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Combining ability estimates and gene action studies from full diallel mating design in maize (*Zea mays* L.)

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ABSTRACT

A study was under taken during kharif season of 2016 at College of Agriculture, Bheemarayanagudi and UAS, GKVK, Bengaluru to estimate the combining ability and investigate gene action involved in inheritance of yield and its components traits of maize inbreds through 20×20 full diallel cross analysis. 380 SCHs synthesized through full diallel mating design were evaluated in simple lattice square lattice design at two locations. Analysis of variance revealed significant differences among the hybrids, parents vs. hybrids and straight crosses for all the characters and among the parents for all the characters except ASI, ear circumference and shelling %. Significant differences were also recorded in reciprocal crosses for all the characters except ear circumference and shelling %. Significant GCA variance for grain yield revealed the role of additive components of genetic variance. SCA variance was also highly significant for all characters except ear circumference and test weight indicating the importance of both additive and non additive components of genetic variance. However, there was predominance of additive gene action recorded for all the characters. GCA: SCA variance ratio was less than unity for all the traits, suggesting the predominance of non-additive gene action. Inbreds MAI 283 and VL 109252 were identified as good general combiners as they registered significant gca effects in positive direction for grain yield and its component traits. Straight cross MAI-283×KDMI-16 and reciprocal cross M 04×KDMI 16 registered highest significant sca effects in positive direction for grain yield along with high and significant sca effects in negative direction for ASI.

Keywords: Combining ability, gene action, diallel mating design, maize

INTRODUCTION

Maize (*Zea mays* L.) called the 'Queen of Cereals' is the second most important cereal crop. It is the most versatile crop with respect to its adaptability, types and uses and possesses huge yield potential. In India maize serves as food, feed, fodder and source of the basic raw material for a number of industrial products thus offering wide latitude for multiple uses and options. Due to increased demand, there is expansion of maize cropping systems which intern has prompted changes in maize variety requirement and research objectives. Nowadays the focus has shifted from Open Pollinated Varieties (OPVs) to hybrid cultivars, with the best performing hybrid varieties being identified through the study of combining abilities (Ngaboyisonga *et al.* 2019). Combining ability is defined as the cultivars or parents ability to combine among each other during hybridization process such that desirable genes or characters are transmitted to their progenies (Fasahat *et al.*, 2016). Mating designs are used to study the combining abilities. Diallel mating design along with providing the information about inheritance pattern of gene action in early generations to breeders for development of hybrid (Hayman, 1954), also helpful in garnering the genetic information about the traits of interest through random and fixed selection sets of parental lines in short time. The concept of combining ability helps the breeder to identify desired lines with increased frequency of desired alleles for a particular character in hybrids and also about selection of desirable parents for development of superior hybrids. It also determines the relative importance of additive and non-additive type of gene actions in controlling a character. The present study therefore, was undertaken to estimate the combining ability and investigate gene action involved in inheritance of yield and its components traits of maize inbreds through 20×20 full diallel cross analysis.

MATERIAL AND METHODS

Experimental material consisted of 380 single cross hybrids (SCHs) of maize synthesized by crossing 20 maize inbreds (Table

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Table 1: Pedigree / Source of maize inbreds used in full diallel crossing

Inbreds	Pedigree / Source
High yielding inbreds	
MAI-283	1108-2 / DMR / AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
MAI-394	777/DMR/ AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
BGUDI-88	Selection from NAI-9202B-1-2, College of Agriculture, Bheemarayangudi
M-04	AICRP-Maize, ARS, Arabhavi, UAS, Dharwad
KDMI-16	X2(Y) Q604, AICRP-Maize, ARS, Arabhavi, UAS, Dharwad
Low yielding inbreds	
MAI-749	
MAI-759	AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
MAI-755	
BGUDI-118	Selection from NAI-9202B-28-5, College of Agriculture, Bheemarayangudi
BGUDI-120	Selection from NAI-9202B-30-3, College of Agriculture, Bheemarayangudi
Inbreds with wider ASI (Days)	
BGUDI-36	Derivative of Parbhat population 47-1, College of Agriculture, Bheemarayangudi
BGUDI-31	Derivative of Parbhat population 35-3, College of Agriculture, Bheemarayangudi
BGUDI-99	Selection from NAI-9202B-10-2, College of Agriculture, Bheemarayangudi
MAI-735	AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
BGUDI-89	Selection from NAI-9202B-2-2, College of Agriculture, Bheemarayangudi
Inbreds with narrow ASI (Days)	
MAI-387	7-1 / AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
VL-109252	CIMMYT, Asia,Hyderabad
MAI-236	Z51-14/ AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
MAI-349	HO7R-7/AICRP-Maize, ZARS, Mandya, UAS, Bengaluru
MAI-769	AICRP-Maize, ZARS, Mandya, UAS, Bengaluru

