EH	CL	CD	GR/C	G/R	G/C	GW	GY/P
DMR QPM 102	-1.64*** (G)	-1.81** (G)	4.376 (A)	3.15 (A)	0.93** (G)	0.14 (A)	-0.15 (A)	1.79* (G)	14.62 (A)	0.77 (A)	9.94** (G)
CML 170	-2.63*** (G)	-2.52** (G)	-3.87 (A)	-3.29 (A)	-0.26 (A)	0.21 (A)	0.39 (A)	1.25 (A)	18.04 (A)	-1.13* (P)	-1.02 (A)
DMR QPM 03-121	0.23 (A)	-0.33 (A)	5.703 (A)	3.38 (A)	0.31 (A)	0.45** (G)	0.19 (A)	1.56* (G)	24.49* (G)	0.52 (A)	14.17** (G)
DMR QPM 103	1.07* (P)	0.64 (A)	12.07*** (P)	6.81** (P)	0.32 (A)	0.51** (G)	0.40* (G)	0.40 (A)	12.35 (A)	1.78** (G)	6.29 (A)
CML 509	0.10 (A)	0.30 (A)	2.52 (A)	1.19 (A)	0.27 (A)	-0.08 (A)	0.03 (A)	0.80 (A)	3.44 (A)	-0.68 (A)	-3.60 (A)
CML 511	0.12 (A)	0.11 (A)	-9.74** (G)	-4.14 (A)	-0.45 (A)	-0.53*** (P)	-0.54** (P)	-1.58* (P)	-24.59* (P)	-0.14 (A)	-10.28** (P)
CML 539	1.45** (P)	1.81***	-8.86** (G)	-4.95* (G)	-0.74* (P)	-0.58*** (P)	-0.48* (P)	-2.93*** (P)	-42.78*** (P)	-0.39 (A)	-9.45* (P)
CML 167	1.30** (P)	1.80***	-2.20 (A)	-2.16 (A)	-0.39 (A)	-0.11 (A)	0.14 (A)	-1.29 (A)	-5.57 (A)	-0.73 (A)	-6.05 (A)
SE± (gi)	0.46	0.48	3.00	2.01	0.28	0.15	0.20	0.70	9.81	0.56	3.66
SE± (gi-gj)	0.70	0.73	4.54	3.14	0.42	0.23	0.30	1.06	14.83	0.85	5.54
Number of parents showing desirable GCA effects	2	2	2	1	1	2	1	1	1	1	2

G = Good general combiner; A = Average general combiner; P = Poor general combiner

*, ** and *** Significant at 0.05, 0.01 and 0.001 levels of probability, respectively

Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

*Heritability (NS) = Heritability Narrow Sense (Range: Low= <30%, Moderate= 30-60%, High= > 60%)

best general combiner with a high significant positive *gca* effect. For cob diameter, highly significant positive *gca* effects were observed in parents DMR QPM 03-121 and DMR QPM 103. Parents/inbred lines with significantly positive *gca* effects were considered as good general combiners for the number of grain rows per cob, the number of grains per row and the number of grains per cob. With respect to the number of grain rows per cob, DMR QPM 103 showed a significant positive *gca* effect. For the number of grains per row, parents DMR QPM 102 and DMR QPM 03-121 showed positive and significant *gca* effects. Parent DMR QPM 03-121 showed a significant and desirable *gca* effect for the number of grains per cob. The result of this study is in conformity with the findings of Abrha *et al.* (2013) and for the number of grain rows per row. The combining ability analysis for the trait 100 grain weight identified the parent/inbred line DMR QPM 103 showed a highly significant positive *gca* value marking it as a good combiner. Similar to the current findings, positive and negative significant *gca* effects for 100 grain weight were reported by Wali *et al*. (2010) and Abrha *et al.* (2013). The rest of the parents/inbreds proved as average combiners because of their positive and non-significant *gca* values. Among the eight parents, highly significant positive *gca* effects for grain yield per plant was observed in DMR QPM 03-121 followed by DMR QPM 102 while CML 511 and CML 539 exhibited significantly negative *gca* effects. The inbred line DMR QPM 03-121 exhibited the maximum *gca* effect whereas CML 511 exhibited the lowest *gca* effect for grain yield/ plant, indicating the existence of best and poorest general combiners in the group of inbreds, respectively. Both positive and negative *gca* effects were reported in maize by several investigators (Abrha *et al*., 2013 and Ahmad and Saleem, 2003).

