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Combining ability study for grain yield and its contributing characters in maize (*Zea mays* L.)

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Abstract

Combining ability for grain yield and its contributing characters was carried out in maize through line × tester analysis of 60 hybrids developed by crossing 15 females and four testers along with parents and checks. The 60 hybrids along with 19 parents and three standard checks were grown in Randomized Completely Block Design with two replications and were evaluated for grain yield and its 12 contributing characters. The experiments were conducted at Zonal Agricultural Research Station, V.C. Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka state during rabi 2010.The analysis of variance indicated the presence of significant variability among the genotypes for almost all the quantitative traits studied. Combing ability analysis showed the predominant role of non-additive gene action for inheritance of all the characters studied. The lines MAI31, MAI28, and MAI35 were best general combiners exhibiting high gca effects in a desirable direction for three traits each. The tester CM500 was identified as a best combiner for grain yield per plot and some other traits studied. The hybrids MAI45×CM202, MAI33×CM202 and MAI43×CM500 were promising with respect to sca effects for grain yield as they showed high sca for that trait. These best crosses involved high × low and low × low performing parental combinations. Further, the promising single cross hybrids having a parental combination of high × high, high × low gca effects could be used for the improvement of parental lines for desired characters by selecting in advanced generations.

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Introduction

Maize (*Zea mays* L.) is one of the most important crops in world agricultural economy and ranks third next to wheat and rice in production. It is a versatile crop with wider genetic variability and able to grow successfully throughout the world coveringtropical, subtropical and temperate agro-climatic conditions (Morris *et al*., 1999). In the year 2013, maize was the leading cerealcrop with 1016 millions of metric tons of the world cereal production(excluding minor cereals) followed by rice 745 millions of metric tons andwheat 713 millions of metric tons (FA0, 2013). Given the great economic importance of maize, genetic breeding in this crop is very intense and mostly targeted at increasing grain yield. A frequent method used in maize breeding is to obtain inbred lines that are later crossed in order to develop different types of hybrids, which exhibit high heterosis when the inbred lines are complementary.

Combining ability analysis is one of the powerful tools in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate productive genes (Sprague and Tatum, 1942). It also helps to understand the genetic architecture of various characters that enable the breeder to design effective breeding plan for future improvement of the existing materials (Kempthorne, 1957). Thus a study was undertaken to estimate the nature and magnitude combining ability in the newly developed lines to evaluate their potential to be exploited in yield heterosis.

Materials and methods

Materials

The present study was conducted at Zonal Agricultural research Station, V.C Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka state, India during *Rabi* 2010 seasons. The isolated parents have been used to effect crosses. Fifteen selected inbred lines (MAI23, MAI2, MAI28 ,MAI29, MAI31, MAI32, MAI33, MAI35, MAI38, MAI40, MAI42, MAI43, MAI44, MAI45 and MAI48) were crossed to 4 testers (CM 500, CM 202, MAI 105 and NAI 137) in line × tester mating design in *Rabi* 2010 to generate 60 F_1s for this study. All the nineteen parents (15lines and four testers) together with 60 crosses and three standard checks 30B07, NAH-1137 and NAH-2049 were evaluated during *Rabi* 2011. Each genotype was grown in two rows of two meters length keeping row-to-row and plant to plant distance of 60 and 20 cm respectively and adopting randomized complete block design into two replications. The recommended packages of cultural practices, fertilizer levels and protection measures were followed to raise good crop. The data were recorded on days to 50 per cent tasseling, days to 50 per cent silking, days to 50 per cent brown husk to maturity, plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), number of kernel rows per cob, number of kernels per row, shelling percentage, 100-grain weight (g), fodder yield (kg/plot) and grain yield (kg/plot).

Methods

Mean values of the 13 quantitative characters recorded on the hybrids and parents were subjected to statistical analysis and variances were estimated following the method of Panse and Sukhatme (1961). According to these authors, the mean data of quantitative characters recorded on all the genotypes are subjected to the analysis of variance (ANOVA) to get MSS due to replications, treatments and error and the error and to find out whether the treatments differ significantly by comparing the calculated F (treatments MSS/error MSS) with the table F value. Treatments might be only LxT hybrids or LxT hybrid and parents (L+T). If parents are included, then the treatments SS is partitioned into SS due to parents, SS due to crosses and SS due to parents Vs crosses to find out the significance of each of the corresponding MS by comparing with the error MSS.

