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Combining ability of maize inbred lines for yield and morpho-agronomic traits

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Abstract

Thirty-nine crosses produced from 13 lines and 2 testers using Line×Tester mating design were evaluated following RBD design. The objectives of this study were to: (i) determine the type of gene action in expiration of traits and (ii) identify inbred lines and crosses with good combining ability for yield and other morpho-agronomic traits. Significant variation was observed among the hybrids (crosses) except days to 75% brown husk. Variance due to specific combining ability (SCA) was larger than general combining ability (GCA) for the all characters indicating the preponderance of non-additive gene action in the expression of various traits. Inbred lines L_6 followed by L_{12}, L_9, L_3, L_8, L_4 and tester T_2 showed good combining ability for yield and some of the important yield-contributing characters, indicating that they could be good parental lines in hybridization programs. Based on the results, SCHs $L_1 \times T_3$, $L_5 \times T_2$, $L_8 \times T_1$, $L_2 \times T_2$, $L_3 \times T_1$, $L_4 \times T_1$, $L_9 \times T_3$, $L_{13} \times T_2$, $L_{11} \times T_2$, $L_9 \times T_3$, $L_6 \times T_2$, $L_3 \times T_3$ and $L_4 \times T_2$ exhibited high specific combining ability (SCA) effects for yield. These hybrids are recommended for further multi-locational evaluation to determine the stability of their performance.

Keywords: Line×Tester, combining ability, gene action, maize

Introduction

Among the cereal crops in India, maize (*Zea mays* L.) is the third most important. Due to high demand, maize gaining popularity in India, particularly in the poultry feed industry. Maize also has a wide variety of uses as a food and a raw material for industry. Due to its high yield potential, maize acreage and production are expanding with the introduction of hybrids. In order to establish a successful breeding programme, it's crucial to understand the type and magnitude of gene action. Combining ability analysis is helpful in determining the type of gene action associated with various quantitative characters as well as assessing potential inbred lines. For plant breeders this knowledge is very useful for making hybrid breeding programmes. As a result, efforts must be undertaken to develop hybrids with high yield potential in order to boost maize production. A plant breeders use a variety of biometrical techniques to characterise genetic control of commercially important traits as a reference when deciding which breeding methodology to use in hybrid breeding programmes. The purpose of this study was to assess the breeding value of genotypes, the nature and extent of gene action, in maize for a number of yield and other its contributing traits. The Line × tester mating design developed by Kempthorne (1957) [16], which offers trustworthy information on the general and specific combining ability effects of parents and their hybrid combinations. Many researchers have used this design in quantitative genetic for studied yield and morpho-agronomic traits in many crops.

Thus, the objective of the present investigation was to unravel the type of gene action in expiration of traits, identify inbred lines and crosses with good combining ability for yield and other morpho-agronomic traits.

Material and Methods

Thirteen phenotypically different inbred lines (females) were developed at the CIMMYT in Hyderabad, India and three testers (males) from different sources were taken for the study. These lines were planted in a single 4m long row during *rabi* 2019-20 and crossed with three testers (Tester$_1$, Tester$_2$, and Tester$_3$) to produce 39 F_1s crosses using the line×tester mating design (Kempthorne, 1957) [16]. For the *kharif* 2020 seasons, the 39 hybrids were evaluated alongside their parents in a randomised block design with three replications at the Irrigation Research Station Farm, Araria, Bihar, India (BAU, Sabour, Bhagalpur).

The experimental plot represent North East Alluvial Plain Zone (BI-2) located at latitude of $26^0$8’59” N, longitude of $87^0$31’11” E and altitude of 47 meters Above MSL. Seeds from each F_1s population and their parents were planted in two rows of length 4 m each, with 0.6 m between rows and 0.2 m between plants within each row. To achieve a healthy crop, the required management methods were applied during the crop growing period.