Highly significant positive *gca* effects would be of interest for traits grain yield per plant and the following traits *viz*., cob length, cob diameter, the number of grain rows per cob, the number of grains per row, the number of grains

per cob, 100 grain weight as they are important yield components that directly contributes to increased grain yield whereas highly significant negative *gca* effects would be useful for days to 50% tasseling, days to 50% silking, plant height and ear height. Thus, inbred lines with negative *gca* values increase selection efficiency in breeding programmes for earliness, short plant height and low ear position while positive *gca* values increase selection efficiency for grain yield and yield component traits in maize. The parents DMR QPM 102, DMR QPM 03-121, DMR QPM 103 and CML 170 were identified as good general combiners as they displayed high or average *gca* effects for the majority of traits and DMR QPM 102 can be given the status of the best general combiner as it recorded highly significant positive *gca* effects for earliness, grain yield and some yield component traits while it proved to be an average combiner for rest of the traits. DMR QPM 03-121 proved to be a good combiner for grain yield, cob diameter, the number of grains per row, the number of grains per cob and an average combiner for earliness and rest of the component traits. DMR QPM 103 was a good combiner for cob diameter, the number of grain rows per cob and 100 grain weight and an average combiner for rest of the yield component traits. CML 170 was a good combiner for days to 50% tasseling and days to 50% silking and average combiner for a majority of yield component traits except 100 grain weight. The rest of the parents were average or poor general combiners for earliness, grain yield per plant and yield component traits. Thus, CML 170 was identified as the most desirable parent for earliness as it showed high combining ability with the highest desirable *gca* effect for days to 50% tasseling and days to 50% silking. Taking this point into account inbred lines identified as good general combiners could be utilized in specific breeding programmes for the improvement of grain yield or other traits of interest in maize as these lines have a high potential to transfer desirable traits to their cross progenies.

Hence, the parents DMR QPM 102, DMR QPM 03-121, DMR QPM 103 and CML 170 which displayed high or average *gca* effects for the majority of traits could be utilized extensively in multiple crossing programmes either for the development of a dynamic population possessing favourable genes or synthetic varieties. As these parents were the best general combiners for various traits with high *per se* performance they can directly be used for the development of superior single cross hybrids.

The estimates of *sca* effects of the twenty eight cross combinations for eleven agro-morphological traits are shown in **Table 7.** In the present investigation, none of the cross combinations exhibited significant *sca* effects in the desired direction simultaneously for all the assessed traits. However, several cross combinations were observed to demonstrate significant and desirable *sca* effects for many traits. With respect to the number of days to 50% tasseling, five cross combinations exhibited a significant to highly significant *sca* effect. Crosses CML 509 x CML 167, DMR QPM 03-121 x CML 539 and CML 509 x CML 539 showed negative estimates of *sca* effect and appeared to be good specific combiner for earliness. In case of days to 50% silking none of the crosses were good specific combiners as they recorded non significant negative *sca* effects. All the crosses were considered as average combiners for this trait because of non significant *sca* effect. For plant height and ear height, the estimates of *sca* effects were found to be significant in 13 and 5 out of 28 crosses, respectively. Crosses CML 509 x CML 167, CML 539 x CML 167, DMR QPM 102 x CML 170, CML 509 x CML 539 and CML 511 x CLM 539 were good specific combiners for plant height. With regard to ear height, Crosses CML 509 x CML 167, CML 539 x CML 167 and CML 509 x CML 539 exhibiting negative significant *sca* effects were the best specific combiners as they show the tendency to reduce ear height. Abrha *et al*. (2013) reported the presence of both positive and negative *sca* effects in maize crosses. For cob length, 8 crosses exhibited significant *sca* effect, out of which five displayed significant positive estimates which were desirable for this trait. The crosses DMR QPM 102 x CML 167, DMR QPM 102 x CML 539, DMR QPM 103 x CML 539, DMR QPM 102 x CML 511 and CML 170 x CML 511 displayed significant positive *sca* effect suggesting them as a good specific combiner for the trait. For cob diameter, the cross combinations DMR QPM 102 x CML 539, DMR QPM 102 x CML 511, CML 170 x CML 511, DMR QPM 03-121 x CML 167, DMR QPM 102 x CML 167, DMR QPM 03-121 x CML 511, DMR QPM 103 x CML 539 and DMR QPM 103 x CML 167 displayed significant desirable (positive) *sca* effect. Only four crosses for the number of rows per cob, six crosses for the number of grains per row and six crosses for the number of grains per cob were found to exhibit desirable (positive and significant) estimates of *sca* effects. The crosses DMR QPM 102 x CML 539, DMR QPM 102 x CML 167, CML 170 x CML 539 and DMR QPM 103 x CML 539 were found as the best specific combiners. With regards to both traits *viz*., number of grains per row and number of grains per cob, crosses DMR QPM 102 x CML 539, DMR QPM 102 x CML 167, CML 170 x CML 511, DMR QPM 03-121 x CML 539, DMR QPM 03-121 x CML 167 and DMR QPM 103 x CML 539 were identified as good specific combiners. This result is in conformity with findings of Abrha *et al*. (2013). Rest of the parents showing significant negative and non-significant estimates of *sca* effects were considered as poor and average combiners, respectively. For 100 grain weight, eight crosses exhibited significant estimates of *sca* effects. The crosses DMR QPM 03-121 x CML 511 , DMR QPM 03-121 x CML 167, DMR QPM 103 x CML 509, DMR QPM 103 x CML 511 and CML 511 x CML 167 showed good specific combination. Crosses with positive and significant *sca* effects for this trait are desirable. Significant *sca* effects in maize inbred lines for 100 grain were reported by other researchers (Abrha *et al*., 2013 and Uddin *et al*., 2006). For grain yield, both significant