The combining ability analysis was done according to the procedure developed by Arunachalam and Bandopadyaya (1979). According to Arunachalam and Bandopadyaya (1979), the analysis of variance for combining ability along with expectations of mean squares is as follows:

Analysis of Variance for Combining Abilit

Source	df	SS	MS	Expectations of mean squares
Crosses	(lt-l)	CSS		
Lines	(l-1)	LSS	MS_1	$\delta_e^2 + r(Cov.FS - 2Cov.HS) + rt$ (Cov.HS)
Testers	(t-1)	TSS	MS_2	$\delta_e^2 + r(Cov.FS - 2Cov.HS) + rt$ (Cov.HS)
Line X testers	(l-1)(t-l)	LxTSS	MS_3	$\delta_e^2 + r(Cov.FS - 2Cov.HS) + rt\ \delta_e^2$
Error	(r-1)(lt-1)	ESS	MS_4	
Total	(rlt-1)			

In addition the Genetic Information technique was used in this study. This technique provides information on the general and specific combining ability variances and effects:

a) Combining Ability Variances

-Variance of GCA= Cov.HS (Covariance of Hals Sibs)

- Variance of GCA=Cov.HS-2Cov.HS (Cov.FS = Coveriance of Full Sibs)

- $Cov.HS = \frac{(MS_1 - MS_3) + (MS_2 - M_3)}{r(l+t)}$

$$Cov.FS = \frac{MS_1 + MS_2 + MS_3 - 3MS_4)}{3r} + \frac{6rCov.HS - r(l+t)Cov.HS}{3r}$$

- $Cov.FS - 2Cov.HS = \left(\frac{MS_3 - MS_4}{r}\right)$i) Where the parents are inbreds or purelines (inbreeding co-efficient, F=1), - $Cov.HS = \frac{1}{2}\delta_D^2 \frac{1}{4}\delta_{DD}^2 +$ other forms of additive epistasis

- $Cov.FS = \delta_D^2 + \delta_H^2 + \delta_{DD}^2 + \delta_{DH}^2 + \delta_{HH}^2 +$ other forms of epistasis

Assuming there is no epitasis,

- δ_D^2 (Additive genetic variance)=2Cov.HS or $2\delta^2 GCA$

- δ_H^2 (Dominance genetic variance)= COV.FS-2Cov.HS or $2\delta^2 SCA$

When the parents are non-inbreds or cross pollinated parents (inbreeding coefficient, F=0),

- $Cov.HS = \frac{1}{4}\delta_D^2 \frac{1}{16}\delta_{DD}^2$ +other forms of additive epistasis

$$Cov.FS = \frac{1}{2}\delta_D^2 + \frac{1}{4}\delta_H^2 + \frac{1}{4}\delta_{DD}^2 + \frac{1}{8}\delta_{DH}^2 + \frac{1}{16}\delta_{HH}^2$$

+other forms of epistasis

Assuming there is no epistasis.

- δ_D^2 (Additive genetic variance) = 4Cov.HS or $4\delta^2 GCA$

- δ_H^2 (Dominance genetic variance) = 4[COV.FS-2Cov.HS] or $4\delta^2 SCA$

b) Combining Ability Effects

-gca effects of lines (*g*$_i$)= $\frac{x_{i..}}{rt} - \frac{x...}{rlt}$

-gca effects of lines (*g*$_j$)= $\frac{x_{.j.}}{rl} - \frac{x...}{rlt}$

-sca effects of hybrids (S_{ij})= $\frac{x_{ij.}}{r} - \frac{x_i}{rt} - \frac{x_{.j.}}{rl} + \frac{x_{...}}{rlt}$

Where,

- $x_{...}$ - Total of all hybrids over replications

- $x_{i..}$ - Total of i^{th}line over *t* testers and replications

- $x_{.j.}$ - Total of j^{th}tester over *l* lines and *r* replications

- x_{ij} - Total of the hybrid between i^{th} line and j^{th} tester over *r* replications.

Significance of effects by't' test

- SE for *gca* effects of lines = $\sqrt{\frac{EMS}{rt}}$

- SE for *gca* effects of testers = $\sqrt{\frac{EMS}{rl}}$

- SE for *sca* effects of hybrids = $\sqrt{\frac{EMS}{r}}$

To test the significance of various effects,

- $t = \dfrac{effect}{SE}$

This calculated'*t*' value can be compared with table'*t*' value at error degrees of freedom.

The overall status of a parent or cross with respect to *gca* and *sca* respectively was determined following a method suggested by Arunachalam and Bandopadyaya (1979).

Results and discussion

1. Analysis of variance for grain yield and its contributing characters in maize ((Zea mays L.)

The analysis of variance (Table 1) revealed significant variation among parents and also among hybrids in respect of 13 characters, there by justifying the appropriateness of genetic material which has been involved in the study.

Table 1. Analysis of variance for grain yield and its contributing characters in maize (*Zea mays* L.).

