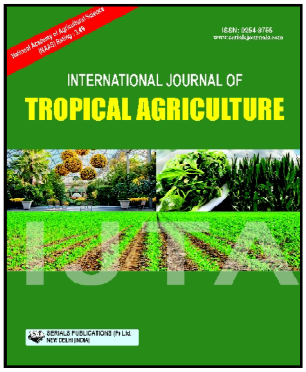

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Estimation of Combining Ability in Maize (*Zea mays* L.) using Line x Tester Analysis”

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Abstract: Combining ability studies provide information on the relative importance of GCA and SCA variance for interpreting the genetic basis of important traits, thus helping maize breeders in anticipating improvement in productivity via hybridization and selection. The analysis of variance revealed that the sufficient variability was present in the material studied. Relatively higher estimates of GCV were obtained for grain yield/plot, cob yield/plot, ear height, cobs/plot and final plant stand. High heritability coupled with high genetic advance was recorded for the traits plant height, 1000 grain weight, ear height and final plant stand that depict the existence of additive gene effects. Mean sum of squares were highly significant for traits such as grain yield, 1000 grain weight, days to 50% pollen shed and silking, plant and ear height, ear length, ear girth, cobs/plot etc. Combining ability analysis revealed that mean squares due to lines, testers and line×testers were significant for almost all the characters. Though the variance due to lines and testers were not significant for cob yield/plot and grain yield/plot but their effect for rest traits and interaction line x tester effect were found significant for all the characters, indicating that the parents used in this study differ significantly and there was preponderance of non additive gene action for the characters. Variance due to sca was greater than gca variance for almost all the traits except for plant height and cob length. Among testers BML-6 (for traits grain yield/plot, cob yield/plot, ear height, plant height, ear girth, cobs/plot and final plant stand) and HKI 1344 (for traits days to 50% pollen shed and silking, days to 80% maturity, plant and ear height, ear length, ear girth) were observed as good testers and among the lines IAMI 24, IAMI 22, IAMI 13, V 938-37 and Z 486-7 were found to be good for various important traits. Hybrids IAMI 24/BML 6, IAMI 31/BML 6 and IAMI 22/BML 6 were identified as promising on the basis of SCA effect, heterosis and mean *per se* performance.

Keywords: combining ability, line x tester analysis, maize, inbred, *gca*, *sca*, gene action.

INTRODUCTION

Maize (*Zea mays L.*), a multipurpose crop, plays an important role in cropping systems throughout the word. Balancing consumer demand for various end-uses of maize and different production practices will be critical for maintaining sustainability of cropping system, food security, feed and fodder supply and bio-energy demands. It is an exciting and leading crop contributing significantly to world agriculture and more importantly to world's food basket of roughly 2000 million metric tons (Vasal, S.K., 2014). Father of green revolution, renowned Noble Laureate Dr Norman E. Borlaug was of the view "after the last two decades saw the revolution in rice and wheat, the next few decades will be known as maize era". It belongs to family Poaceae and is the third most important cereal crop in the world. It is used as a staple food by many people in Mexico, Central, South America and developing countries like India and Africa. In Europe and the rest of North America, maize is grown mostly for use as animal feed. In Canada and the United States, maize is commonly referred to as "corn" (Yadav *et al.*, 2015).

In India, the production of maize witnessed a significant increase of more than 14 times from a mere 1.73 million tons in 1950-51 to 24.17 million tons in 2014-15. Presently it occupies 9.23 million hectare area with the mean yield of 2.56 tons/hectare (ICAR-IIMR, 2015). In Chhattisgarh maize occupies 225.85 thousands hectare land with the productivity of 1825 Kg/ha in *Kharif* 2013-14. It is cultivated mainly in Bastar, Dantewara, Jashpur, Kanker, Korba, Koriya, Surajpur, Balrampur and Sarguja districts. These are pre-dominantly tribal regions. It occupies about 2.72 per cent of the total cropped area in the state with all the maize-prominent districts showing an increasing trend in the maize yield. The state has got very good potential for maize but the productivity is very low due to cultivation of open pollinated varieties (OPVs) and improper input management practices. The real potential can be realized by the adoption of hybrid maize with full package of practices. As the major chunk of maize acreage of the state is rainfed, there is a need to popularize single cross hybrids which have better adaptability under stress environments. Further, advancement in the yield of corn requires certain information regarding the nature of combining parents available for use in the hybridization program and also the nature of gene action involved in expression of quantitative and qualitative traits of economic importance. General and specific combining ability effect is very important in constructing the next phase of breeding program. Information's on the heterotic patterns and combining ability among maize germplasm are essential in maximizing the effectiveness of hybrid development. Thus, the study of combining ability analysis will help in identifying suitable combination to exploit heterosis or link up fixable favourable gene(s) that may lead to the development of superior hybrids. The line x tester analysis which is similar to North Carolina Design-2 which is also known as Factorial Design (Comstock and Robinson, 1948, 1952) is one of them which have been advocated by Kempthorne, 1957. The design has been widely used in maize by several workers and continues to be applied in quantitative genetic studies in maize (Joshi *et al.,* 2002; Sharma *et al.,* 2004). Recently developed inbreds are available at the AICRP on Maize, Raj Mohini Devi College of Agriculture and Research Station, Ambikapur, Chhattisgarh whose combining ability has not yet been studied. Thus, the present investigation was carried out to unravel the genetics of yield and other important trait, nature and magnitude of gene action lines and crosses of maize for yield and other important traits and to study the magnitude of heterosis in maize.