Table 7. Estimates of specific combining ability effects for various agro-morphological traits in Maize

Cross combinations	DT 50%	DS 50%	PH	EH	CL	CD	GR/C	G/R	G/C	GW	GY/P
DMR QPM 102 x CML 170	-1.77	-0.70	-30.40 **	-6.78	-1.36	-0.81	-0.60	-3.14	-48.37	1.91	-12.65
DMR QPM 102 x DMR QPM 03-121	0.13	0.57	0.96	4.21	-1.43	-1.12 *	-0.93	-1.02	-62.22 *	1.66	-13.24
DMR QPM 102 x DMR QPM 103	2.29	2.07	1.49	-5.91	-1.34	-0.18	-0.17	-4.49 *	-55.91	-1.96	-11.06
DMR QPM 102*CML 509	0.43	0.34	14.17	8.90	-0.23	0.31	-0.37	-0.13	-2.30	2.03	9.06
DMR QPM 102 x CML 511	2.74	1.20	22.09 *	17.64 **	1.99 *	1.14 *	0.71	1.05	20.96	2.32	15.51
DMR QPM 102 x CML 539	-0.72	-1.60	21.69 *	8.84	2.52 **	1.78 ***	1.31 *	4.57 *	91.49 **	1.77	40.68 **
DMR QPM 102*CML 167	1.16	0.61	21.16 *	12.89	2.88 **	1.08 *	1.93 **	7.40 **	159.17 ***	-1.08	37.25 **
CML 170 x DMR QPM 03-121	3.69 *	3.59 *	19.07 *	4.89	0.52	0.22	-0.71	-5.07*	-78.44 *	2.56	-10.14
CML 170 x DMR QPM 103	0.51	0.39	-17.20	-10.37	0.65	-0.21	-0.42	-0.65	-2.03	-0.63	3.87
CML 170 x CML 509	-2.22	-1.51	-14.08	-10.32	-1.00	-0.56	-0.61	-0.71	-24.36	-1.28	-9.07
CML 170 x CML 511	2.93 *	1.95	26.11 **	7.58	1.85 *	1.14 *	1.23	7.13 **	129.17 ***	-1.62	22.01
CML 170 x CML 539	-2.16	-2.45	8.77	11.58	-0.13	0.21	1.53*	3.05	58.16	-0.60	14.88
CML 170 x CML 167	-0.35	-1.04	1.50	7.90	0.47	-0.25	0.59	-0.89	-28.15	1.78	0.78
DMR QPM 03-121 x DMR QPM 103	0.55	1.53	-17.77	-7.11	0.17	-0.02	-0.45	-0.56	-17.18	0.55	-12.42
DMR QPM 03-121 x CML 509	0.05	0.00	-1.72	-3.20	0.52	0.10	1.16	0.35	31.83	-5.23 **	-5.23
DMR QPM 03-121 x CML 511	-2.47	-2.55	20.04 *	6.61	1.01	1.29 *	0.60	3.46	55.36	4.43 *	37.49 **
DMR QPM 03-121 x CML 539	-2.93 *	-2.57	7.09	-1.39	1.20	0.64	0.64	4.61 *	73.581 *	0.18	-5.41
DMR QPM 03-121 x CML 167	-0.65	-1.57	18.00	5.36	1.70	1.34 **	0.36	5.77*	109.06 **	3.99 *	43.46 ***
DMR QPM 103 x CML 509	-2.02	-1.24	16.78	10.84	-0.22	0.41	-0.92	-0.87	-29.06	4.98 **	15.61
DMR QPM 103 x CML 511	-0.78	-1.05	19.14 *	12.25	1.17	-0.37	-1.58 *	0.41	-1.27	3.81 *	20.26
DMR QPM 103 x CML 539	-1.74	-1.71	31.06 **	17.18 *	2.36 *	0.98 *	1.33 *	5.80 *	110.32 **	-0.64	28.73 *
DMR QPM 103 x CML 167	-1.76	-2.24	14.83	11.40	0.15	1.01 *	-0.36	1.23	11.27	2.40	17.03
CML 509 x CML 511	2.66	2.12	17.52	9.06	-0.65	0.35	0.89	1.45	43.71	-1.07	1.95
CML 509 x CML 539	-2.93 *	-2.40	-26.09 **	-14.80 *	1.27	-1.14 *	-1.01	0.30	-34.07	2.15	-9.91
CML 509 x CML 167	-5.02 **	-3.00	-47.65 ***	-35.92 ***	-3.56 ***	-0.94	0.42	-6.41 **	-97.72 **	-7.97 ***	-44.08 ***
CML 511 x CML 539	-1.52	-1.08	-24.47 *	-11.47	-1.80 *	-0.12	0.53	-0.03	1.96	-6.23 **	-14.66
CML 511 x CML 167	0.96	2.92	5.27	4.68	-0.01	-1.05 *	-2.68	-6.97 **	-130.92 ***	5.65 **	-23.12 *
CML 539 x CML 167	1.41	3.63 *	-34.11 ***	-23.88 ***	-3.19 ***	-1.34 **	-2.01	-10.44 ***	-182.63 ***	3.40	-45.29 ***
SE± (S_{ij})	1.42	1.47	9.20	6.37	0.85	0.47	0.61	2.16	30.01	1.72	11.22
SE± (S_{ij}-S_{ik})	2.11	2.18	13.61	9.43	1.26	0.66	0.86	3.01	44.50	2.54	15.66
Number of crosses showing desirable *sca* effects	3	0	5	3	5	8	4	6	6	5	5