1) following full diallel mating design (Griffing, 1956). Of these 20 inbreds; 10 inbreds contrasted for anthesis silking interval (ASI) (five with narrow and other five with wider ASI) and 10 inbreds contrasted for grain yield per plant (five high and five low yielding) (Table 1). These 380 SCHs, 20 inbreds and 11 check hybrids (five public institute bred hybrids *viz.,* Arjun, Nityashree, Hema, RCRMH-1 and RCRMH-2 and six private institute bred hybrids *viz.,* NK 6240, GK 3059, CP 818, 900 M, P 3501 and P 3550) were sown during rainy season 2016 at College of Agriculture, Bheemarayangudi (UAS, Raichur) and UAS, GKVK, Bengaluru following simple lattice square design with two replications. Each genotype was sown in a single row of 3 m length with row to row spacing of 60 cm and plant to plant spacing of 30 cm. Recommended packages of practices and cultural operations were followed to raise a healthy crop under protective irrigation condition. Five competitive plants from each genotype from each replication were selected randomly for recording the observations. The data was recorded on eleven different morphological and yield parameters *viz.,* days to anthesis, days to silking, anthesis silking interval (ASI), cob length, cob diameter, plant height, kernels rows^{-1}, kernel rows ear^{-1}, test weight, shelling % and grain yield plant^{-1}. The mean values for all the characters over two locations were subjected for statistical analysis to compute the combining ability effects and their variance and to eestimate components of variation and their genetic interpretation. The statistical analysis of the data was carried out using 'WINDOWSTAT VERSION 9.1 from Indostat services, Hyderabad, software packages installed at the Department of Genetics and Plant Breeding, UAS, GKVK, Bengaluru.

RESULTS AND DISCUSSION

Analysis of variance of full diallel crosses

The analysis of variance of 20 × 20 full diallel crosses (Table 2) revealed significant differences among the parents for all the characters except ASI, ear circumference and shelling %. Reciprocal crosses registered significant differences for all the characters except ear circumference and shelling %. In consistence with the finding in this investigation, Amare *et al.* (2016) reported the presence of significant differences among genotypes for grain yield and its contributing traits in maize.

Table 2: ANOVA for general and specific combining ability of 20 × 20 full diallel crosses and their parents (inbreds) for grain yield and its component traits in maize across two locations

