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Research Article

Combining ability studies in maize (*Zea mays* L.) for yield and its attributing traits using Griffing's diallel approach

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Abstract
Studies on combining ability and heterosis were carried out at Agricultural Research Farm, PAJANCOA & RI, Karaikal, during *kharif* 2013 for thirteen agronomic yield traits *viz*., 100 grain weight, grain yield for 30 single cross hybrids developed using 6 x 6 full diallel method. The combining ability analysis revealed the presence of higher magnitude of SCA than GCA variance for all characters under study. The ratio of additive to dominance variance was lower than unity for all traits, indicating higher non additive variance than additive variance. Among the 6 parents, inbred line namely UMI 213 was found to be the best parent for grain yield, however, The estimates of *sca* effects has resulted in the identification of the following hybrids *viz*., UMI 66 x UMI 112, UMI 112 x UMI 213 and UMI 122 x UMI 133 as best ones, since these above hybrids registered significant and favourable *sca* effects for majority of the traits including grain yield per plant.

Key words
Diallel, combining ability, grain yield, *Zea mays* L.

Introduction

Maize (*Zea mays* L.) is the third most important cereal in India after wheat and rice (Poehlman, 2006). In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material to the industry for production of starch, oil, protein, alcoholic beverages, food sweeteners and more recently bio-fuel. In India it is cultivated over 7.27 million hectares with 15.86 million tones production with an average productivity of 2181 kg/ha, contributing nearly 8 per cent in the national food basket (Agriculture statistics at a Glance, 2012). A major shift in maize cultivation has been observed in recent years due to short duration, less cost of cultivation, less water requirement and less risk compared to other crops. Keeping in mind the future demand of maize as a food for human and as a feed for livestock, there is a continuous need to evolve new hybrids with high yield. To achieve this target, combining ability studies is one of the best options. In order to choose the best hybrid combinations a subjectively chosen inbred lines were crossed. It would be a considerable advantage to be able to estimate the combining ability of parents, gene action and heterotic effects of crosses before making crosses among inbred lines. Combining ability describes the breeding values of parental lines to produce hybrids. Sprague and Tatum (1942) used the term General Combining Ability (GCA) to designate the average performance of a line in hybrid combinations and used the term Specific Combining Ability (SCA) to define those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Diallel crossing programs have been applied to achieve this goal by providing a systematic approach for the detection of suitable parents and crosses for the investigated characters. Combining ability analysis proposed by Griffing (1956) had been applied for present study to unravel Reciprocal Combining Ability effects along with *gca* and *sca* effects with full diallel mating design.

Materials and methods

The present study was carried out at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Union Territory of Puducherry. A total of six inbreds *viz.*, UMI 66, UMI 112, UMI 122, UMI 133, UMI 176 and UMI 213 were crossed in all possible combinations to obtain 30 F_1 hybrids. Further in *Kharif* 2013 the parents along with the resultant hybrids were evaluated in three replicated randomized blocks. Seeds of parental genotype were obtained by selfing and F_1 Hybrid seeds were obtained by hand cross pollination. Plots consisted of two rows each of length 2.5 m. The distance between rows was 60 cm and between plants along the row was 25 cm. To avoid any border effect, plots were surrounded by a row of non-experimental material. The observations for days to tasseling, days to silking, anthesis silking interval, days to maturity, plant height, ear length, ear girth, number of kernel rows per ear, number of kernels per row, ear weight, shelling percent, 100 grain weight and grain yield per plant was recorded from randomly selected five plants of the each plot. Analysis of data for general and specific combining ability was carried out following Griffing (1956) Method II, Model I (fixed effect model). The statistical analysis was carried out using AGRISTAT software.

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Results and discussion

Analysis of variance: The analysis of variance revealed that the lines differed among themselves at p=0.01 or 0.05 for all the characters under studied (Table 1). Therefore, analysis of variance suggested presence of wide variability for the respective traits among the parents. The ANOVA revealed that mean squares due to genotypes were significant for all the yield attributing traits under evaluation indicating presence of sufficient amount of variability among the parents and crosses. The mean sum of squares due to general combining ability (GCA) and specific combining ability (SCA) were significant for all the characters under studied. This implies both the additive and non-additive gene actions were playing significant role in the expression of these characters as suggested by Cheralu*et al.* (1999), Singh and Singh (2005).