*, ** and *** Significant at 0.05, 0.01 and 0.001 levels of probability, respectively

Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

*Heritability (NS) = Heritability Narrow Sense (Range: Low= <30%, Moderate= 30-60%, High= > 60%)

negative and positive estimates of *sca* effects were observed among the crosses. Eight cross combinations exhibited a significant *sca* effect, out of which five crosses registered significant positive values for the trait. Crosses DMR QPM 102 x CML 539, DMR QPM 03-121 x CML 167, DMR QPM 102 x CML 167, DMR QPM 03-121 x CML 511 and DMR QPM 103 x CML 511 were good specific combiners. The results of the current study are in agreement with the findings of Shams *et al*. (2010) and Abrha *et al*. (2013) who reported significant to a highly significant level of *sca* effects in most of the crosses they studied for grain yield in maize.

Specific combining ability (*sca*) includes non additive genetic effects which arise largely from dominance and epistatic interactions which can be related to heterosis. Dominance and interaction effects are difficult to fix. This can be exploited by intercrossing and postponing selection to later generations i.e. segregating generation by reduction of heterozygosity. So it is important to identify hybrids which could be forwarded for further selection in segregating generations and hybrids suitable for heterosis breeding. Hybrids having highly significant *sca* effects of the crosses indicate significant deviation from what would have been predicted based on their parental performances (Abrha *et al*., 2013).