Characters / Source of Variation	Df	Mean sum of Squares										
		Days to anthesis	Days to silking	ASI (Days)	Ear length (cm)	Ear circumference (cm)	Kernel rows ear^{-1}	Kernels row^{-1}	Plant height (cm)	Test weight (g)	Shelling %	Grain yield plant^{-1} (g)
Replication	01	61.02**	150.03**	21.84**	21.11**	1.71	5.41*	97.71**	3969.42**	0.09	50.48	226.86
Genotypes (Parents + Hybrids)	399	12.31**	15.20**	2.73**	6.75**	4.86*	2.71**	32.65**	651.92**	25.61**	34.70**	1085.32**
Parents	19	20.79**	23.32**	1.53	6.65**	2.14	2.91**	35.37**	925.70**	43.70**	18.67	1759.57**
Hybrids	379	10.93**	14.16**	2.78**	6.63**	4.94*	2.59**	30.48**	605.34**	23.65**	34.64**	1012.39**
Parent *Vs*. Hybrids	1	375.13**	253.03**	6.28*	56.02**	27.84**	43.06**	801.77**	13103.47**	425.89**	362.50**	15913.15**
Straight hybrids	189	11.45**	15.02**	2.68**	5.22**	8.22**	2.75**	31.82**	721.46**	24.56**	51.28**	863.41**
Reciprocal hybrids	189	10.46**	13.28**	2.87**	8.07**	1.65	2.45**	28.93**	489.51**	22.86**	18.13	1154.89**
Straight *Vs*. Reciprocal hybrids	1	2.07	19.16*	6.53*	0.18	5.41	0.38	71.33*	549.53	1.74	8.96	2238.031*
Error	399	1.72	3.27	1.22	2.28	3.93	0.96	12.33	212.42	12.84	24.63	452.16
Total	799	7.08	9.41	2.00	4.54	4.39	1.84	22.58	436.59	19.21	29.69	768.06
GCA	19	53.18**	65.15 **	09.06 **	23.69 **	07.24 **	07.49**	51.95**	2803.44**	49.28**	60.26**	1943.86**
SCA of Straight Hybrids (F_1's)	190	04.09**	04.82**	00.98**	02.51**	02.19	01.04**	17.66**	216.32**	11.69**	15.88*	562.97**
SCA of Reciprocal Hybrids (F_1's)	190	03.53**	04.62**	00.98**	02.21**	02.19	01.06**	11.42**	187.86**	10.27**	14.52	382.22**
Error	399	00.86	01.64	00.61	01.14	01.96	00.48	06.17	106.21	6.42	12.32	226.08
GCA/ SCA Ratio		0.41	0.50	0.56	0.41	0.57	0.31	0.10	0.61	0.20	0.33	0.12

***** *Significant at P=0.05, ** Significant at P=0.01*

Table 3: Estimates of general combining ability (*gca*) effects of 20 parents (inbreds) for grain yield and its component traits in maize across two locations

Characters / Inbreds	Days to anthesis	Days to silking	ASI (Days)	Ear Length (cm)	Ear Circumference (cm)	Kernel rows ear^{-1}	Kernels row^{-1}	Plant height (cm)	Shelling %	Test weight (g)	Grain yield plant^{-1} (g)
BGUDI-118	1.55**	1.02**	-0.50**	1.28**	-0.31	-0.73**	1.75**	6.45**	-0.36	0.56	7.72**
BGUDI-120	1.41**	1.85**	0.27*	0.89**	0.29	0.00	1.70**	7.08**	-0.95*	-1.82**	4.66*
BGUDI-36	0.01	0.86**	0.85**	-0.69**	0.12	0.04	-1.94**	6.39**	0.85*	1.61**	-1.41
BGUDI-88	1.05**	1.33**	0.27*	0.56**	-0.45*	-0.71**	0.97*	8.62**	0.23	0.21	3.92
BGUDI-99	0.67**	1.13**	0.40**	0.22	-0.17	-0.43**	0.70	16.37**	-0.72	0.38	2.81
MAI-394	0.36*	-0.04	-0.35**	-0.09	0.10	-0.17	0.78*	7.56**	1.03**	0.21	1.82
MAI-236	0.43**	0.25	-0.22	-0.49**	-0.47*	-0.31**	-1.48**	6.22**	0.33	1.22*	-3.04
BGUDI-89	-0.29*	0.37	0.58**	1.22**	-0.78**	0.07	0.74	7.81**	0.96*	-1.50**	-4.85*
MAI-735	0.67**	1.04**	0.29*	0.70**	0.04	0.35**	0.28	1.73	-0.99*	0.15	-0.25
MAI-349	0.57**	0.88**	0.16	0.52**	0.27	0.25*	1.06**	1.33	-0.54	0.75	7.49**
VL-109252	0.26	-0.42*	-0.48**	-0.35*	1.18**	0.81**	0.64	-1.80	1.80**	0.08	8.14**
BGUDI-31	-1.31**	-0.53**	0.81**	0.36*	-0.08	0.55**	0.26	2.18	0.96*	-0.76	0.52
MAI-769	0.34*	-0.57**	-0.86**	-0.98**	-0.57**	-0.28**	-0.01	-5.29**	1.14**	-1.54**	-6.23**
MAI-283	0.17	-0.57**	-0.63**	0.08	0.31	-0.20	0.63	-6.12**	1.24**	1.32*	12.79**
KDMI-16	-0.46**	-0.31	0.17	0.52**	0.03	0.03	-0.67	-5.73**	-0.95*	1.49**	4.47
MAI-749	-3.24**	-3.71**	-0.46**	-1.32**	-0.02	0.24*	-1.03**	-13.50**	0.73	-3.01**	-14.45**
M -04	0.79**	0.84**	0.11	-0.55**	0.27	0.71**	-0.93*	-6.55**	-0.81*	-0.70	-1.30
MAI-755	-0.14	-0.38	-0.19	-0.09	-0.19	-0.17	-0.64	-12.94**	-0.51	1.09*	-13.37**
MAI-387	-0.80**	-1.12**	-0.31*	-1.30**	0.44*	0.41**	-2.24**	-10.38**	-2.84**	-0.13	-3.65
MAI-759	-2.06**	-1.90**	0.08	-0.49**	0.00	-0.45**	-0.58	-9.42**	-0.60	0.41	-5.77*
CD (gi – gj) @ P=0.05	0.43**	0.60**	0.37**	0.50**	0.66**	0.33**	1.16**	4.82**	1.19**	1.64**	7.04**
CD (gi – gj) @ P=0.01	0.59**	0.82**	0.50**	0.68**	0.90**	0.44**	1.59**	6.59**	1.62**	2.25**	9.62**