Combining ability effects: The knowledge on combining ability assists in the selection of suitable parental lines. Among the various biometrical techniques available, combining ability analysis proposed by Griffing (1956) had been extensively used by the breeders (Table 2). It provides information on the performance of genotypes in hybrid combination and also the nature of gene action involved in the control of metric traits. The general and specific combining ability of parents and hybrids for the grain yield and its component traits are discussed hereunder.

General combining ability effects: The general combining ability effects of the six parents for thirteen traits were presented in the Table 3. Among the six parents studied, UMI 133 (-0.99) alone registered significant and negative *gca* effect for days to tasseling while parents UMI 122 (-0.31) and UMI 133 (-1.28) were articulated *gca* effects in a negative direction for the trait Days to silking. For days to maturity four parents *viz.,* UMI 112 (-0.53), UMI 122 (-1.44), UMI 133 (-0.53) and UMI 176 (-2.67) showed significantly negative *gca* effects. The significant negative *gca* effects was registered for plant height (cm) by the two parents UMI 112 (-5.37) and UMI 122 (-3.66). While two parents UMI 112 (0.25) and UMI 213 (0.99) registered significant positive *gca* effects for ear length. For Ear girth (cm), parent UMI 176 (0.35) alone exhibited significant positive *gca* effects. The trait number of kernel rows per ear was recorded significant positive *gca* effects in two parents UMI 112 (0.39) and UMI 122 (0.37) while the parent UMI 112 (0.38) alone explored positive significant *gca* effect for the trait number of kernels per row. Ear weight four parents *viz.,* UMI 66 (0.91), UMI 112 (1.97), UMI 133 (0.74) and UMI 213 (1.63) recorded significant positive *gca* effects for ear weight. For 100 grain weight (g) the parents UMI 133 (1.25) and UMI 122 (0.71) registered significant positive *gca* effects. For the trait grain yield per plant, three parents *viz.,* UMI 66 (2.07), UMI 133 (2.38) and UMI 213 (1.04) exhibited significant positive *gca* effects. UMI 133 for eight traits (days to tasseling, days to silking, anthesis silking interval, days to maturity, ear weight, shelling per cent, 100 grain weight and grain yield per plant), UMI 66 for three traits (ear weight, shelling per cent and grain yield per plant) and UMI 213 for three traits (ear length, ear weight and grain yield per plant) expressed significant and favourable *gca* effects. These three parents are adjudged as best combiners based on *gca* effects. The high positive value of *gca* effect of these parents indicate that their contribution in transferring those traits to their hybrids is high. This is in accordance with the findings of Unay *et al.* (2004).