In the present investigation, none of the cross combinations exhibited significant *sca* effects in the desired direction simultaneously for all the assessed traits. The estimates of *sca* effects revealed that out of the 28 crosses, five crosses were found to be good specific combiners for grain yield as they showed positive and significant *sca* effects, while 10 crosses were found to be average combiners. The crosses DMR QPM 03-121 x CML 167 followed by DMR QPM 102 x CML 539, MR QPM 03-121 x CML 167, DMR QPM 102 x CLM 167 and DMR QPM 103 x CML 167 showed the highest desirable *sca* effect and can be given the status of best specific combiners for grain yield. They also exhibited average to high *sca* effects for most of the yield component traits. For yield component traits like cob length, cob diameter, the number of grain rows per cob, the number of grains per row, the number of grains per cob and grain yield per plant, crosses DMR QPM 102 x CML 539, DMR QPM 102 x CML 167 and DMR QPM 103 x CML 539 were identified as the best cross combinations. The cross CML 170 x CML 511 was a good specific combiner for cob length, cob diameter, the number of grains per row and the number of grains per cob and average combiner for grain yield per plant and the number of grain rows per cob. Crosses CML 509 x CML 167 and CML 509 x CML 539 expressed significant positive *sca* effect for days to 50% tasseling, plant height and ear height and thus were the promising combinations for achieving earliness and short plants. DMR QPM 03-121 x CML 539 was a good combiner for days to 50% tasseling and average combiner for plant height, ear height and all the yield component traits.

Seven promising cross combinations identified on the basis of high *sca* effect were DMR QPM 102 x CML 539, DMR QPM 102 x CML 167, DMR QPM 103 x CML 539 and DMR QPM 03-121 x CML 167 which were good specific combiners for grain yield per plant and yield component traits whereas, CML 509 x CML 167 and CML 509 x CML 539 were good specific combiners for days to 50% tasseling, plant height and ear height. These cross combinations can be further exploited for developing promising single cross hybrids in realizing higher yields and early maturity.

The six cross combinations *viz*., DMR QPM 103 x CML 539, DMR QPM 103 x CML 509, DMR QPM 102 x CML 167, CML 170 x DMR QPM 03-121, DMR QPM 102 x CML 509 and DMR QPM 102 x CML 539 which were the highest yielding had one of the parents as a good or average combiner for grain yield per plant and it's component traits. The highest yielding cross combination DMR QPM 103 x CML 539 possessed a high significant *sca* effect and involved average x poor general combiners as parents. Similarly, for days to 50% tasseling, days to 50% silking and yield component traits all the cross combinations exhibiting desirable significant *sca* effect were having one parent as a good or average combiner for each of the eleven agro morphological traits studied. It was clear that these hybrids were the combinations of either the parents as good general combiners or one of the parents as a good general combiner for yield and yield related traits. Hence, they can be used as a potential single cross hybrid combination and tested further. Among the top six crosses for grain yield per plant three crosses *viz*., DMR QPM 103 x CML 539, DMR QPM 102 x CML 167 and DMR QPM 102 x CML 539 exhibited significant *sca* effects. If a cross combination exhibited high *sca* effects as well as per se performance having at least one parent as good general combiner for a particular trait, it is expected that such cross combinations would throw some desirable transgressive segregants in later generations subjected to sufficient population grown.

The results of the present investigation revealed that in general there was no relationship between *gca* effects of the parents and the *sca* effects of the single crosses. However, mean performance of single crosses was largely dependent upon the mean performance of the parents involved, so the high *gca* value of parents is no guarantee of high *sca* effects of their crosses and the selection of parents should be based on specific combing ability tests. Similar results have been reported by Gowhar *et al.* (2007).

Based on the finding of the present study the following conclusions are drawn that there is the prevalence of greater magnitude of non additive gene effects relative to additive gene effects in the inheritance of yield and it's component traits indicating that heterosis breeding would be more effective as it is not-fixable, thus favouring the development of single cross hybrids. Moreover the

inbred lines with desirable *gca* effects for grain yield and other agro-morphological traits could be inter-crossed to develop an improved base population and subsequent recurrent selection efforts would facilitate the derivation of elite lines excelling in desirable character. Superior single cross hybrids were identified that displayed significant *sca* effect, good *per se* performance and suppressed better parents by a significant margin as well as were better or at par with the checks for earliness, grain yield per plant and it's component traits. Thus, these hybrids could be used for extensive testing in multiple environments (across time and space) to verify their suitability for commercial exploitation.

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REFERENCES

Abrha, S. W., Zeleke, H. Z. and Gissa, D. W. 2013. Line x tester analysis of maize inbred lines for grain yield and yield related traits. *Asian Journal of Plant Science and Research*, **3**(5):12-19

Ahmad, A. and Saleem, M. 2003. Combining ability analysis in maize (*Zea mays* L.). *International J. Agric. Biol.,* **5**(3): 1-6.