MATERIALS & METHOD

The experimental/biological materials used in the research work comprised of ten maize inbred lines *viz.*, V938-37, Z486-7, P62C6, IAMI-8, IAMI-12,

IAMI-13, IAMI-18, IAMI-22, IAMI-24, IAMI-31 and three well established inbreds *viz.*, HKI-1344, BML-7 and BML-6 as tester. Total thirty crosses were made by adopting line x tester design (Kempthorne, 1957). Five checks *viz.,* NK-30, Hishell, Pro 4212, DHM 117 and NMH 731 were also included to evaluate the standard heterosis. The parents were grown in different sowing dates to raise good crop during *Spring-Summer* 2015, in such a way so as to ensure synchronization in flowering for the purpose of hybridization. The above crosses and their parents were sown in RCBD (Randomized Complete Block Design) with three replication at Research field of Ajirma farm, RMD, CARS, Ambikapur, 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) during *kharif* 2015. Each genotype was sown as four rows of 4 meter lengths with row-to-row and plant-to-plant distance of 75 cm and 25 cm respectively. Recommended agronomical packages and practices were followed during the crop growth period**.** Observations were recorded on traits namely plant height, ear height, ear length, ear girth, cobs per plot, day to 50% pollen shed, day to 50% silking, day to 80% maturity, cob yield per plot, grain yield per plot, final plant stand, shelling percentage and 1000 grain weight. The data so obtained were analyzed and genetic parameters (GCV, PCV, heritability and genetic advance), combining ability effects (GCA & SCA) and all kinds of heterosis were worked out as per standard procedure (Kempthorne, 1957; Meredith and Bridge, 1972).

RESULT & DISSCUSSION

The results (Table 1) 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 height, cobs/plot and final plant stand 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. High heritability coupled with high genetic advance was

Table 1
Genotypic and phenotypic coefficient of variance (GCV and PCV), heritability (h^2) and genetic advance as a percentage of mean for different characters in maize

SN	*Characters*	*Range*	*GCV %*	*PCV %*	*Heritability (h^2)*	*GA as percentage of mean*
1	Final Plant Stand	38.67-80.00	22.05	23.42	88.66	24.00
2	Day to 50% Pollen Shed	47.00-62.33	5.90	6.00	96.63	6.59
3	Day to 50% Silking	50.00-65.33	5.63	5.71	97.35	6.63
4	Day to 80% Maturity	90.00-107.67	4.66	4.77	95.39	9.33
5	No. of Cobs/Plot	38.00-80.33	22.66	24.17	87.87	24.34
6	Plant height (cm)	149.93-265.80	14.88	16.39	82.36	60.38
7	Ear height (cm)	43.13-118.73	20.64	23.30	78.43	32.75
8	Ear length (cm)	10.67-18.80	11.00	13.50	66.29	2.89
9	Ear girth (cm)	10.70-15.87	8.85	10.68	68.65	2.04
10	1000 grain weight (gm)	238.93-339.67	8.07	8.37	92.95	45.88
11	Shelling Percentage (%)	72.97-78.30	0.75	3.12	5.70	0.28
12	Cobs Yield/Plot (kg)	1.60-11.80	51.16	52.63	94.50	5.45
13	Grain Yield/Plot (kg)	1.20-9.10	53.02	54.41	94.96	4.18

recorded for the traits plant height, 1000 grain weight, ear height and final plant stand 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), Wannows *et al.* (2010) and Hussein *et al.* (2015).