Specific combining ability effects: The specific combining ability effects of 15 direct crosses in respect to the 13 traits are presented in Table 4. The estimate of the *sca* effects of the 15 hybrids ranged from -9.85 (UMI 66 x UMI 133) to 15.92 (UMI 66 x UMI 122) for grain yield per plant. For days to silking and anthesis the cross combination UMI 122 x UMI 176 showed the least *sca* effects with -3.65 and -3.64, respectively. Four hybrids *viz.,* UMI 66 x UMI 112 (-1.10), UMI 66 x UMI 122 (-1.30), UMI 112 x UMI 213(-1.35) and UMI 122 x UMI 133 (-0.94) exhibited significant negative *sca* effects for anthesis silking interval. For days to maturity Two hybrids UMI 66 x UMI 176 (-1.58) and UMI 122 x UMI 133 (-2.31) expressed significant negative *sca* effects. The significant positive *sca* effects were found for ear length in 4 hybrids *viz.,* UMI 66 x UMI 133 (1.66), UMI 112 xUMI 213 (1.62), UMI 122 x UMI 176 (1.31) and UMI 122 x UMI 213 (1.88). Among the 15 direct cross combinations studied, two hybrids UMI 112 x UMI 213 and UMI 122 x UMI 133 exhibited significant positive *sca* effects. 4 hybrids *viz.,* UMI 66 x UMI 112 (0.74), UMI 66 x UMI 133 (0.83), UMI 66 x UMI 213 (1.19) and UMI 176 x UMI 213 (1.57) attained the level of significance for *sca* in a positive direction for the trait number of kernel rows per ear. The trait number of kernels per row showed *sca* effects varied ranges from -2.75 (UMI 112 x UMI 176) to 3.53 (UMI 66 x UMI 133). The *sca* effects of the hybrids revealed that a total of seven out of 15 hybrids showed positive and significant *sca* effects. For ear weight the cross combination UMI 112 x UMI 176 (-8.91) have shown the least *sca* effects for this trait, while the highest *sca* effects was recorded by the hybrid UMI 133 x UMI 176 (15.62). Eight hybrids showed significant positive *sca* effects for this trait. The observed variation of *sca* effects for shelling per cent ranged between -9.58 (UMI 66 x UMI 133) and 9.12 (UMI 66 x UMI 122). Significantly positive *sca* effects were recorded by five hybrids for shelling per cent. For 100 grain weight trait, the *sca* values for this trait ranged from -1.42 (UMI 112 x UMI 176) to 2.20

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(UMI 112 x UMI 122). Six hybrids exhibited significantly positive *sca* effects for 100 grain weight. Existence of reciprocal effects (Table 5) among the crosses indicated the importance of choice of male and female parents in hybridization programme (Mahgoub, 2011).

Good general combining inbred parents have not always showed high SCA effects in their cross combinations. Thus it may be concluded that the information on GCA effects alone may not be sufficient to predict the extent of hybrid vigour by a particular cross combination (Chakraborty *et al*., 2010). Therefore, information on GCA effects of the inbred need to be supplemented with that on SCA effects. In many crosses significant SCA effects for yield per plant were associated with negative SCA effects of days to maturity. This is desirable because we want hybrids having high yield and early in crop duration (Gupta *et al.* 2006).In general, crosses involving good general combiner as well as one good and the other poor combiner showed high SCA effects, which is due to additive × additive and additive × dominant gene action. Evaluation of parental inbreds together with *per se* and *gca* effects resulted in the identification of UMI 213 as the best parent. The estimates of *sca* effects of hybrids revealed that the hybrids *viz*., UMI 66 x UMI 112, UMI 112 x UMI 213 and UMI 122 x UMI 133 registered significant and favourable *sca* effects for majority of the traits including grain yield per plant.

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Table 1. Analysis of variance for parents and hybrids in maize

Source	Degrees of freedom	Days to tasseling	Days to silking	Anthesis silking interval	Days to maturity	Plant height	Ear length	Ear girth
Replication	2	1.510	0.771	0.558	2.527	1.800	0.176	0.374
Genotype	35	20.723**	17.893**	5.425**	37.133**	339.890**	11.854**	3.240**
Error	70	1.071	0.542	0.863	1.956	0.969	0.569	0.513
SE(d)		0.438	0.407	0.224	0.586	1.774	0.331	0.173
CD at 5 per cent		0.873	0.811	0.447	1.169	3.538	0.661	0.345
CD at 1 per cent		1.159	1.077	0.593	1.553	4.697	0.877	0.459

Source	Degrees of freedom	No. of kernel rows per ear	No. of kernels per row	Ear weight	Shelling per cent	100 Grain weight	Grain yield per plant
Replication	2	0.922	2.019	1.552	1.930	0.830	2.107
Genotype	35	3.580**	20.231**	328.200**	148.370**	10.698**	306.400**
Error	70	0.484	1.321	1.394	1.233	0.750	1.743
SE(d)		0.182	0.433	1.743	1.774	0.315	1.774
CD at 5 per cent		0.363	0.863	3.477	2.337	0.628	3.359
CD at 1 per cent		0.482	1.146	4.616	3.103	0.833	4.460

*, ** Significant at 5 and 1 per cent level, respectively

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Table 2. Analysis of variance for combining ability in maize