Source of Variance	df	Mean of squares												
		Days to 50% tasseling	Days to 50% silking	Days to 50% husk brown maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows per cob	Kernels per row	Shelling (%)	100-grain weight (g)	Fodder yield/plot (kg)	Grain yield/plot (kg)
Replication	1	0.10	0.76	1.06	19.91	0.82	0.24	0.67	0.02	0.19	0.05	0.31	0.12**	0.0001
Genotypes	78	11.07**	11.92**	2.06	762.15**	287.71**	5.95**	3.70**	3.78**	23.93**	17.99**	17.34**	0.42**	0.32**
Parents	18	18.82**	21.63**	36.44**	867.71**	260.02**	8.91**	2.55**	3.47**	29.90**	18.71**	15.10**	0.20**	0.19**
Crosses	59	8.71**	8.95**	27.70**	410.31**	230.51**	2.35**	1.31**	2.33**	20.93**	9.80**	16.03**	0.31**	0.16**
Lines(c)	14	15.64**	16.08**	54.03**	561.01**	211.86**	2.16**	1.20**	5.33**	31.78**	14.35**	26.32**	0.32**	0.16**
Testers(c)	3	2.61**	7.03**	12.32**	247.13**	244.72**	2.60**	0.26	0.64	29.51**	5.62**	3.08**	0.29**	0.19**
L×T (c)	42	6.83**	6.71**	20.01**	371.73**	235.71**	2.40**	1.41**	1.45**	16.70**	8.59**	13.52**	0.31**	0.16**
Parents Vs Crosses	1	11.51**	13.01**	116.45**	20161.00**	4234.85**	166.17**	165.24**	19.72**	94.28**	495.76**	133.19**	8.41**	15.90**
Error	78	0.56	0.80	0.39	6.62	2.18	0.54	0.47	0.43	1.62	2.28	0.54	0.01	0.001

*Significant at P = 0.05 level

**Significant at P = 0.01 level.

The mean sum of squares for parents was highly significant for all the characters which indicated the presence of sufficient variability among parents. Highly significant mean square variances for almost all the characters were also observed in case of males and females, which indicated the significance of additive variance and significance of mean sum of squares for line × tester indicate the significance of dominance variance.

The mean sum of squares for hybrids was highly significant, which indicated the diverse performance of different cross combinations for all traits. The parents versus hybrids mean sum of squares were highly significant for all traits, which revealed the presence of heterosis due to the significant difference in the mean performance of hybrids and parents. Similar results were also reported earlier by Ali and Topara (1986), Dass *et al.* (1987) and Paul and Debanath (1999).

2. General combining ability effects of parents for grain yield and its contributing characters in maize (Zea mays L.).

The analysis of variance for combining ability revealed that the variances dues to sca were highly significant than variances dues to gca for all the characters. The ratio of gca to sca variance was less than the unity for all the traits. The higher sca variance revealed the predominance of non additive genetic variance. Also from the estimates of additive and dominance variance, it was observed that dominance variance was predominant for all the characters which suggested the predominance of non-additive gene action in the inheritance of those characters. Similar results were also reported earlier by Mathur and Bhatnagar (1995), Paul and Debanath (1999), Rana and Vinod Kumar (2001), Alamnie *et al.* (2003) and Amit-Dadheech and Joshi (2007).

Table 2. General combining ability effects of parents for grain yield and its contributing characters in maize (*Zea mays* L.).