***** *Significant at P=0.05, ** Significant at P=0.01*

Among straight *vs* reciprocal crosses, significant differences were recorded for days to silking, ASI, kernels row^{-1} and grain yield plant^{-1} indicating significance reciprocal effects for these traits and also revealed the genetic variation between hybrids obtained from different parental combinations. On contrary, non significant differences registered for days to anthesis, ear length, ear circumference, kernel rows ear^{-1}, plant height, test weight and shelling % among straight *vs* reciprocal crosses revealed that order of the parents in generating hybrids does not influence the characters. Similar findings were reported by Augusto *et al.* (2018). The analysis of variance for parents *vs* hybrids was significant for all the traits, indicating the diverse nature of the parents involved in crossing and presence of heterosis for these traits. This further justified the estimation of combining ability effects of the parents which are helpful in choosing parents for developing hybrids (Table 2). Similar findings were reported by Pavan *et al.* (2011).

Combining ability variance

Analysis of variance for combining ability (Table 2) revealed that the estimates of mean squares due to GCA were highly significant for grain yield and its component traits revealing the role of additive components of genetic variance in controlling these traits. The significant GCA variance enable the breeder to select the best parents based on the additive genetic effects to form a composite with favorable alleles in higher frequency and to develop maize inbreds which in different combinations yield better hybrids. (Pavan *et al.* 2011 and Augusto *et al.* 2018). SCA were also highly significant for all traits except ear circumference and test weight indicating the importance of both additive and non additive components of genetic variance in controlling these traits as reported by Pavan *et al.* (2011) and Augusto *et al.* (2018). The ratio of GCA: SCA helps to predict the progeny performance based on the GCA. Closer the ratio of GCA: SCA to unity, the better the transmission of trait to the progenies (Murtadha *et al.*, 2018). In the present study, GCA and SCA variance ratio was less than unity for all the traits, suggesting the predominance of non-additive gene action governing the traits and suitability of heterosis breeding and population improvement programmes for their improvement. These results are in confirmation with the results obtained by Pavan *et al.* (2011), Aminu *et al.* (2014), Pavan (2014) and Anilkumar (2015).

General combining ability effects of parents

The inbreds *viz*., MAI 749 (-3.24), MAI 759 (-2.06), BGUDI 31(-1.31), MAI 387 (-0.80), KDMI 16 (-0.46) and BGUDI 89 (-0.29) for days to anthesis, MAI 749 (-3.71), MAI 759 (-1.90), MAI 387 (-1.12), MAI 769 (-0.57), MAI 283 (-0.57), BGUDI 31(-0.53) and VL-109252 (-0.42) for days to silking and BGUDI 118 (-0.50), MAI 349 (-0.35), VL 109252 (-0.48), MAI 769 (-0.86), MAI 283 (-0.63), MAI 749 (-0.46) and MAI 387 (-0.31) for ASI registered significant *gca* effects in desirable (negative) direction (Table 3). These inbreds might be useful as donor for developing early maturing genotypes and hybrids. Pavan *et al.* (2011) and Murtadha *et al.* (2018) found significant positive and negative *gca* effects for days to anthesis, days to silking, ASI and Yazachew Genet Ejigu *et al.* (2017) for ASI in their studies on maize.