Data were recorded on twelve agro-morphological traits from each replication. The traits which were studied include days to 50 per-cent anthesis, days to 50 per-cent silking, anthesis-silking intervals, days to 75 per-cent brown husk, ear height, ear diameter, plant height, ear length, 1000 kernel weight, kernel row per ear, kernel per row, and grain yield (Kg ha^{-1}). On a plot basis, days to 50 per-cent anthesis, days to 50 per-cent silking, anthesis-silking intervals, and days to 75 per-cent brown husk were recorded out of the twelve quantitative characters. The remaining attributes were recorded using five randomly picked plants at the relevant stage. The data were subjected for analysis of variance for all the characters studied as per the method suggested by Panse and Sukhatme (1961) [23]. The variance of combining ability was estimated as per the procedure developed by Kempthorne (1957) [16]. The mean squares for GCA and SCA were tested against desired error variance. The data were analyzed using the Windowstat 9.2 computer application.

Results and Discussion

Analysis of variance for combining ability was carried out for yield and its contributing traits and the mean sum of squares are presented in Table 1. The mean squares due to the treatment, parents and crosses were found to be highly significant for all traits under study except days to 75 per cent brown husk, while mean square due to Parents *vs* Crosses was highly significant for all traits. This indicates presence of genetic variability among the genotypes for those characters. When the effects of crosses partitioned into lines, testers and line×tester interaction effects, the interaction effects (line×testers) were found to be highly significant for all traits except days to 75 per cent brown husk indicating that hybrids differed significantly in their SCA effects. However the line effect and tester effect were significant for number of kernel rows per ear and 1000-kernels weight, respectively.

Table 1: Mean squares for grain yield and its yield components characters in maize

Source of variation	**df**	**Grain yield (kg ha^{-1}**	**1000-kernels weight (g)**	**Kernels per row**	**Kernel rows per ear**	**Ear diameter (cm)**	**Ear length (cm)**	**Plant height (cm)**	**Ear height (cm)**	**Days to 75% brown husk**	**Days to 50% anthesis**	**Days to 50% silking**	**Anthesis-silkin interval**
Replicates	2	27368.25	13.91	0.27	0.01	0.20	1.35	79.02	6.28	5.38	2.44	2.91	0.05
Treatments	54	16389390.00**	7246.33**	121.92**	20.04**	2.87**	27.27**	3625.22**	1051.27**	47.23	51.26**	80.40**	6.12**
Parents	15	1241848.00**	1679.392**	16.84**	8.61**	0.89**	4.32**	1228.24**	289.93**	10.46	9.86**	28.33**	5.02**
Parents (Line)	12	1013630.00**	1410.01**	17.89**	8.24**	0.50**	3.28**	823.41	183.10**	7.24	8.04**	21.30**	3.42**
Parents (Testers)	2	456893.10	832.50	6.54	3.73*	1.63**	0.74	1196.77	256.91**	7.00	4.77	15.44**	3.11**
Parents (L vs T)	1	5550380.00**	6605.64**	24.92*	22.73**	4.01**	23.95**	6149.16**	1637.89**	56.07	41.88**	138.39**	28.01**
Parents vs Crosses	1	582464400.00**	188929.60**	2321.65**	677.14**	71.86**	784.77**	109941.20**	30468.70**	300.68**	694.48**	480.13**	19.72**
Crosses	38	7471975.00**	4662.67**	105.51**	7.26**	1.84**	16.39**	1773.61**	577.65**	55.07	50.68**	90.44**	6.20**
Line Effect	12	6970547.00	5191.81	147.98	12.93*	1.54	14.67	1717.47	497.44	48.11	47.27	82.36	5.27
Tester Effect	2	13487720.00	13343.33*	35.17	3.10	4.34	42.66	4746.55	1309.98	141.85	105.26	192.62	13.10
Line *Tester Eff.	24	7221376.00**	3674.71**	90.13**	4.76**	1.78**	15.07**	1553.94**	556.73**	51.32	47.83**	85.96**	6.09**
Error	108	265923.70	339.912	3.99	1.03	0.13	1.27	453.84	30.73	40.35	1.86	2.29	0.38
Total	164	5571962.00	2610.00	42.77	7.27	1.04	9.83	1493.51	366.46	42.19	18.13	28.02	2.27