Characters	Days to 50% Tasseling	Days to 50% silking	Days to 50% brown husk maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows per cob	Kernels per row	Shelling %	100 -grain weight (g)	Fodder yield/plot(kg)	Grain yield/plot(kg)	Overall gca status
Lines														
MAI23	-0.50 *	-1.09 **	-2.17 **	-9.38 **	-9.22 **	0.26	-0.09	-0.65 **	-3.91 **	0.71	2.11 **	0.02	0.10 **	L
MAI27	-2.13 **	-2.47 **	-4.17 **	-12.25 **	-1.93 **	0.21	-0.26	-1.25 **	-0.91 **	0.16	-1.89 **	-0.04 *	0.01	H
MAI28	-3.13 **	-3.09 **	-6.04 **	-10.29 **	-7.45 **	-0.10	-0.41	-0.63 *	-2.31 **	-2.82 **	1.48 **	-0.13 **	-0.31 **	H
MAI29	-0.75 **	-0.84 **	-1.67 **	-0.05	2.35 **	0.28	-0.49 *	-0.45	-0.23	1.16 *	2.98 **	-0.26 **	0.15 **	L
MAI31	1.00 **	1.16 **	2.58 **	11.36 **	-0.63	0.21	0.03	1.20 **	3.29 **	2.00 **	-0.52	-0.01	0.28 **	L
MAI32	1.38 **	1.41 **	1.58 **	6.31 **	5.35 **	0.08	-0.68 **	1.37 **	1.59 **	-0.29	-2.64 **	0.39 **	0.02	L
MAI33	0.00	0.91 **	0.83 **	5.10 **	-2.78 **	0.17	0.36	0.65 **	1.43 **	1.17 *	-2.14 **	0.36 **	-0.09 **	L
MAI35	1.00 **	0.53	0.71 **	13.16 **	7.92 **	1.11 **	0.08	0.30	2.89 **	1.67 **	0.73 **	0.14 **	0.01	L
MAI38	2.00 **	1.78 **	2.71 **	1.22	-2.79 **	0.61 *	0.18	0.87 **	1.67 **	-0.62	-1.89 **	0.04	0.07 **	H
MAI40	-1.00 **	-0.34	-0.92 **	6.08 **	4.98 **	-0.72 **	-0.32	0.37	-0.66 *	-2.02 **	-2.14 **	0.02	-0.13 **	H
MAI42	1.50 **	1.53 **	2.83 **	0.70	2.40 **	-0.45	-0.12	-0.70 **	-0.11	-0.85	0.86 **	-0.15 **	-0.06 **	H
MAI43	0.25	0.03	-0.04	6.06 **	2.07 **	-0.25	0.77 **	0.45	-0.68 *	0.61	1.98 **	-0.08 **	0.15 **	L
MAI44	0.88 **	0.66 *	2.46 **	-12.22 **	-7.60 **	-0.47	0.43	0.02	0.27	-0.40	0.61 *	-0.36 **	-0.09 **	H
MAI45	-0.50 *	-0.09	0.71 **	-4.42 **	4.42 **	-0.94 **	0.32	-0.78 **	-2.63 **	0.17	-0.39	-0.00	-0.14 **	H
MAI48	0.00	-0.09	0.58 **	-1.38 *	2.92 **	0.01	0.21	-0.78 **	0.29	-0.67	0.86 **	0.07 **	0.02 *	H
SE	0.24	0.32	0.22	0.69	0.35	0.24	0.24	0.24	0.32	0.56	0.27	0.02	0.01	
Testers														
CM500	-0.27 *	-0.46 **	-0.33 **	0.83 *	-3.15 **	0.05	-0.09	-0.21	0.60 **	-0.17	0.48 **	0.12 **	0.12 **	L
CM202.	-0.20	-0.32 *	-0.77 **	-4.50 **	-1.70 **	-0.28 *	0.11	0.04	-0.22	0.59 *	-0.08	-0.10 **	-0.03 **	L
MAI105	0.13	0.34 *	0.57 **	1.54 **	1.63 **	0.42 **	-0.04	0.16	0.95 **	0.00	-0.32 *	-0.01	-0.02 **	L
NAI137	0.33 **	0.44 **	0.53 **	2.12 **	3.21 **	-0.19	0.02	0.02	-1.33 **	-0.42	-0.08	-0.01	-0.07 **	H
SE	0.12	0.16	0.11	0.36	0.18	0.12	0.13	0.12	0.16	0.29	0.14	0.01	0.01	

*Significant at P=0.05 level

**Significant at P=0.01 level.

Among the parents with significant gca effects, the ones with higher magnitude of gca effects were considered as superior to those with lower magnitude. Eight out of 15 lines and one out of 13 testers had high overall general combining ability status, while the remaining parents had low (L) overall general combining ability status implying that around 50 (47.3) per cent of parents were high overall general combiners which suggested their ability to transmit additive genes in desirable direction for the traits under study (Table 2).

Study of gca effects of parents (Table 2) indicated that the genotypes MAI23, MAI27, MAI28, MAI29, MAI40 and MAI45 among lines and CM 500, CM202 among testers had significant gca effects in desirable direction for maturity characters like days to 50 per cent tasseling, days to 50 per cent silking and days to 50 percent brown husk maturity. Sanghi (1982), Suneetha *et al.* (2001), Desai and Singh (2001) also reported good combiners for maturity characters. The lines *viz,* MAI31, MAI32, MAI33, MAI35, MAI40, MAI43 MAI48 and testers MAI105, NAI137 are the best general combiners for plant height and ear height. Desai and Sing (2001), Kumar *et al.* (1998), Amer *et al.* (2002) reported predominant role of gca effects for these traits.

3. Specific combining ability effects for grain yield and its contributing characters in maize (Zea mays L.).

The parents *viz.*, MAI35, MAI38 and MAI43 were good sources of favourable genes for increased ear length and ear diameter and lines MAI31, MAI32, MAI33, MAI35 and MAI38 showed high general combining ability effects for traits like kernel rows per cob and kernels per row. Lines MAI29, MAI31, MAI33 and MAI35 and tester CM202 were good general combiners for shelling percentage whereas, lines MAI23, MAI28, MAI29, MAI35, MAI42, MAI43, MAI45 and MAI48 were having high general combining ability effects for test (100-grain) weight. Kara (2001), Desai and Singh (2001), Malik *et al.* (2004) also reported significant gca effects for kernel rows per cob, ear diameter and test weight. Based on the gca effects, the best general combiners for fodder yield per plot were MAI32, MAI33, MAI35 and MAI48 in lines and CM500 among testers whereas, the lines MAI23, MAI29, MAI31, MAI38, MAI43 and one tester CM500 were identified as good combiners for grain yield per plot as evident from their significant gca effects in positive direction for this trait (Table 2). Mohamed (1993), Kumar *et al.* (1998) and Amer *et al.* (2002) also reported good combiners for grain yield per plot.