Two inbreds BGUDI 118 (1.28) and BGUDI 89 (1.22) recorded highest positive significant *gca* effects for ear length. Inbreds VL 109252 (1.18.) and BGUDI 89 (-0.78) exhibited highly significant *gca* effects for ear circumference in positive and negative direction, respectively. Seven inbreds namely, MAI 387 (0.41), M-04 (0.71), MAI 749 (0.24), BGUDI-31(0.55), VL 109252 (0.81), MAI 349 (0.25) and MAI 735 (0.35) recorded significant positive *gca* effects for kernel rows ear^{-1}. Inbred BGUDI 118 (1.75) exhibited highly significant *gca* effects in positive direction for kernel rows^{-1} followed by BGUDI 120 (1.70), MAI 349 (1.06), BGUDI 88 (0.97) and MAI 387 (-2.24). These findings are in line with the result reported by Pavan *et al.* (2011) for ear length, ear circumference, kernel rows^{-1} and kernel rows ear^{-1}, Rajesh *et al.* (2018) for test weight and Brahmbhatt *et al.* (2018) for ear length, ear girth, grains rows ear^{-1} and grains row^{-1}. These results indicates that theses parents contribute to the increased ear length, ear circumference, kernel rows ear^{-1} and kernel rows^{-1}.

The magnitude of *gca* effects for plant height ranged from -13.50 (MAI 749) to 16.37 (BGUDI 99). The minimum and maximum estimates of *gca* effects for shelling % were

Table 4: Best straight crosses with specific combining ability (*sca*) effects in desirable direction for some selected traits in maize across two locations

Components	Days to anthesis	Days to silking	ASI (Days)	Kernel rows ear^{-1}	Plant height (cm)	Test weight (g)	Grain yield plant^{-1} (g)
Best straight crosses with *sca* effects in desirable direction	BGUDI 120 x MAI 755 (-3.25**)	BGUDI 120 X MAI 755 (-3.77**)	MAI-394x BGUDI-31 (-1.46**)	BGUDI-118x BGUDI-89 (3.62**)	MAI-394x MAI-749 (26.87**)	MAI-755 x MAI-759 (27.26**)	MAI-283x KDMI-16 (61.67**)
	BGUDI 99 X MAI 759 (-2.67**)	BGUDI 118 X KDMI 16 (-3.39**)	BGUDI-118x MAI-349 (-1.275*)	MAI-735x M -04 (1.59**)	MAI-236x VL-109252 (20.94**)	BGUDI-36x MAI-283 (4.27)	BGUDI-88x MAI-394 (42.03**)
	BGUDI 118 X KDMI 16 (-2.52**)	BGUDI-36X MAI-749 (-2.99**)	BGUDI-89x MAI-283 (-1.22*)	BGUDI-99x M -04 (1.34**)	BGUDI-118x BGUDI-89 (18.39**)	BGUDI-99x MAI-236 (4.24)	BGUDI-120x VL-109252 (39.03**)
	M 04 X MAI 755 (-2.44**)	M -04 X MAI 755 (-2.73**)	BGUDI-36x MAI-394 (-1.09*)	BGUDI-120x MAI-387 (1.22**)	MAI-236x MAI-755 (17.91*)	BGUDI-120x BGUDI-99 (4.2)	BGUDI-88x MAI-349 (36.16**)
	MAI 749 X MAI 759 (-2.35**)	BGUDI-36x M -04 (-2.55**)	BGUDI-88x BGUDI-89 (-1.05*)	BGUDI-36x MAI-759 (1.17*)	MAI-349x MAI-755 (17.33*)	BGUDI-88x M -04 (3.91)	M -04x MAI-755 (33.19**)
	MAI 236 X MAI 735 (-2.11**)	BGUDI-118 x MAI-349 (-2.49**)	BGUDI-120x VL-109252 (-1.02)	BGUDI-120x MAI-769 (1.15*)	BGUDI-99x BGUDI-31 (17.01*)	MAI-394x VL-109252 (3.53)	BGUDI-118x MAI-349 (32.77**)
	VL 109252 X BGUDI 31 (-2.09**)	MAI-749 X MAI-759 (-2.47**)	BGUDI-88x MAI-735 (-1.00)	BGUDI-99x MAI-394 (1.13*)	BGUDI-88x MAI-759 (16.57*)	MAI-236x VL-109252 (3.44)	MAI-735x M -04 (31.29**)
	BGUDI 89 X KDMI 16 (-2.07**)	MAI-394 X BGUDI-31 (-2.39**)	BGUDI-120 x MAI-387 (-0.91)	BGUDI-118x KDMI-16 (1.10*)	MAI-735x MAI-749 (15.25*)	MAI-394x MAI-749 (3.18)	BGUDI-120x MAI-349 (27.59**)
	MAI 769 X MAI 749 (-2.07**)	VL-109252 X MAI-759 (-2.39**)	BGUDI-36x M -04 (-0.81)	BGUDI-88x MAI-749 (1.06*)	MAI-735x M -04 (14.03*)	MAI-749x MAI-755 (3.05)	MAI-387x MAI-759 (25.96*)
	MAI 349 X MAI 759 (-2.02**)	BGUDI-31 X MAI-283 (-2.39**)	MAI-283 x KDMI-16 (-0.8)	BGUDI-88x MAI-349 (1.02*)	MAI-394x VL-109252 (13.87*)	BGUDI-118x MAI-735 (2.8)	KDMI-16x MAI-749 (25.28*)
Range	-3.25 to 3.49	-3.77 to 3.66	-1.46 to 3.45	-1.60 to 3.62	-26.17 to 26.87	-5.48 to 27.26	-47.32 to 61.67
Number of crosses with positive significant *sca* effects	24	15	12	14	10	01	16
Number of crosses with negative significant *sca* effects	29	24	05	11	09	02	14