Analysis of variance for parents, crosses and parents vs. crosses were highly significant for all the traits except shelling percentage (Table 2). This indicated the presence of sufficient variability among parents and hybrids. The mean sum of squares for hybrids were highly significant for days to 50 per cent pollen shed, days to 50 per cent silking, days to maturity, plant height, ear height, cob yield, grain yield, 1000-grain weight, which implies that hybrids showed diverse performance of different cross combinations for these traits and hence, selection is possible to identify the most desirable crosses. The parents versus hybrids mean sum of squares were highly significant for all traits revealing the presence of average heterosis due to the significant differences in the mean performances of hybrids and parents.

GCA mean squares of Line and Tester were found highly significant for most of the trits viz., 1000 grain weight, days to pollen shed and silking, plant and ear height, grain yield, cob yield (Table-3). Character wise estimation of GCA effects of testers revealed that BML 6 is good combiner for most of the traits *viz.*, grain yield/plot, cob yield/plot, ear height, plant height, ear girth, cobs/plot and final plant stand. HKI 1344 is found to be a good combiner for traits *viz.*, days to 50% pollen shed and silking, days to 80% maturity, plant and ear height, ear length, ear girth with a view of earliness and short stature plant. BML 7 is in between this two. Lines IAMI 24, IAMI 13, IAMI 12 are good for grain yield/plot, cob yield/plot and cobs/plot. IAMI 22 and V 938-37 are better than others for short stature of the plant. IAMI 24, IAMI 22 and Z 486-7 are good for earliness. Analysis of variance for SCA also showed highly significant differences for grain yield, 1000 grain weight, plant height and ear height, days to pollen shed, silking, maturity. Both positive and negative and significant estimates of SCA effects were observed among the crosses for grain yield. Out of the 30 hybrids, twenty two hybrids have shown significant SCA effects (eleven positive and eleven negative). The hybrid V938-37 x HKI-1344 (2.19) followed by IAMI-31 x BML-6 (1.87) showed positive significant effect. Highly significant SCA effects of the crosses indicate that significant deviation from what would have been predicted based on their parental performances. Estimates of SCA effects (Table 4) of hybrids revealed that highest SCA effect shown by IAMI 12/HKI 1344 for 1000 grain weight. Crosses IAMI 31/BML 6, IAMI 22/BML 6, IAMI 18/BML 6, IAMI 8/HKI 1344, V 938-37/HKI 1344 are good for grain yield and other yield attributing characters like cob yield, number of cobs. With the character earliness crosses IAMI 24/HKI 1344, V 938-37/BML 7, IAMI 12/BML 7, IAMI 18/BML 7, IAMI 8/BML 6 are found to be good. Crosses V 938-37/BML 7, IAMI 8/BML 6 are also good from the short plant stature point of view. The results of analysis of combining abilities obtained from this study indicated the importance of both additive and non-additive gene actions in controlling in these agronomical important traits such as 1000 grain weight, days to pollen shed and silking, plant and ear height, grain yield. Therefore, both additive and non-additive variances are important in determining for the exploitation breeding behavior of the genetic potential of the inbred lines in variety development program. Though the variance due to lines and testers were not significant for trait cob yield/plot and grain yield/plot but their effect for rest traits and interaction line x tester effect were found significant for all the characters, indicating that the parents used in this study differ significantly and there was preponderance of non additive gene action for the characters. These results are in general agreement with those of Pal *et al.* (1986), Vasal *et al.*