Table 3. Specific combining ability effects for grain yield and its contributing characters in maize (*Zea mays* L.).

Sl. No.	Crosses	Days to 50% tasseling	Days to 50% silking	Days to 50% brown husk maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows per cob	Kernels per row	Shelling (%)	100-grain weight (g)	Fodder yield/plot (kg)	Grain yield/plot (kg)	Overall sca status
1	*MAI23 × CM500*	*1.27 **	*1.46 **	*-0.17*	*13.80 ***	*14.38 ***	*1.70 ***	*0.96 **	*0.69*	*4.25 ***	*0.66*	*0.39*	*-0.22 ***	*-0.11 ***	*L*
2	MAI27 × CM500	-0.80	-1.17	-1.73 **	3.03 *	-3.42 **	-0.17	-1.24 *	0.94	-0.33	-2.95 *	-2.04 **	-0.35 **	-0.17 **	H
3	MAI28 × CM500	0.37	0.16	0.93 *	-3.55 *	-2.50 **	-1.97 **	0.62	-0.08	-1.90 **	2.28 *	1.19 *	0.66 **	0.29 **	L
4	MAI29 × CM500	-0.83	-0.44	0.97 *	-13.28 **	-8.47 **	0.44	-0.35	-1.54 **	-2.02 **	0.01	0.46	-0.09 *	-0.02	H
5	MAI31 × CM500	1.39 **	1.33 *	6.83 **	-14.07 **	-13.60 **	0.35	-0.67	-0.32	1.25	-2.04	0.39	-0.36 **	-0.22 **	H
6	MAI32 × CM500	1.33 **	1.70 **	-0.73	-0.89	-2.35 **	-0.92	1.13 *	1.44 **	-0.63	0.30	-0.54	-0.29 **	0.09 **	H
7	MAI33 × CM500	-0.01	0.03	-1.57 **	15.57 **	12.42 **	-0.32	-0.02	-0.08	2.10 **	-0.02	-0.31	0.22 **	0.08 **	L
8	MAI35× CM500	-2.71**	-3.07 **	-4.53 **	-0.61	3.54 **	0.89	-0.43	-1.04 *	-2.72 **	1.76	0.46	0.43 **	0.05 *	L
9	MAI38 × CM500	0.39	0.46	1.21 **	0.12	1.12	1.16 *	0.58	0.66	0.75	-4.01 **	-0.98	0.28 **	-0.33 **	H
10	MAI40 × CM500	-1.17 *	-1.17	-2.86 **	-9.25 **	-4.43 **	-1.56 **	-0.92	-0.29	-0.43	0.82	-5.92 **	-0.05	-0.06 **	H
11	MAI42 × CM500	-0.01	0.16	0.81	0.86	2.44 **	-0.30	0.38	0.19	-1.10	2.86 *	4.82 **	-0.49 **	-0.03	L
12	MAI43 × CM500	0.79	0.56	0.84	8.28 **	0.87	0.70	-0.03	-0.57	0.78	0.33	2.08 **	0.26 **	0.42 **	L
13	MAI44 × CM500	1.52 **	0.71	-1.67 **	-17.57 **	-16.48 **	0.57	-2.54 **	-0.41	0.88	1.31	1.02	-0.44 **	0.03	H
14	MAI45 × CM500	0.95	1.07	3.27 **	11.16 **	8.37 **	-1.19 *	1.26 *	-0.16	1.69 **	-4.45 **	2.58 **	0.09 *	0.02	L
15	MAI48 × CM500	-5.38**	-4.59 **	-7.57 **	-13.38 **	0.04	0.11	0.02	-0.68	-2.47 **	0.83	-0.18	-0.40 **	-0.11 **	L
16	MAI23 × CM202	2.92 **	2.81 **	5.97 **	19.79 **	8.07 **	0.51	1.25 *	1.26 *	-0.09	2.31 *	-3.42 **	0.75 **	0.06 **	L
17	MAI27 × CM202	-3.73**	-3.29 **	-5.92 **	0.77	-4.80 **	-0.65	-0.46	-0.76	-1.25	-0.93	0.02	-0.24 **	0.18 **	H
18	MAI28 × CM202	2.20 **	2.58 **	3.02 **	14.85 **	14.65 **	-0.72	-0.26	0.19	-0.33	1.21	0.08	0.14 **	0.02	H