***** *Significant at P=0.05, ** Significant at P=0.01*

Table 5: Best reciprocal crosses with specific combining ability (*sca*) effects in desirable direction for some selected traits in maize across two locations

Components	Days to anthesis	Days to silking	ASI (Days)	Kernel rows ear^{-1}	Plant height (cm)	Test weight (g)	Grain yield plant^{-1} (g)
Best reciprocal Crosses with *sca* effects in desirable direction	MAI 759 X MAI 735 (-3.74**)	MAI 755x MAI-283 (-3.83**)	MAI-394x BGUDI-99 (-2.88**)	M -04x BGUDI-36 (2.67**)	MAI-755x BGUDI-36 (30.51**)	MAI-759 x MAI-755 (29.63**)	M -04x KDMI-16 (43.97**)
	MAI 759 X BGUDI 36 (-3.43**)	MAI-759 x MAI-735 (-3.78**)	M -04x MAI-769 (-2.05**)	MAI-755x MAI-394 (1.70**)	M -04x BGUDI-89 (29.48**)	MAI-749x KDMI-16 (4.98*)	M -04x BGUDI-89 (37.63**)
	M 04 X BGUDI 118 (-2.99**)	MAI-394 x BGUDI-99 (-3.69**)	BGUDI-31 xBGUDI-88 (-2.02**)	MAI-387x MAI-236 (1.56**)	MAI-394x BGUDI-88 (20.88**)	MAI-387x BGUDI-31 (4.03)	MAI-349x BGUDI-88 (34.88**)
	M 04X KDMI 16 (-2.98**)	M -04 x KDMI-16 (-3.63**)	BGUDI-31x MAI-735 (-1.63**)	M -04x BGUDI-120 (1.50**)	M -04x BGUDI-118 (20.10**)	MAI-755x BGUDI-36 (3.9)	MAI-755x BGUDI-36 (33.12**)
	MAI 755 X MAI 283 (-2.64**)	MAI-759x BGUDI-36 (-3.44**)	MAI-283x BGUDI-120 (-1.59**)	KDMI-16x MAI-735 1.34**	BGUDI-120x BGUDI-118 (18.84**)	MAI-394x BGUDI-36 (3.26)	VL-109252x BGUDI-120 (32.59**)
	MAI 283 X BGUDI 31 (-2.26**)	MAI-283x BGUDI-31 (-3.41**)	MAI-236x BGUDI-36 (-1.54**)	M -04x BGUDI-89 (1.27**)	MAI-283x BGUDI-118 (17.45*)	MAI-759x MAI-769 (3.25)	M -04x BGUDI-36 (29.91**)
	MAI 759 X MAI 236 (-2.21**)	MAI 755x VL-109252 (-2.77**)	MAI-387x BGUDI-99 (-1.46**)	MAI-749x KDMI-16 1.23**)	BGUDI-99x BGUDI-36 (16.56*)	MAI-755x MAI-236 (3.25)	BGUDI-31x BGUDI-36 (29.84**)
	MAI 387 X BGUDI 118 (-2.18**)	MAI-394x BGUDI-120 (-2.62**)	MAI-387x BGUDI-88 (-1.27*)	MAI-755x BGUDI-36 (1.22**)	MAI-749x BGUDI-118 (15.52*)	MAI-755x MAI-283 (2.99)	MAI-394x BGUDI-36 (29.08**)
	MAI 759 X BGUDI 120 (-2.17**)	MAI-759xBGUDI-120 (-2.53**)	MAI-769x MAI-349 (-1.26*)	MAI-755x BGUDI-89 (1.21*)	KDMI-16x BGUDI-36 (14.06*)	VL-109252x BGUDI-99 (2.96)	MAI-755x MAI-283 (27.36**)
	MAI 749 X MAI 394 (-2.16**)	MAI-387x BGUDI-99 (-2.46**)	KDMI-16x MAI-394 (-1.16*)	M -04x MAI-236 (1.10*)	VL-109252x BGUDI-36 (14.06*)	MAI-394x BGUDI-120 (2.94)	MAI-759x KDMI-16 (26.56**)
Range	-3.74 to5.62	-3.83 to 5.15	-2.88 to 2.27	-2.46 to 2.67	-30.83 to 30.15	-4.29 to 29.63	-52.00 43.97 to
No. of crosses with positive significant *sca* effects	26	31	07	16	10	02	16
No. of crosses with negative significants *sca* effects	35	18	17	21	17	00	08