Table 2
ANOVA for L x T and Combining Ability Analysis

SV	*Degree of freedom*	*Final Plant Stand*	*Day to 50% Pollen Shed*	*Day to 50% Silking*	*Day to 80% Maturity*	*No. of Cobs/Plot*	*Plant height (cm)*	*Ear height (cm)*	*Ear length (cm)*	*Ear girth (cm)*	*1000 grain weight (gm)*	*Shelling percentage (%)*	*Cob Yield/ Plot (Kg)*	*Grain Yield/ Plot (Kg)*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Replication	2	73.976*	21.44**	23.77**	52.32**	80.86*	1184.68**	340.41	3.99	1.46	426.79**	7.69	1.51*	0.68
Parent	12	57.367**	33.19**	28.45**	48.31**	59.3**	1142.34**	593.02**	14.67**	3.4**	1106.6**	6.79*	0.48*	0.26*
Crosses	29	331.91**	24.26**	25.78**	64.33**	348.89**	987.13**	426.42**	3.17**	1.15*	1260.6**	3.57	10.37**	5.96**
Parent Vs Hybrid	1	9569.7**	176.61**	176.3**	333.62**	9943.1**	103030**	24486.02**	181.69**	155.3**	19697.5**	10.2	536.27**	312.3**
Line effect	9	205.732	28.496**	25.91**	71.58**	224.48**	881.05**	901.55**	2.96*	1.986**	3285.00**	2.91	3.85	2.38
Tester effect	2	282.63	67.517*	78.48**	259.37**	338.81	5562.08**	674.5*	24.85**	2.92*	617.16	0.84	23.27	13.40
Line x Tester Effect	18	400.48**	17.349**	19.87**	39.031**	412.21**	531.84*	177.4*	0.875	0.547	319.98**	4.206	12.197**	6.933**
Error	84	19.05	0.386	0.299	0.897	21.2	221.83	89.94	1.63	0.682	37.58	5.56	0.421	0.235
Total	128	21632.37	1354.1	1338	2959	22716	166369	52494.72	595.041	290	73547.95	678.8	881.4	509.85
Variance GCA		-8.015	1.572	1.657	6.484	-6.695	137.93	31.31	0.668	0.098	83.64	-0.119	0.0701	0.0493
Variance SCA		125.53	5.662	6.525	12.762	128.69	96.64	309.88	-0.04	0.263	93.4	-0.05	4.011	2.299
Variance GCA/SCA		-0.064	0.278	0.254	0.508	-0.052	1.427	0.101	-16.700	0.372	0.896	2.380	0.0175	0.0214

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

Table 3

General Combining Ability Effects of Parents for grain yield and its components in maize.

Characters	*Final Plant Stand*	*Day to 50% Pollen Shed*	*Day to 50% Silking*	*Day to 80% Maturity*	*No. of Cobs/Plot*	*Plant height (cm)*	*Ear height (cm)*	*Ear length (cm)*	*Ear girth (cm)*	*1000 grain weight (gm)*	*Shelling percentage (%)*	*Cob Yield/ Plot (kg)*	*Grain Yield/ Plot (kg)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Parents													
Line													
V938-37	-7.71**	1.63**	1.40**	3.10**	-8.36**	-5.00	-9.26**	0.70**	-0.09	-21.47**	-0.97	-0.80**	-0.68**
Z486-7	-2.71*	1.30**	1.07**	-2.34**	-3.36*	3.77	6.07**	-0.50	-0.98**	-13.96**	-0.60	-0.54**	-0.44**
P62C6	-5.16**	0.52**	0.29**	-1.01**	-5.13**	-3.16	2.82	-0.45	-0.03	-30.59**	-0.37	-0.59**	-0.48**
IAMI-8	0.07	1.52**	1.62**	1.66**	0.53	-1.96	-0.71	0.12	0.69**	22.28**	0.83	-0.34	-0.22
IAMI-12	5.18**	2.63**	2.73**	3.21**	5.31**	21.88**	16.78**	0.61*	-0.11	15.61**	0.22	0.33	0.28
IAMI-13	4.51**	-0.37**	-0.60**	2.32**	4.87**	-1.56	3.49	-0.03	-0.18	-7.77**	-0.29	0.67**	0.49**
IAMI-18	-1.60	-1.48**	-1.04**	-0.57**	-1.91	1.15	-2.33	-0.43	0.43**	6.43**	0.58	-0.37	-0.26
IAMI-22	-1.60	2.70**	-2.60**	-3.57**	-0.58	-17.69**	-20.66**	0.44	-0.09	0.06	-0.18	0.08	0.06
IAMI-24	7.62**	-1.92**	-1.82**	-4.57**	7.76**	-2.52	-2.40	-0.99**	0.53**	29.19**	0.41	1.30**	1.00**
IAMI-31	1.40	-1.14**	-1.04**	1.77**	0.87	5.08	6.20*	0.52*	-0.16	0.21	0.35	0.26	0.25
SE (Lines)	1.29	0.16	0.14	0.23	1.35	4.11	2.57	0.26	0.16	1.67	0.55	0.20	0.15
Testers													
HKI 1344	-0.83	-1.18**	-1.11**	-3.38**	-0.91	-15.59**	-1.50	-0.86**	-0.32**	5.24**	-0.14	-0.82**	-0.63**
BML-7	-2.57**	1.69**	1.86**	1.39**	-2.81**	6.04**	-3.81**	0.95**	0.03	-2.58**	0.19	-0.12	-0.08
BMLL-6	3.40**	-0.51**	-0.74**	1.99**	3.72**	9.56**	5.31**	-0.09	0.30**	-2.65**	-0.05	0.93**	0.70**
SE(Testers)	0.61	0.07	0.07	0.11	0.64	1.94	1.21	0.12	0.07	0.79	0.26	0.10	0.07