19	MAI29 × CM202	-0.13	-0.59	1.68 **	9.71 **	-4.88 **	0.49	0.59	-0.33	0.30	-0.05	-0.68	0.15 **	0.13 **	L
20	MAI31 × CM202	1.67 **	1.31 *	1.22 **	-25.32 **	-4.96 **	0.89	0.13	0.91	1.28 *	-0.23	0.58	-0.05	-0.33 **	H
21	MAI32 × CM202	0.89	0.96	2.58 **	10.17 **	2.52 **	-1.63 **	-0.90	-0.94	-1.35 *	3.41 **	2.64 **	0.51 **	0.11 **	H
22	MAI33 × CM202	-0.17	-0.67	-1.98 **	-3.80 **	-6.68 **	1.71 **	1.25 *	-0.39	3.47 **	1.40	2.21 **	-0.06	0.63 **	L
23	MAI35× CM202	-0.51	0.66	1.68 **	-7.59 **	10.29 **	-0.99 *	-1.29 **	0.69	1.30 *	-1.37	-2.56 **	-0.20 **	-0.39 **	H
24	MAI38 × CM202	-0.21	-0.94	-2.28 **	1.23	-6.13 **	0.91	0.94	0.63	-3.42 **	-3.44 **	-2.29 **	-0.25 **	-0.35 **	H
25	MAI40 × CM202	-4.23**	-3.54 **	-7.17 **	-18.97 **	-11.75 **	-0.92	-0.19	-1.51 **	-3.34 **	-0.75	-0.86	-0.31 **	-0.35 **	H
26	MAI42 × CM202	-0.30	-1.18	2.77 **	8.76 **	4.60 **	0.12	0.51	0.34	-2.07 **	1.84	2.71 **	0.01	0.06 **	L
27	MAI43 × CM202	2.37 **	3.16 **	3.93 **	0.22	-3.03 **	1.72 **	-0.33	0.62	6.46 **	-0.23	-1.06	0.27 **	0.16 **	H
28	MAI44 × CM202	2.17 **	1.56 *	0.47	9.99 **	10.19 **	-0.92	0.00	0.56	-1.06	-0.86	-0.79	0.03	0.13 **	H
29	MAI45 × CM202	-0.23	0.33	4.96 **	37.97 **	28.95 **	0.64	0.99 *	-0.27	5.65 **	0.25	1.77 **	0.96 **	1.00 **	L
30	MAI48 × CM202	-0.30	-0.30	-1.11 *	-21.40 **	-15.20 **	0.08	-0.61	-0.71	-5.33 **	1.99	0.83	-0.36 **	-0.36 **	H
31	MAI23×MAI105	0.37	0.03	-0.94 *	0.46	-2.73 **	0.89	0.64	0.47	1.70 **	-1.68	4.07 **	-0.00	-0.32 **	L
32	MAI27×MAI105	0.17	-0.07	-2.91 **	-17.02 **	-11.01 **	-1.61 **	-1.02 *	0.51	-2.02 **	-0.56	-6.67 **	-0.60 **	-0.31 **	H
33	MAI28×MAI105	1.27 *	1.08	0.46	5.40 **	6.76 **	-1.06 *	0.39	0.56	-1.82 **	1.54	-1.11 *	0.16 **	-0.19 **	H
34	MAI29×MAI105	-0.80	-0.55	-1.11 *	0.98	-1.29	0.48	-0.21	-0.29	0.99	-1.17	0.96	0.04	0.12 **	L
35	MAI31×MAI105	-0.13	-0.72	-0.44	-8.81 **	1.73 *	0.58	-0.26	-0.81	-0.07	-0.64	1.69 **	0.10 *	0.09 **	L
36	MAI32×MAI105	-0.33	0.18	1.09 *	2.42	-7.19 **	-0.01	0.08	0.53	0.91	0.28	-1.54 **	-0.30 **	-0.01	H
37	MAI33×MAI105	2.27 **	2.21 **	2.08 **	-3.36 *	0.93	0.77	0.69	-0.34	2.20 **	-2.17	1.14 *	-0.02	0.25 **	H
38	MAI35×MAI105	-0.80	-1.42 *	-1.48 **	-14.33 **	-4.07 **	-0.39	-0.01	0.41	-0.28	1.63	0.21	-0.04	-0.10 **	L
39	MAI38×MAI105	0.87	0.41	-0.82	-5.57 **	-4.60 **	-0.89	-0.16	-0.01	-5.95 **	-0.29	-1.06	0.12 **	-0.05 *	H