** Significant at P=0.05, ** Significant at P=0.01* recorded by MAI 387 (-2.84) and VL 109252 (1.80), respectively. Inbreds BGUDI 36 (1.61), KDMI 16 (1.49), MAI 283(1.32), MAI 236 (1.22) and MAI 755 (1.09) recorded significant *gca* effects for kernel size. These findings are in confirmation with the earlier reports of Pavan *et al.* (2011) for plant height, test weight and shelling %, Yazachew Genet Ejigu *et al.* (2017) for plant height, Brahmbhatt *et al.* (2018) for shelling % and Murtadha *et al.* (2018) for plant height and test weight who reported both significant positive and negative *gca* effects.

Inbreds *viz*., MAI 283 (12.79), VL 109252 (8.14), MAI 349 (8.14), BGUDI 118 (7.72) and BGUDI 120 (4.66) manifested significant *gca* effects in desirable direction for grain yield plant^{-1}. Previously, Andayani *et al.* (2018), Murtadha *et al.* (2018) and Elmyhun *et al.* (2020) identified maize inbreds with significant positive and negative *gca* effects for grain yield in their studies.

In the present investigation, inbred MAI 283 recorded highest *gca* effects in desired direction for grain yield, shelling %, test weight, ear circumference, days to silking and ASI. Inbred VL 109252 also manifested significant *gca* effects in desired direction for grain yield plant^{-1}, shelling % and ear circumference. This suggested that the inbreds with significant *gca* effects in desirable direction for flowering characters and grain yield can be used in developing and deploying early maturing, high yielding hybrids for commercial cultivation, if the hybrids exhibit high heterosis. These results were in confirmation with the reports of Anilkumar (2015), Legesse *et al.* (2017), Murtadha *et al.* (2018), Andayani *et al.* (2018) and Elmyhun *et al.* (2020).

Specific combining ability effects of crosses

The estimates of *sca* effects of both straight and reciprocal crosses of 20 × 20 full diallele mating design for 11 characters are presented in supplementary Table. The best 10 hybrids (both straight and reciprocal) with *sca* effects in desirable direction, number of hybrids with positive and negative significant *sca* effects are summarized in Table 4 and 5. In maize, flowering characters such as anthesis, silking and ASI are associated with earliness hence, significant *sca* effects in negative direction is desirable (Mohammad *et al.*, 2016). Contrastingly, grain yield requires significant *sca* effects in the positive direction.