Source	Degrees of freedom	Days to tasseling	Days to silking	Anthesis silking interval	Days to maturity	Plant height	Ear length	Ear girth
GCA	5	3.277**	2.693**	2.136**	56.926**	180.618**	4.733**	0.680**
SCA	15	9.240**	3.253**	5.518**	5.395**	137.593**	3.562**	1.254**
RCA	15	5.578**	2.903**	2.344**	3.500**	66.069**	3.556**	0.847**
Error	70	0.357	0.364	0.896	0.652	0.323	0.190	0.171
GCA / SCA		0.370	0.060	0.550	0.990	1.320	1.400	0.610

Source	Degrees of freedom	No. of Kernel rows per ear	No. of Kernels per row	Ear weight	Shelling per cent	100 Grain weight	Grain yield per plant
GCA	5	1.740**	1.469**	69.134**	21.981**	7.607**	55.723**
SCA	15	9.812**	1.733**	146.812**	49.759**	4.061**	93.413**
RCA	15	5.254**	0.477**	82.830**	49.767**	1.769**	89.089**
Error	70	0.440	0.162	0.465	0.410	0.250	0.581
GCA / SCA		0.93	0.18	0.47	0.41	1.99	0.54

*, ** Significant at 5 and 1 per cent level, respectively

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Table 3. General combining ability effects of parents for different traits in maize

S. No.	Parents	Days to tasseling	Days to silking	Anthesis silking interval	Days to maturity	Plant height	Ear length	Ear girth
1.	UMI 66	0.34*	0.08	-0.26	3.14**	1.81**	-0.72**	0.09
2.	UMI 112	0.29	0.42**	0.13	-0.53*	-5.37**	0.25*	0.16
3.	UMI122	-0.13	-0.31**	-0.18	-1.44**	-3.66**	0.10	-0.10
4.	UMI 133	-0.99*	-1.28**	-0.29*	-0.53*	0.36*	0.00	-0.27*
5.	UMI 176	0.09	0.36**	0.27	-2.67**	1.67**	-0.63**	0.35**
6.	UMI 213	0.40*	0.72**	0.32*	2.03**	5.18**	0.99**	-0.22*
	SE (g_i)	0.16	0.11	0.14	0.21	0.15	0.11	0.11

S. No.	Parents	No. of Kernel rows per ear	No. of kernels per row	Ear weight	Shelling per cent	100 grain weight	Grain yield per plant
1.	UMI 66	-0.02	-0.57**	0.91**	0.93**	-0.26	2.07**
2.	UMI 112	0.39**	0.38*	1.97**	-2.49**	-0.80**	-2.00**
3.	UMI122	0.37**	-0.12	-0.75**	-0.03	0.71**	-0.31
4.	UMI 133	-0.12	0.22	0.74**	1.61**	1.25**	2.38**
5.	UMI 176	-0.55**	-0.27	-4.51**	-0.21	-0.41**	-3.18**
6.	UMI 213	-0.08	0.34	1.63**	0.20	-0.49**	1.04**
	SE(g_i)	0.11	0.17	0.18	0.17	0.13	0.20

*, ** Significant at 5 and 1 per cent level, respectively

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Table 4. Specific combining ability effects of direct crosses for different traits in maize