*, **: level of significance at 5% and 1%, respectively

The relative contribution of general and specific combining ability towards crop improvement, however, be determined by the magnitude of additive and non-additive genetic variation. The variance of *SCA* was higher than the *GCA* variances for all the traits under study were less than one, indicating preponderance of non-additive gene action in the inheritance of the traits. It could be concluded that, improvement of these characters with greater non-additive genetic component could be contemplated for the exploitation of heterosis and transgressive breeding may not be useful for these traits. This is corroborated by the fact that the GCA variance to SCA variance ratio is less than one (Table 2). Non additive gene action was mostly responsible for grain yield. This is corroborated with previous findings by Zelleke (2000); Amiruzzaman *et al.*, (2013) [32, 6], who found that dominant gene effects influenced grain yield more than additive gene effects. Similar findings were reported by Akbar *et al.*, (2008); Kanagarasu *et al.*, (2010); Akhi *et al.*, (2018) [3, 15, 4] for grain yield, ear length, plant height, ear height, 1000-kernels weight, kernel rows per ear, days to 50 per cent anthesis and days to 50 per cent silking. In contrary, Abuali *et al.*, (2012) [1] reported higher SCA for grain yield, 1000-

kernels weight, ear length and higher GCA variance for kernels per row. Higher SCA variance for grain yield, kernel rows per ear, ear length and ear diameter was also reported by Wali *et al.*, (2010) [31].

Table 2: Variance due to general and specific combining ability

Sl. No.	Characters	GCA	SCA	GCA/SCA
1.	Days to 50 per cent anthesis	3.10*	15.32**	0.20
2.	Days to 50 per cent silking	5.63*	27.88**	0.20
3.	Anthesis silking interval	0.36*	1.90**	0.19
4.	Days to 75 per cent brown husk	2.27*	3.65	0.62
5.	Ear height (cm)	36.37*	175.33**	0.21
6.	Plant height (cm)	115.75*	366.69**	0.32
7.	Ear length (cm)	1.14*	4.60**	0.25
8.	Ear diameter (cm)	0.11*	0.54**	0.20
9.	Kernel rows per ear	0.29**	1.24**	0.23
10.	Kernels per row	3.64	28.71**	0.13
11.	1000- kernels weight (g)	371.98**	1111.60**	0.33
12.	Grain yield (kg/ha)	415133.81*	2318484.02**	0.18

*, **: level of significance at 5% and 1%, respectively

General combining ability (GCA) effects

GCA effects estimates for various traits were either negative or positive. Inbred lines with greater and positive GCA effects values shown good general combining ability characteristics for that trait in general (Krause *et al.*, 2012) [18]. Negative GCA effects, on the other hand, were desirable for some characters (Ejigu *et al.*, 2017) [13]. Earliness is preferable for characters such as anthesis, silking and maturity. Highly significant negative *GCA* effects for days to 50 per cent anthesis, days to 50% silking and anthesis-silking interval were noticed in lines L_{12} and they were grouped as best general combiners for early flowering followed by lines L_6, and L_8 (Table 3). The results are in general agreement with the findings of Dar *et al.*, (2018) [10], Chiuta and Mutengwa (2020) [9]. The exploitation of this inbreds promotes early maturing hybrids with short duration. None of the lines showed significant negative *GCA* effects for days to 75 per cent brown husk. This is corroborated with the earlier findings of Akula *et al.*, (2018) [5]; Dar *et al.*, (2018) [10]. Among the testers, T_2 was the best general combiner due to significant negative GCA effects for early anthesis, silking and anthesis-silking intervals.

Table 3: Estimates of *gca* effects for lines and testers in individual environment (E) for twelve characters in Maize