Straight crosses BGUDI 120 × MAI 755 (-3.25), BGUDI 120 × MAI-755 (-3.77) and MAI 394 × BGUDI 31 (-1.46) and reciprocal crosses MAI 759 × MAI 735 (-3.74), MAI 755 × MAI 283 (-3.83) and MAI 394 × BGUDI 99 (-2.88) manifested lowest *sca* effects for days to anthesis, days to silking and ASI, respectively. Straight cross MAI 735 × BGUDI 31 (4.76) for ear length; BGUDI 120 × VL 109252 (11.61) for ear circumference; BGUDI 118 × BGUDI 89 (3.62) for kernel rows ear^{-1}; BGUDI 120 × VL 109252 (14.47) for kernel rows^{-1} and reciprocal cross MAI 749 × BGUDI 118 (3.44) for ear length; VL 109252 × BGUDI 120 (12.42) for ear circumference; M 04 × BGUDI 36 (2.67) for kernel rows ear^{-1}; VL 109252× BGUDI 120 (12.94) for kernel rows^{-1} manifested highest significant *sca* effects.

Straight cross MAI 394 × MAI 749 (26.87) and reciprocal cross MAI 755 × BGUDI 36 (30.51) recorded highest significant *sca* effects for plant height. Hybrids BGUDI 118 × KDMI 16 (4.21) and M 04 × BGUDI 89 (10.43) manifested highest *sca* effects for shelling % in straight and reciprocal crosses, respectively. It was interesting to note that only one straight cross MAI 755 × MAI 759 (27.26) recorded the highest magnitude of *sca* effects for test weight and its counterpart MAI 759 × MAI 755 (29.63) in reciprocal combination. A total of 16 and 14 hybrids in straight crosses and 16 and eight hybrids in reciprocal crosses manifested *sca* effects for grain yield plant^{-1} in positive and negative directions, respectively. The straight cross MAI-283×KDMI-16 and the reciprocal cross M 04×KDMI 16 registered highest significant *sca* effects in positive direction for grain yield along with highly significant *sca* effects in negative direction for ASI. As many as 32 crosses registered high *sca* effects in positive direction for grain yield in both the type of crosses. The crosses which manifested significant *sca* effects for grain yield involved parents with over all high as well as low general combining ability effects and it is interesting to note that grain yield seem to be governed by both additive and non additive gene actions.

Overall in the present study 130 and 122 straight crosses and 144 and 145 reciprocal crosses recorded significant positive and negative *sca* effects, respectively, among the characters studied. This revealed the involvement of both additive and non additive type of gene effect. However, additive gene action was predominant. In consistence with the findings in this investigation, Ndhlela *et al.* (2012) reported predominance non-additive gene effect in the control of ASI, plant height and grain yield and Haron *et al.* (2014) for grain yield only. However, these results are contradictory to those of Badu-Apraku *et al.* (2013) and Ifie *et al.* (2014) who reported predominance of additive gene effects compared to non-additive gene effects for grain yield.

In the conclusion, the present investigation revealed the existence of significant differences for different source of variation which could be because of the diverse nature of the genotypes, thus justifying the selection of parents used in crossing programme. This further justified the estimation of combining ability effects of the parents which are helpful in choosing parents for developing better hybrids. Highly significant estimates of mean squares due to GCA for grain yield revealed the role of additive gene action and enable the breeder to select the best parents to form a composite with favorable alleles in higher frequency and to develop inbred maize lines which in different combinations yield better hybrids. Significant SCA for yield related traits highlighted the importance of both additive and non additive components of genetic variance. Ratio of GCA and SCA variance less than unity suggested the predominance of non-additive gene action and suitability of heterosis breeding and population improvement programmes for improvement. The inbred MAI 283 manifesting highest *gca* effects in positive direction for grain yield and its component traits make it a good general combiner. Straight cross MAI-283×KDMI-16 and the reciprocal cross M 04×KDMI 16 registered highest significant *sca* effects in positive direction for grain yield along with high and significant *sca* effects in negative direction for ASI.

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