S. No.	Hybrids	Days to tasseling	Days to silking	Anthesis silking interval	Days to maturity	Plant height	Ear length	Ear girth
1.	UMI 66 x UMI 112	2.52**	1.42**	-1.10*	1.44*	-1.82**	0.15	-0.53
2.	UMI 66 x UMI 122	1.77**	0.47	-1.30**	0.86	10.01**	0.35	0.20
3.	UMI 66 x UMI 133	-3.54**	-2.72**	0.81	1.94**	3.45**	1.66**	0.60
4.	UMI 66 x UMI 176	0.88	0.31	-0.57	-1.58*	-4.29**	0.72	-0.07
5.	UMI 66 x UMI 213	0.07	0.44	0.37	-0.44	2.48**	-0.52	0.07
6.	UMI 112 x UMI 122	-1.34**	-0.36	0.98*	0.86	0.63	-1.35**	-1.06**
7.	UMI 112 x UMI 133	-2.81**	-3.22**	-0.41	-0.89	10.72**	0.54	-0.82*
8.	UMI 112 x UMI 176	0.77	1.31**	0.54	0.75	1.09**	0.11	0.58
9.	UMI 112 x UMI 213	0.80	-0.56	-1.35**	1.39*	0.70	1.62**	1.11**
10.	UMI 122 x UMI 133	1.77**	0.83*	-0.94*	-2.31**	-0.50	-0.96**	0.91*
11.	UMI 122 x UMI 176	-3.65**	-3.64**	0.01	2.33**	-1.39**	1.31**	-0.30
12.	UMI 122 x UMI 213	1.21*	2.50**	1.29**	0.31	-4.38**	1.88**	0.51
13.	UMI 133 x UMI 176	1.55**	1.00**	-0.55	0.08	-2.54**	0.13	0.24
14.	UMI 133 x UMI 213	0.07	-0.36	-0.44	-0.94	10.99**	0.69	0.16
15.	UMI 176 x UMI 213	-2.34**	-2.17**	0.18	-1.31	-10.34**	-1.00**	0.43
	SE(S_{ij})	0.50	0.35	0.45	0.67	0.47	0.36	0.34

*, ** Significant at 5 and 1 per cent level, respectively

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Table 4. Specific combining ability effects of direct crosses for different traits in maize (Contd.,)

S. No.	Hybrids	No. of kernel rows per ear	No. of kernels per row	Ear weight	Shelling per cent	100 grain weight	Grain yield per plant
1.	UMI 66 x UMI 112	0.74*	2.17**	1.18*	5.13**	0.43	7.57**
2.	UMI 66 x UMI 122	-0.33	-0.38	5.02**	9.12**	-1.06*	15.92**
3.	UMI 66 x UMI 133	0.83*	3.53**	5.89**	-9.58**	1.02*	-9.85**
4.	UMI 66 x UMI 176	0.35	-2.15**	0.61	-2.27**	0.48	-2.30**
5.	UMI 66 x UMI 213	1.19**	-1.05	2.47**	-3.40**	0.89*	-2.88**
6.	UMI 112 x UMI 122	-0.28	1.52**	-1.86**	-2.53**	2.20**	-4.42**
7.	UMI 112 x UMI 133	-0.18	-1.22*	-0.61	4.18**	-0.20	5.59**
8.	UMI 112 x UMI 176	-0.26	-2.75**	-8.91**	0.61	-1.42**	-4.29**
9.	UMI 112 x UMI 213	-0.32	2.35**	14.60**	-0.26	-0.24	8.13**
10.	UMI 122 x UMI 133	0.51	0.61	4.69**	0.86	1.37**	4.27**
11.	UMI 122 x UMI 176	-0.29	1.85**	-7.40**	3.62**	1.25**	-0.28
12.	UMI 122 x UMI 213	-0.70*	0.24	1.65**	-7.00**	0.43	-8.64**
13.	UMI 133 x UMI 176	-0.28	1.16*	15.62**	-4.36**	-0.26	3.65**
14.	UMI 133 x UMI 213	-0.25	-2.03**	-6.26**	2.22**	-1.38**	-0.10
15.	UMI 176 x UMI 213	1.57**	2.76**	-2.10**	-0.29	1.43**	-2.16**
	SE(S_{ij})	0.33	0.55	0.57	0.53	0.41	0.63

*, ** Significant at 5 and 1 per cent level, respectively

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Table 5. Reciprocal effects for different traits in maize