Sl. No.	Lines	Grain yield (kg ha^{-1})	1000- kernels weight (g)	Kernels per row	Kernel rows per ear	Ear diameter (cm)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to 75 per cent brown husk	Days to 50 per cent anthesis	Days to 50 per cent silking	Antheisi-silking interval
1.	L_1	-262.71	-1.47	-1.88**	0.09	-0.07	-0.26	1.07	1.19	0.56	-0.32	-0.27	0.05
2.	L_2	-497.41**	-4.23	-2.84**	0.08	-0.14	-0.80*	-4.24	-1.82	-0.33	0.35	0.51	0.16
3.	L_3	593.95**	15.30*	-1.04	0.73*	0.07	0.39	0.67	-0.51	-0.33	0.35	0.40	0.05
4.	L_4	453.25*	2.33	-0.58	1.28**	0.22	0.27	0.73	2.43	-0.11	-0.31	-0.26	0.05
5.	L_5	-1011.16**	-2.81	-5.64**	0.04	-0.33**	-1.15**	-16.55*	-8.24**	-2.44	1.90**	2.73**	0.82**
6.	L_6	1462.58**	34.34**	-1.61*	2.05**	0.63**	1.93**	20.61**	12.32**	3.11	-3.53**	-4.70**	-1.17**
7.	L_7	-1662.81**	-49.45**	3.16**	-2.37**	-0.73**	-2.22**	-22.86**	-12.60**	-3.55	3.46**	4.84**	1.38**
8.	L_8	585.25**	24.11**	-1.83**	0.72*	0.19	0.76*	8.79	5.24**	1.77	-1.20**	-1.93**	-0.72**
9.	L_9	780.83**	-10.62	10.33**	-1.48***	0.31*	0.68	3.55	2.19	0.55	-0.76	-0.93	-0.17
10.	L_{10}	-401.17*	-26.23**	5.08**	-1.23**	-0.30*	-0.41	-2.75	-2.79	-0.77	1.46**	1.40**	-0.06
11.	L_{11}	-325.83	-3.87	-1.42*	-0.05	-0.25*	-0.69	-8.16	-4.55*	-1.33	1.23**	1.84**	0.60**
12.	L_{12}	927.73**	37.53**	-1.19	0.72*	0.72**	2.44**	28.29**	13.24**	5.00*	-4.87**	-6.26**	-1.39**
13.	L_{13}	-642.50**	-14.92*	-0.51	-0.59	-0.34**	-0.93*	-9.13	-6.10**	-2.11	2.23**	2.62**	0.38
Range		-1662.81	-49.45	-5.64	-2.37	-0.73	-2.22	-22.86	-12.60	-3.55	-4.87	-6.26	-1.39
		1462.58	37.53	10.33	2.05	0.72	2.44	28.29	13.24	5.00	3.46	4.84	1.38
C.D. 5%		342.35	12.24	1.32	0.67	0.24	0.74	14.14	3.68	4.21	0.90	1.00	0.41
Sl. No.	**Testers**	**Grain yield (kg ha^{-1})**	**1000- kernels weight (g)**	**Kernels per row**	**Kernel rows per ear**	**Ear diameter (cm)**	**Ear length (cm)**	**Plant height (cm)**	**Ear height (cm)**	**Days to 75 per cent brown husk**	**Days to 50 per cent anthesis**	**Days to 50 per cent silking**	**Antheisi-silking interval**
1.	T_1	-501.07**	-12.25**	-0.89**	-0.14	-0.23**	-0.83**	-9.49**	-4.80**	-1.53	1.35**	1.83**	0.48**
2.	T_2	647.43**	21.27**	-0.09	0.32*	0.38**	1.17**	12.10**	6.43**	2.13*	-1.82**	-2.47**	-0.64**
3.	T_3	-146.36	-9.02**	0.99**	-0.18	-0.14*	-0.34	-2.61	-1.63	-0.60	0.47*	0.63*	0.15
C.D. 5%		164.46	5.88	0.63	0.32	0.11	0.35	6.79	1.76	2.02	0.43	0.48	0.19

*, **: level of significance at 5% and 1%, respectively

In the lines, L_{12} had a propensity to increase plant height, due to significant positive GCA effects but L_7 and L_5 had a tendency to decrease plant height because of significant negative GCA effects. However, In the lines, L_7, L_5, L_{13} and L_{11} had a tendency to decrease ear height because of significant negative GCA effects. For lodging resistance in maize, shorter plant and ear height are preferred. Inbred lines with negative plant and ear height GCA effects were reported by Matin *et al.*, (2016); Ahmed *et al.*, (2017); Kuselan *et al.*, (2017) [20, 2, 19].