40	MAI40×MAI105	-2.33**	-1.19	0.22	23.25 **	7.73 **	0.51	-0.52	-0.07	4.03 **	0.83	-0.29	-0.05	-0.10 **	L
41	MAI42×MAI105	-1.23 *	-1.17	-0.17	-1.42	5.87 **	-1.29 **	0.89	0.24	-2.65 **	2.22	0.64	0.35 **	-0.22 **	L
42	MAI43×MAI105	0.70	0.20	-1.23 **	7.36 **	2.72 **	0.34	-0.51	-0.71	0.87	-0.44	-2.29 **	0.22 **	0.12 **	H
43	MAI44×MAI105	-0.13	-0.47	2.43 **	-1.78	-11.41 **	0.85	-0.26	1.37 **	-0.10	-0.25	0.94	-0.12 **	-0.11 **	H
44	MAI45×MAI105	0.67	1.43 *	-1.03 *	-4.16 **	2.82 **	0.10	-0.12	-0.89	1.88 **	-1.53	0.71	-0.46 **	0.21 **	H
45	MAI48×MAI105	0.02	-0.67	-1.79 **	-5.98 **	-7.30 **	0.51	-0.30	1.69 **	3.83 **	1.46	-1.48 **	-0.42 **	0.23 **	L
46	MAI23 ×NAI137	-0.55	0.20	0.64	0.70	2.05 **	0.54	0.10	-0.26	-2.06 **	-2.30 *	2.08 **	-0.00	-0.35 **	H
47	MAI27× NAI137	-0.88	-1.47 *	-2.19 **	8.61 **	-1.68 *	-0.55	-0.15	-0.58	-1.22	1.33	-3.68 **	-0.04	0.17 **	L
48	MAI28 ×NAI137	1.42 **	1.93 **	3.34 **	-3.32 *	6.94 **	-0.50	0.34	-0.84	-0.54	-0.49	3.08 **	0.46 **	-0.04	H
49	MAI29 ×NAI137	0.39	0.21	0.71	5.29 **	11.12 **	0.92	0.74	0.01	-3.12 **	-2.03	-0.61	-0.19 **	-0.04 *	H
50	MAI31 ×NAI137	-0.68	-0.43	1.64 **	8.57 **	8.52 **	0.56	-0.06	-0.74	2.19 **	0.61	-0.54	0.34 **	-0.17 **	L
51	MAI32 ×NAI137	1.49 **	1.41 *	-0.19	-8.02 **	-9.11 **	0.56	-0.51	0.44	-0.77	-0.40	-2.81 **	0.05	0.06 **	H
52	MAI33× NAI137	-1.21 *	-1.19	-2.16 **	-5.85 **	-10.53 **	-2.04 **	-0.17	0.28	1.71 **	1.82	3.96 **	-0.20 **	0.15 **	L
53	MAI35 ×NAI137	0.27	-0.04	-0.54	-7.81 **	-15.05 **	-0.30	-0.85	-0.29	-1.42 *	1.00	-1.11 *	-0.20 **	-0.04	H
54	MAI38 ×NAI137	1.20 *	1.83 **	0.89 *	8.67 **	16.00 **	1.03 *	0.00	0.76	0.39	-1.41	-2.04 **	0.12 **	-0.05 *	L
55	MAI40 ×NAI137	0.37	0.16	0.06	0.88	2.77 **	0.24	0.61	-0.56	1.93 **	-0.73	-0.31	-0.37 **	-0.01	H
56	MAI42 ×NAI137	-1.83**	-1.94 **	-0.41	-1.75	-3.71 **	-0.96 *	0.24	0.08	-0.89	1.14	3.46 **	0.44 **	0.09 **	L
57	MAI43 ×NAI137	-0.23	-0.04	-1.42 **	-4.34 **	-2.65 **	-0.75	0.66	1.01 *	-3.85 **	0.09	-1.86 **	0.13 **	-0.30 **	H
58	MAI44 ×NAI137	-0.80	-0.68	0.02	-14.41 **	-19.45 **	0.08	-0.44	-0.54	1.87 **	2.92 *	1.71 **	0.20 **	0.20 **	L
59	MAI45×MAI105	1.37 **	1.66 *	2.18 **	12.39 **	10.27 **	-0.42	0.12	-0.66	-0.20	-1.64	-0.06	0.06	0.04	H
60	MAI48 ×NAI137	-0.33	-0.94	-0.78	6.37 **	11.84 **	1.09 *	-0.35	0.18	2.18 **	-1.37	0.21	-0.39 **	0.06 **	L
	SE	0.48	0.63	0.43	1.38	0.70	0.47	0.48	0.47	0.63	1.12	0.53	0.03	0.02	