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

Table 4

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

Crosses	*Final Plant Stand*	*Day to 50% Pollen Shed*	*Day to 50% Silking*	*Day to 80% Maturity*	*No. of Cobs / Plot*	*Plant height (cm)*	*Ear height (cm)*	*Ear length (cm)*	*Ear girth (cm)*	*1000 grain weight (gm)*	*Shelling Percentage (%)*	*Cob Yield/ Plot (kg)*	*Grain Yield/ Plot (kg)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
V938-37 * HKI 1344	15.94**	-2.93**	-3.00**	-1.07**	16.02**	2.39	-0.01	0.50	0.17	12.62**	-0.26	2.93**	2.19**
V938-37 * BML-7	-11.32**	-1.80**	-1.97**	-2.17**	-11.41**	-24.10**	-12.77**	-0.31	-0.05	-3.99	0.55	-3.04**	-2.25**
V938-37 * BML-6	-4.62*	4.73**	4.97**	3.23**	-4.61*	21.71**	12.78**	-0.20	-0.12	-8.63**	-0.29	0.11	0.06
Z486-7 * HKI1344	0.28	-1.60**	-1.67**	0.04	0.36	2.95	-4.21	0.37	0.12	-2.56	-0.32	0.09	0.06
Z486-7 * BML-7	7.68**	0.87**	0.70**	3.94**	7.92**	2.59	0.76	-0.11	-0.16	4.26	-0.39	0.99**	0.71**
Z486-7 * BML-6	-7.96**	0.73**	0.97**	-3.99**	-8.28**	-5.53	3.44	-0.26	0.03	-1.70	0.71	-1.09**	-0.77**
P62C6 * HKI 1344	-9.61**	1.18**	1.11**	-3.29**	-9.20**	-5.59	-6.90	-0.21	-0.36	-3.12	1.11	-1.75**	-1.27**
P62C6 * BML-7	18.79**	1.31**	1.14**	1.61**	18.70**	-0.95	2.28	0.18	0.09	4.40	-0.32	2.22**	1.68**
P62C6 * BML -6	-9.18**	-2.49**	-2.26**	1.68**	-9.50**	6.53	4.62	0.03	0.28	-1.27	-0.79	-0.47	-0.40
IAMI-8 * HKI 1344	12.50**	2.18**	2.78**	1.04**	12.80**	12.61	5.90	0.68	0.06	-1.12	0.14	2.19**	1.70**
IAMI-8 * BML-7	-2.10	2.31**	1.81**	-0.06	-2.30	10.05	6.34	-0.20	-0.49*	1.70	-1.69*	0.73*	0.46*
IAMI-8 * BML-6	-10.40**	-4.49**	-4.59**	-0.99**	-10.50**	-22.67**	-12.24**	-0.48	0.43	-0.57	1.55*	-2.92**	-2.16**
IAMI-12 * HKI 1344	8.39**	1.07**	1.67**	-2.51**	9.02**	12.70*	5.88	-0.61	0.32	24.54**	-1.45	1.76**	1.24**
IAMI-12 * BML-7	-3.21	-2.47**	-2.97**	-1.94**	-3.74	-0.12	-2.28	0.38	0.37	-7.30**	1.32	-0.27	-0.14
IAMI-12 * BML-6	-5.18**	1.40**	1.30**	4.46**	-5.28**	-12.58*	-3.60	0.23	-0.70**	-17.24**	0.12	-1.49**	-1.09**
IAMI-13 * HKI 1344	-5.28**	0.40	0.33**	-3.62**	-4.87*	8.75	11.10**	-0.10	-0.34	-7.41**	0.43	0.62*	-0.44*
IAMI-13 * BML-7	0.79	-0.80**	-0.97**	-1.06**	0.03	-4.68	-5.32	-0.51	0.11	-2.06	-0.70	0.55	0.38
IAMI-13 * BML-6	4.49*	0.40	0.63**	4.68**	4.83**	-4.07	-5.78	0.60	0.23	9.47**	0.27	0.07	0.06
IAMI-18 * HKI 1344	-8.83**	2.18**	2.44**	5.93**	-9.09**	-10.76	-4.81	-0.90*	-0.45*	-2.28	0.96	-1.57**	-1.15**
IAMI-18 * BML-7	-0.43	-1.69**	-1.52**	-4.17**	-0.52	1.21	-1.30	0.02	-0.17	1.67	0.10	0.53	0.43**
IAMI-18 * BML-6	9.27**	-0.49*	-0.92**	-1.77**	9.61**	9.56	6.11	0.87*	0.62*	0.61	-1.07	1.04**	0.72**
IAMI-22 * HKI 1344	-8.50**	-0.27	-0.67**	0.27	-8.76**	-17.05*	-3.01	0.04	-0.36	-5.90*	-0.38	-1.33**	-1.04**
IAMI-22 * BML-7	-5.43**	0.53*	1.03**	3.50**	-5.19**	9.12	3.83	-0.24	0.42	1.92	-0.48	-0.63*	-0.52**
IAMI-22 * BML-6	13.93**	-0.27	-0.37	-3.77**	13.94**	7.93	-0.82	0.20	-0.05	3.98	0.86	1.96**	1.56**
IAMI-24 * HKI 1344	8.94**	-2.04**	-2.44**	3.27**	8.58**	-3.03	-0.41	0.33	0.55*	-3.37	1.30	0.89**	0.78**
IAMI-24 * BML-7	-8.99**	0.76**	1.26**	-0.50	-7.86**	-1.92	1.03	0.31	-0.07	4.18	0.53	-1.27**	-0.93**
IAMI-24 * BML-6	0.04	1.29**	1.19**	-2.77**	-0.72	4.96	-0.62	-0.64	-0.48*	-0.82	-1.83*	0.38	0.15
IAMI-31 * HKI 1344	-13.83**	-0.16	-0.56**	-0.07	-14.87**	-2.96	-3.54	-0.12	0.30	-11.39**	-1.54	-2.61**	-2.06**
IAMI-31 * BML-7	4.23*	0.98**	1.48**	0.83*	4.37*	8.81	7.43*	0.47	-0.05	-4.77	1.07	0.19	0.19
IAMI-31 * BML-6	9.60**	-0.82**	-0.92**	-0.77*	10.5**	-5.84	-3.89	-0.35	-0.25	16.16**	0.47	2.14**	1.87**
Sem ±	1.83	0.22	0.20	0.32	1.91	5.81	3.63	0.37	0.22	2.36	0.78	0.29	0.21