L_6 followed by L_4, L_3, L_8 and L_{12} had significantly positive GCA effects were noticed for kernel rows per ear and lines *viz*., L_9 followed by L_{10} and L_7 had highly significant positive GCA effect for kernels per row, were found to be good general combiners. Whereas, three lines *i.e*., L_{12} followed by L_6 and L_9 were evident for ear diameter while, three lines *i.e*., L_{12} followed by L_6 and L_8 were evident for ear length were best general combiner because of significant positive GCA effects (Table 3). Among the testers, T_2 was the best general combiner for kernel rows per ear, ear length, and ear diameter due to significant positive GCA effect. The lines, namely, L_{12} followed by L_6, L_8 were highly significant positive and L_3 significant positive *GCA* effects and they were grouped as good general combiners for higher 1000-kernels weight. Among the testers, T_2 was the best general combiner for 1000-kernel weight due to significant positive GCA effects while, T_1 and T_2 were poor combiner for 1000 kernels weight because of significant positive and negative GCA effects. As a result, inbred lines with a positive and significant GCA effect might be chosen for further breeding programmes. Positive and negative significant GCA effects for 1000-kernel weight were observed by Koppad (2007) [17]; Wali *et al*., (2010) [31]; Shushay *et al*., (2013); Amiruzzaman *et al*., (2013) [6]; Dar *et al*., (2017) [11] and Ejigu *et al*., (2017) [13], which are similar to the current findings.

Grain yield in maize is the most important economic trait. Lines possessing significantly positive *GCA* effects for grain yield was observed in six lines, namely, L_6 followed by L_{12}, L_9, L_3, L_8 and L_4 had highly significant positive GCA effects and they were grouped as good general combiners for higher grains yield. Because inbred lines with good general combining ability have a high potential to transmit desirable traits to their cross progenies, they could be used in grain yield improvement programmes to improve the traits of interest. These lines were good general combiners for grain yield and can be utilised to contribute favourable alleles to the development of high yielding hybrids and synthetic varieties. This finding is corroborated with the finding of Akula *et al*., (2018) [5]. According to Rawi *et al*., (2016) [24] positive significant GCA effects for maize lines showed that they are a suitable parent for maize hybrid development and participation in the maize breeding programme because they can be a good allele source in the varietal development process. From the tester, T_2 was the best general combiner, whereas T_1 and T_3 were poor general combiners for grain yield. The inbred lines L_7, L_5, L_{13}, L_2 and L_{10} had significant negative GCA effects for grain yield, revealing that they were unsuitable combiner for producing high-yielding hybrids and synthetic varieties. Shah *et al*., (2015) [25] and Andayani *et al*., (2018) [7] identified inbred lines with significant positive and significant negative GCA effects for grain yield in their studies. The researchers *viz*., Shenawy *et al*., 2009) [28]; Shushay *et al*., (2014) [29]; Ejigu *et al*., (2017) [13] found both positive and negative GCA effects for these trait in maize.

Specific combining ability effects

According to Ejigu *et al*., (2017) [13]; Dar *et al*., (2018) [10]; Chiuta and Mutengwa, (2020) [9] earliness is preferable for characters such as anthesis, silking and maturity. Significantly negative SCA effects were noticed for days to 50 per cent anthesis and silking. The significant negative specific combing effects were noticed in $L_1 \times T_3$ followed by $L_1 \times T_3$, $L_8 \times T_1$, $L_2 \times T_2$, $L_{12} \times T_3$, $L_5 \times T_2$, $L_3 \times T_1$, $L_6 \times T_2$, $L_4 \times T_1$, $L_{12} \times T_2$ and $L_7 \times T_3$ for days to 50 per cent anthesis, $L_1 \times T_3$, $L_8 \times T_1$, $L_2 \times T_2$, $L_5 \times T_2$, $L_{12} \times T_3$, $L_3 \times T_1$, $L_6 \times T_2$, $L_4 \times T_1$, $L_{12} \times T_2$, $L_7 \times T_3$, $L_{10} \times T_2$ and $L_4 \times T_2$ for days to 50 per cent silking (Table 4). The crosses were significant negative specific combing effects for anthesis-silking interval, were $L_1 \times T_3$, $L_5 \times T_2$, $L_8 \times T_1$, $L_2 \times T_2$, $L_{12} \times T_3$, $L_7 \times T_3$, $L_4 \times T_1$ $L_4 \times T_1$ and $L_6 \times T_2$ (Table 4). This result is same as previous finding of Dar *et al*., (2017) [11] and Ejigu *et al*., (2017) [13]; Dar *et al*., (2018) [10].