S. No.	Hybrids	Days to tasseling	Days to silking	Anthesis silking interval	Days to maturity	Plant height(cm)	Ear length(cm)	Ear girth (cm)
1.	UMI 112 x UMI 66	1.83**	1.33**	-0.50	-1.00	-5.26**	1.52**	0.00
2.	UMI 122 x UMI 66	-2.33**	-2.67**	-0.33	-0.50	-2.36**	-1.96**	0.01
3.	UMI 122 x UMI 112	-0.83	-0.83**	0.00	-0.17	6.58**	1.05**	0.51
4.	UMI 133 x UMI 66	0.33	-0.50	-0.83*	-0.50	-12.08**	0.01	-0.83
5.	UMI 133 x UMI 112	-3.50**	-2.00**	1.50**	-0.33	2.67**	-0.24	0.09
6.	UMI 133 x UMI 122	-2.50**	-0.83**	1.67**	-2.83**	2.97**	-2.03**	1.24**
7.	UMI 176 x UMI 66	0.17	-0.67*	-0.83*	-1.00	-6.19**	-1.72**	-1.14**
8.	UMI 176 x UMI 112	-1.17**	-1.50**	-0.33	2.83**	-3.15**	-1.65**	-0.77*
9.	UMI 176 x UMI 122	0.17**	0.33	0.17	-0.50	2.11**	-0.60	1.09**
10.	UMI 176 x UMI 133	0.00	-0.67*	-0.67	-1.67**	-2.88**	1.32**	-0.31
11.	UMI 213 x UMI 66	1.00*	2.17**	1.17**	-2.17**	-12.58**	-0.88**	-1.17**
12.	UMI 213 x UMI 112	-0.17	-0.67*	-0.50	-0.83	2.47**	1.75**	-0.21
13.	UMI 213 x UMI 122	-0.33	0.17	0.50	1.17*	-4.88**	-1.19**	0.11
14.	UMI 213 x UMI 133	-2.83**	-1.17*	1.67**	-1.17*	2.94**	-1.28**	0.84**
15.	UMI 213 x UMI 176	-2.17**	-0.33	1.83**	-2.00**	-1.72**	-2.13**	-0.11
	SE(r_{ij})	0.42	0.30	0.38	0.57	0.41	0.31	0.29

*, ** Significant at 5 and 1 per cent level, respectively

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Table 5. Reciprocal effects for different traits in maize (Contd.,)

S. No.	Hybrids	No. of kernel rows per ear	No. of kernels per row	Ear weight (g)	Shelling per cent	100 Grain weight (g)	Grain yield per plant (g)
1.	UMI 112 x UMI 66	-0.70*	3.32**	0.48	0.17	-0.42	0.55
2.	UMI 122 x UMI 66	0.27	-0.20	4.92**	3.65**	0.47	8.62**
3.	UMI 122 x UMI 112	-0.81**	0.52	5.69**	0.58**	0.35	3.85**
4.	UMI 133 x UMI 66	-0.23	-1.68**	7.09**	4.11**	2.06**	9.63**
5.	UMI 133 x UMI 112	0.35	0.05	-5.01**	-5.21**	-0.57	-10.28**
6.	UMI 133 x UMI 122	0.80**	-0.95*	-4.50**	-7.47**	-0.24	-12.64**
7.	UMI 176 x UMI 66	-0.12	0.35	-2.72**	1.48**	-0.79*	0.33
8.	UMI 176 x UMI 112	0.10	-1.30**	-3.12**	4.75**	0.87*	4.14**
9.	UMI 176 x UMI 122	0.72*	0.73	0.11	-1.67**	-0.50	-2.53**
10.	UMI 176 x UMI 133	-0.48	0.85	11.69**	-0.89**	0.18	6.06**
11.	UMI 213 x UMI 66	-0.23	-3.30**	7.61**	-7.06**	-1.62**	-3.91**
12.	UMI 213 x UMI 112	-0.76**	-2.27**	-1.45**	7.90**	1.12**	10.21**
13.	UMI 213 x UMI 122	-0.76**	-2.08**	-6.55**	0.88**	0.31	-2.43**
14.	UMI 213 x UMI 133	0.20	-1.20*	-11.71**	-1.17**	0.47	-9.06**
15.	UMI 213 x UMI 176	0.41	-0.40	9.71**	-11.11**	1.39**	-8.81**
	SE(r_{ij})	0.28	0.47	0.48	0.21	0.35	0.76

*, ** Significant at 5 and 1 per cent level, respectively