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

Table 5
Average (MP-parent) Heterosis, Heterobeltiosis and Standard heterosis for grain yield in maize

Cross combination	*Grain Yield (Kg/plot)*						
	Average Heterosis (%)	*Heterobeltiosis (%)*	*Standard Heterosis (%)*				
			NK 30	*Hisbell*	*Pro 4212*	*DHM*	*NMH 731*
V938-37							
V938-37 * HKI 1344	340.51**	335.00**	-36.26**	-20.55**	18.37**	7.41**	-10.77**
V938-37 * BML-7	46.15**	42.50**	-79.12**	-73.97**	-61.22**	-64.81**	-70.77**
V938-37 * BML-6	279.75**	275.00**	-45.05**	-31.51**	2.04**	-7.41**	-23.08**
Z486-7							
Z486-7 * HKI1344	151.61**	116.67**	-57.14**	-46.58**	-20.41**	-27.78**	-40.00**
Z486-7 * BML-7	232.61**	183.33**	-43.96**	-30.14**	4.08**	-5.56**	-21.54**
Z486-7 * BML-6	183.87**	144.44**	-51.65**	-39.73**	-10.20*	-18.52**	-32.31**
P62C6							
P62C6 * HKI 1344	97.40**	94.87**	-72.20**	-65.34**	-48.37**	-53.15**	-61.08**
P62C6 * BML-7	376.32**	376.32**	-33.74**	-17.40**	23.06**	11.67**	-7.23**
P62C6 * BML -6	268.83**	264.10**	-48.02**	-35.21**	-3.47**	-12.41**	-27.23**
IAMI-8							
IAMI-8 * HKI 1344	249.49**	188.33**	-36.59**	-20.96**	17.76**	6.85**	-11.23**
IAMI-8 * BML-7	210.20**	153.33**	-44.29**	-30.55**	3.47**	-6.11**	-22.00**
IAMI-8 * BML-6	95.96**	61.67**	-64.51**	-55.75**	-34.08**	-40.19**	-50.31**
IAMI-12							
IAMI-12 * HKI 1344	300.00**	262.50**	-36.26**	-20.55**	18.37**	7.41**	-10.77**
IAMI-12 * BML-7	246.51**	210.42**	-45.38**	-31.92**	1.43**	-7.96**	-23.54**
IAMI-12 * BML-6	231.03**	200.00**	-47.25**	-34.25**	-2.04**	-11.11**	-26.15**
IAMI-13							
IAMI-13 * HKI 1344	246.67**	233.33**	-52.42**	-40.68**	-11.63**	-19.81**	-33.38**
IAMI-13 * BML-7	362.16**	350.00**	-37.36**	-21.92**	16.33**	5.56	-12.31**
IAMI-13 * BML-6	393.33**	374.36**	-32.20**	-15.48**	25.92**	14.26**	-5.08**
IAMI-18							
IAMI-18 * HKI 1344	75.51**	45.76**	-68.46**	-60.68**	-41.43**	-46.85**	-55.85**
IAMI-18 * BML-7	209.28**	154.24**	-45.05**	-31.51**	2.04**	-7.41**	-23.08**
IAMI-18 * BML-6	271.43**	208.47**	-33.30**	-16.85**	23.88**	12.41**	-6.62**
IAMI-22							
IAMI-22 * HKI 1344	106.25**	73.68**	-63.74**	-54.79**	-32.65**	-38.89**	-49.23**
IAMI-22 * BML-7	175.79**	129.82**	-51.98**	-40.14**	-10.82**	-19.07**	-32.77**
IAMI-22 * BML-6	352.08**	280.70**	-20.55**	-0.96**	47.55**	33.89**	11.23**
IAMI-24							
IAMI-24 * HKI 1344	328.24**	295.65**	-33.30**	-16.85**	23.88**	12.41**	-6.62**
IAMI-24 * BML-7	250.00**	219.57**	-46.15**	-32.88**	0.00	-9.26**	-24.62**
IAMI-24 * BML-6	377.65**	341.30**	-25.60**	-7.26**	38.16**	25.37**	4.15**
IAMI-31							
IAMI-31 * HKI 1344	89.74**	89.74**	-72.86**	-66.16**	-49.59**	-54.26**	-62.00**
IAMI-31 * BML-7	310.39**	305.13**	-42.09**	-27.81**	7.55**	-2.41**	-18.92**
IAMI-31 * BML-6	494.87**	494.87**	-15.05**	5.89**	57.76**	43.15**	18.92**