Amiruzzamman, M., Islam, M.A., Hassan, L., Kadir, M. and Rohman, M. M. 2013. Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.). *Emir. J. Food Agric.,* **25(**2): 132-137. [Cross Ref]

Aung N., Khaing T.T., Than, H. and Zar, M.T. 2016. Evaluation of hybrid maize (*Zea mays* L.) performance crossing within inbreds developed by composite line selection method. *Journal of Agricultural research*, **3**(1): 47-54.

Correjado, V. M. and Magulama, E. E. 2008. Usefulness of improved open- Pollinated varieties in the development of top-cross white maize hybrids. *USM RD J.,* **16**(2): 97-103.

Dawod, K.M., Al-Falahy, M.A.H. and Mohammad, A.A. 2012. Genetic variances and gene effects controlling grain yield and some of its components in maize. *Journal of Agricultural Science and Technology*, **2**: 814-823.

Gowhar, A., Ishfaq, A., Rather, A.G., Wani, S.A., Gul, Z. and Makhdoomi, M.I. 2007. Heterosis and combining ability for grain yield and its components in high attitude maize inbreds (*Zea mays* L.). *Indian Journal of Genetics and Plant Breeding*, **67** (1): 81-82.

Griffing, B. 1956a. Concepts of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences*, **9**: 463-493. [Cross Ref]

Griffing, B. 1956b. A generalized treatment of the use of diallel crosses in quantitative inheritance. *Heredity*, **10**: 31-50. [Cross Ref]

Iqbal, A.M., Nehvi, F.A., Wani, S.A., Qadir, R., Dar, Z.A. 2007. Combining ability analysis for yield and yield related traits in maize (*Zea mays* L.). *Int. J. Plant Breed. Genet*., **1**(2):101-105. [Cross Ref]

Kamara, M. M. 2015. Diallel analysis of some yellow maize inbred lines under low and normal nitrogen levels. *International Journal of Plant Breeding and Genetics*, **9**: 32-43. [Cross Ref]

Moradi, M. 2014. Genetic analysis for grain yield and yield contributing characters in maize (*Zea mays* L.). *International Journal of Biosciences*, **5**(8): 173-179. [Cross Ref]

Paliwal, R.L. 2000. Hybrid maize breeding, In Paliwal R.L., H. Granador, H. R. Lafitte, A.D. Violic (editorial). *Tropical maize improvement and production. FAO, Rome, Italy.* 363p.

Rajitha A, and Reddy. 2013. Combining ability and gene action in maize (*Zea mays* L.). M.Sc. (Ag.) Thesis. Acharaya NG Ranga Agricultural University, Hyderabad, India.

Rovaris, S.R.S., Zagatto, M.E.A.G. and Sawazaki, E. 2014. Combining ability of white corn genotypes with two commercial hybrids. *Maydica*, **59**: 96-103.

Shams, M, Choukan, R, Majidi, E. and Darvish, F. 2010. Estimation of combining ability and gene action in maize using line × tester method under three irrigation regimes. *Journal of Research in Agricultural Science,* **6**:19-28

Talukder, M.Z.A., Karim, A.N.M.S., Ahmed, S. and Amiruzzaman, M. 2016. Combining ability and heterosis on yield and its component traits in maize (*Zea mays* L.). *Bangladesh J. Agril. Res*., **41**(3): 565-577. [Cross Ref]

Tiwari, D.K., Pandey, P., Giri, S. P. and Dwivedi, J.L. 2011. Prediction of gene action, heterosis and combining ability to identify superior rice hybrids. *International Journal of Botany*, **7**(2): 126-144. [Cross Ref]

Uddin, M.S., Khatun, F., Ahmed, S., Ali, M. R. and Bagum, S.A. 2006. Heterosis and combining ability in corn (*Zea mays* L.) *Bangladesh Journal of Botany*, **35**(2): 109-116.

Wali, M.C, Kachapur, R.M., Chandrashekhar, C.P., Kulkarni, V.R. and Devaranavadagi, S.B. 2010. *Karnataka*, *J. Agric. Sci.,* **23**(4): 557-562.

Wani,M.A., Wani, S.A., Dar, Z.A., Lone, A.A., Abedi, I. and Gazal, A. 2017. Combining ability analysis in early maturing maize inbred lines under temperate conditions. *Int. J. Pure App. Biosc.,* **5** (2): 456-466. [Cross Ref]

Wright, J. A., Hallauer, A.R., Penny, L.H. and Eberhart, S. A. 1971. Estimating genetic variance in maize by use of single and three way crosses among unselected unselected inbred lines. *Crop Sci.,* **11**: 690. [Cross Ref]