*Significant at P=0.05 level

**Significant at P=0.01 level

Among hybrids with significant sca effects, the ones with high magnitudes were considered as superior to others. The hybrids from the different combinations of the parents with high/low gca effects are referred as H×H (High × High), H×L (High × Low) and L×L (Low × Low) combinations. Thirty three out of 60 hybrids had high overall specific combining ability status, implying that 55 per cent of the hybrids were high overall specific combiners.

Within 60 crosses, MAI45 × CM202 (H×L) was found top good specific combiner for four traits viz., plant height, ear height fodder yield per plot and grain yield per plot. The hybrid MAI48 × CM500 (H×L) followed by MAI40 × CM202 (H×L) and MAI27 × CM202 (H×L) was good specific combiner for maturity traits and the involvement of high and low combiners revealed the significance of importance of non-additive genetic variance in the inheritance of earliness to maturity(Table 3). Sanghi (1982), Desai and Singh (2001) also reported similar results.

With respect to plant height 45 crosses recorded significant sca effects (Table 3). Of these 20 crosses recorded significant sca effects in positive direction of which MAI45 x CM202 (H×L), MAI40 × MAI105 (H×L) and MAI23 × CM202 (L×L) are the best three specific combiners for increased plant height expressing significant sca effects in positive direction. Singh *et al.* (2000) and Hee Chung *et al.* (2006) also reported good specific combiners for this trait. On the other hand 25 crosses showed significant sca effects in positive direction for ear height and the crosses *viz.,* MAI45 × CM202 (H×L), MAI44 × NAI137 (H×H)and MAI23 x CM500 (L×L) were the top three specific combiners with sca effects in desirable direction. Mohamed *et al.* (1993), Amer *et al.* (2002) and Desai and Sing (2001) reported good specific combiners for ear height.

The hybrid MAI43 × CM202 (L×L) with over dominance and epistasis gene action variance was the top of the few good specific combiners for ear length and number of kernel rows per cob. The hybrid MAI45 × CM500 (H×L) recorded the highest significant positive sca effects followed by MAI23 × CM202 (L×L), MAI33 x CM202 (L×L) for ear diameter. For number of kernel rows per cob crosses MAI48 × MAI105 (H×L), MAI32 × CM500 (L×L) and MAI44 × MAI105 (H×L) were the top three specific combiners with sca effects in positive direction (Table 3). It was to note that very less proportion of over dominance and epistasis gene action variance indicated the importance of non-additive gene action in the inheritance of this character which is in agreement with the reports of Pal and Prodhan (1994), Dehghanapour *et al.* (1997) and Kumar *et al.* (1998).

As far as the shelling percentage is concerned the crosses, *viz.*, MAI32 × CM202 (L×L), MAI44 × NAI137 (H×H) and MAI42 × CM500 (H×L) showing involvement of over dominance and epistasis gene action, additive gene action and non additive gene action in the inheritance of this trait were identified as top three specific combiners among 5 crosses showing positive sca effects. Mathur *et al.* (1998) reported the importance of good specific combiners and sca variance inheritance of this trait in the environment without stress.

For 100-grain weight three crosses *viz.,* MAI42 × CM500 (H×L), MAI23 × MAI105 (L×L) and MAI33 x NAI137 (L×H) were identified as top specific combiners for this trait among 16 crosses showing positive sca effects. It was important to note the predominant involvement of non-additive gene action for good specific combining ability status in the inheritance of this trait (Table 3). Kumar *et al.* (1998) and Mohammad (1993) reported good specific combiners for this trait.

Among fifty crosses which showed significant sca effects for grain yield per plot, 26 were in the positive direction. The crosses *viz.*, MAI45 x CM202 (H×L), MAI33 x CM202 (L×L) and MAI43 x CM500 (L×L) were top three specific combiners in the desirable direction. In these hybrids the predominance of over dominance and epistasis gene action and non-additive gene action were observed in the inheritance of this trait (Table 3). Murthy (1981), Paul and Duara (1991), and Konak *et al.* (2001) stressed the importance of sca variance for grain yield per plot and reported good specific combiners for this trait.

Crosses *viz.,* MAI45 × CM202, MAI33 × CM202 and MAI43 × CM500 were promising with respect to sca effects for grain yield. In most of the cases significantly higher sca effects were associated with high heterosis for different characters.

Conclusion

The study on the general combining ability effects of parents showed that eight out of 15 lines and one out of four testers had high (H) overall general combining ability status implying that about 50 (47.3) per cent of parents were high overall general combiners suggesting their ability to transmit additive genes in the desirable direction for all the traits under study. Among the 15 lines MAI31, MAI28 and MAI35 were the best general combiners which exhibited high gca effects each in desirable direction for the three characters. Among the testers (male parents), CM 500 was the best combiner grain yield per plot and some other characters.

Crosses *viz.,* MAI45 × CM202, MAI33 × CM202 and MAI43 × CM500 were promising with respect to sca effects for grain yield. In most of the cases significantly higher sca effects were associated with high heterosis for different characters.

This study provided combining ability information on tested inbreed lines. The promising lines have to be maintained and used in hybridization program. The promising single crosses could be tested across locations and seasons to fix the desirable characters through advanced selection generations.

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