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

Table 6
crosses with desirable *sca,* gca and per se effects of the parents

Characters	*Significant crosses*	*sca effects*	*gca effects*		*per se performance*		
			line	*tester*	*F1*	*line*	*Tester*
Grain yield per plot	V938 *HKI 1344	2.19**	-0.68**	-0.63**	5.80	1.33	1.30
	IAMI 31 * BML 6	1.87**	0.25	0.70	7.73	1.30	1.30
	IAMI 8 *HKI 1344	1.70**	-0.22	-0.63**	5.77	2.00	1.30
Days to 50 % pollen shed (Earliness)	**IAMI8*BML6**	-4.49**	1.52**	-0.51**	51.00	56.00	58.00
	V938*HKI 1344	-2.93**	1.63**	-1.18**	52.00	54.67	58.33
	P62 * BML 6	-2.49**	0.52**	-0.51**	52.00	57.67	58.00
Days to 50 % silking (Earliness)	IAMI 8 *BML 6	-4.59**	1.62**	-0.74**	54.00	59.00	56.97
	V938-37 * HKI1344	-3.00**	1.40**	-1.11**	55.00	58.33	56.60
	IAMI 12 * BML 7	-2.97**	2.73**	-1.86**	59.00	64.33	59.57
Plant height (cm)	**V938 * BML 7**	-24.10**	-5.00	6.04**	214.93	149.93	186.60
	IAMI 8 *BML 6	-22.67**	-1.96	9.56**	222.93	205.13	198.30
	IAMI 22 * HKI 1344	-17.05*	17.69**	15.59**	91.00	152.27	173.6
Ear height (cm)	V938 * BML 7	-12.77**	-9.26**	-3.81	86.80	43.73	69.47
	IAMI 8 * BML 6	-12.24**	-0.71	5.31**	89.93	79.60	83.90
	P62 * HKI1344	-6.90	2.82	-1.50	92.00	61.60	75.20
Ear length (cm)	**IAMI 18 * BML 6**	0.87*	-0.43	-0.09	16.87	16.60	14.67
	IAMI 8 * HKI 1344	0.68	0.12	-0.86	16.47	15.73	12.07
	IAMI 13 * BML 6	0.60	-0.03	-0.09	17.00	11.33	14.67
Ear girth (cm)	IAMI 18 * BML 6	0.62*	0.43**	0.30**	15.80	12.40	13.40
	IAMI 24 * HKI 1344	0.55*	0.53**	-0.32**	15.20	11.87	11.47
	IAMI 8 * BML 6	0.43	0.69**	0.30**	15.87	13.53	13.40
Days to 80 % dry husk (Earliness)	**IAMI 18 * BML 7**	-4.17**	-0.57**	1.86**	94.33	101.00	101.00
	Z 486-7 * BML 6	-3.99**	-2.34**	-0.74**	93.33	100.67	105.00
	IAMI 22 * BML 6	-3.77**	-3.57**	-0.74**	92.33	96.33	105.00
Days to 80 % dry husk (Late)	IAMI 18 * HKI 1344	5.93**	-0.57**	-3.38**	99.67	101.00	97.33
	IAMI 13 * BML 6	4.68**	2.32**	-0.74**	106.67	94.33	105.00
	IAMI 12 *BML 6	4.46**	3.21**	-0.74**	107.33	107.67	105.00
1000 grain weight in gram (Boldness)	**IAMI 12 * HKI 1344**	24.54**	15.61**	5.24**	339.67	267.27	238.93
	IAMI 31 * BML 6	16.16**	0.21	-2.65**	308.00	282.87	269.07
	V938 * HKI 1344	12.62**	-21.47**	5.24**	290.67	240.73	238.93
Shelling % (High)	IAMI 8 * BML 6	1.55*	0.83	-0.05	78.30	77.00	73.00
	IAMI 12 * BML 7	1.32	0.22	0.19	77.70	74.63	77.30
	IAMI 24 * HKI 1344	1.30	0.41	-0.14	77.53	74.33	76.57

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

(1992), Satyanarayana *et al.* (1994), Joshi *et al.* (2002), Prasad and Pramod Kumar (2003), Vijayabharathi *et al.* (2009), Kanagarasu *et al.* (2010), Pavan *et al.* (2011), Abrha *et al.* (2013), Gowda *et al.* (2013) and Hussein *et al.* (2015). Contrarily, importance of additive gene effects was also reported by Sharma *et al.* (2004), Alamnie *et al.* (2006) and Dar *et al.* (2015).

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. A high degree of relative heterosis and heterobeltiosis was observed for grain yield in all the hybrids. The highest significant positive average heterosis was recorded by cross IAMI-31/BML-6 (494.87 %) followed by IAMI-13/BML-6(393.33%) and IAMI-24/BML-6(377.65%). Highest significant positive heterosis over better parent recorded by cross IAMI-31/BML-6 (494.87%) followed by P62C6/BML-7 (376.32%) and IAMI-13/BML-6(374.36%). The standard heterosis (over NK-30) ranged from -15.05 % (IAMI-31/BML-6) to -79.12% (V938-37/BML-7). High standard heterosis was recorded against check Pro 4212 and DHM 117 for this trait in crosses *viz*., IAMI 24/BML 6, IAMI 22/ BML 6, IAMI 18/BML 6, IAMI 31/BML 6, IAMI 13/BML 6, IAMI 13/BML 7, IAMI 8/HKI 1344, IAMI 12/HKI 1344, V 938-37/HKI 1344 and P62C6/BML 7 (Table-5). These findings are in confirmatory with the results of Mohammed (2005), Muraya *et al.* (2006), Hussain *et al.* (2011), and Padma and Razdan (2017).

Three best crosses with significant sca effects for various traits along with per se performance and gca effects of parents involved in the crosses are listed in Table 6. Most of the crosses selected on the basis of significant sca effects also had high per se performance. Among thirty crosses, many of the crosses were ranked as top crosses for one or more characters. None of the crosses was found desirable simultaneously for all the characters i.e., different crosses expressed significant sca effects for different characters. However, out of 30 crosses, 5 crosses (V938-37 x HKI 1344, IAMI 31 x BML 6, IAMI 8 x HKI 1344, P 6266 x BML 7 and IAMI 22 x BML 6) had shown highly significant positive sca effects for grain yield. Similarly the crosses which exhibited significant desirable sca effects for earliness were IAMI 8 x BML 6 & V 938-37 x HKI 1344 for days to 50 per cent tasseling and also for days to 50 per cent silking; V 938-37 x BML 7 for short plant height and ear height. Considering cob and grain characters, the crosses viz., IAMI 18 x BML 6 (cob length and cob diameter), and IAMI 12 x HKI 1344 (100 grain weight) were exhibited significant sca effects. The results of the present study obtained are in agreement with the earlier findings of Pal and Prodhan (1994), Rao *et al*., (1996), Mahto and Gunguli (2003), Malik *et al*., (2004) and Kanagarasu *et al*., (2010) for grain yield and other component characters.

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