With respect to plant height, the estimates of *SCA* effects were found to be significant negative in 3 crosses of the 39 crosses evaluated in the current study. Crosses $L_2 \times T_3$ followed by $L_{12} \times T_1$, and $L_8 \times T_2$ were good specific combiners due to significant negative SCA effects (Table 4). The dwarf type hybrids are advantageous in case of lodging resistance. With regard to ear height the crosses namely, $L_8 \times T_2$, $L_{12} \times T_1$, $L_2 \times T_2$, $L_4 \times T_3$, $L_3 \times T_2$, $L_5 \times T_3$ $L_1 \times T_2$, $L_1 \times T_1$, $L_6 \times T_3$, $L_7 \times T_2$, $L_{10} \times T_2$ and $L_5 \times T_1$ were best specific combiners because of significant negative SCA effects they show the tendency to reduce ear height. This finding is corroborated with the previous finding of Dar *et al*., (2017) [11]. The existence of both positive and negative *SCA* effects for these traits in maize crosses has been also reported by Shenawy *et al*., (2013); Dar *et al*., (2018) [10]. Parents with a high GCA for grain yield but a low GCA for plant height, ear height, days to 50 per cent anthesis, and days to 50 per cent silking may be utilised widely as a donor in the hybridization programme to develop early and small statured hybrids with higher yield. It is possible to take advantage of cross combinations with high SCA effects for yield.

Table 4: Estimates of *SCA* effects for hybrids in individual environment (E) for twelve characters in Maize

Sl. No.	Hybrid	Grain yield (kg/ha)	1000-kernels weight (g)	Kernels per row	Kernel rows per ear	Ear diameter (cm)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to 75 per cent brown husk	Days to 50 per cent anthesis	Days to 50 per cent silking	Antheisi-silking interval
1	L_1XT_1	-1107.93**	-33.70**	-0.14	-0.58	-0.66**	-1.88**	-23.75	-11.96**	-3.58	2.98**	4.49**	1.51**
2	L_1XT_2	-1241.19**	-27.10*	-0.21	-0.95	-0.71**	-1.80**	-19.24	-12.51**	-4.24	4.49**	5.47**	0.97**
3	L_1XT_3	2349.12**	60.81**	0.36	1.53*	1.37**	3.68**	43.00**	24.47**	7.82*	-7.47**	-9.96**	-2.48**
4	L_2XT_1	-379.43	-5.14	0.54	-0.54	-0.18	0.01	-1.55	-1.36	-0.69	1.65*	1.71	0.06
5	L_2XT_2	1742.25**	24.43*	3.03*	1.06	0.87**	2.26**	31.20*	17.22**	5.30	-5.17**	-6.97**	-1.80**
6	L_2XT_3	-1362.82**	-19.29	-3.58**	-0.51	-0.68**	-2.26**	-29.65*	-15.86**	-4.615	3.52**	5.25**	1.73**
7	L_3XT_1	1592.35**	31.16**	2.01	0.86	0.82**	2.05**	16.91	10.38**	2.64	-3.35**	-4.17**	-0.82*
8	L_3XT_2	-2270.36**	-46.32**	-1.54	-1.65**	-0.88**	-2.95**	-22.19	-12.79**	-3.35	3.82**	5.13**	1.30**
9	L_3XT_3	678.01*	15.16	-0.47	0.79	0.06	0.89	5.28	2.41	0.71	-0.47	-0.96	-0.48
10	L_4XT_1	1315.51**	34.02**	-2.40*	2.24**	0.49*	1.69*	15.83	6.49*	2.41	-2.68**	-3.50**	-0.82*
11	L_4XT_2	672.96*	-36.92**	11.49**	-1.86**	0.35	0.50	7.66	8.26*	0.41	-1.17	-1.86*	-0.69

12	L_4XT_3	-1988.48**	2.89	-9.09**	-0.38	-0.84**	-2.20**	-23.50	-14.75**	-2.83	3.85**	5.36**	1.51**
13	L_5XT_1	-630.73*	4.58	-1.65	-0.50	-0.41	-1.45*	-11.49	-6.62*	-2.58	1.09	1.82*	0.73*
14	L_5XT_2	2220.26**	27.21*	5.53**	0.98	1.01**	3.78**	31.31*	19.17**	6.75	-3.72**	-6.19**	-2.47**
15	L_5XT_3	-1589.53**	-31.79**	-3.87**	-0.48	-0.59**	-2.32**	-19.81	-12.55**	-4.17	2.63**	4.36**	1.73**
16	L_6XT_1	745.26*	-5.19	4.61**	-0.52	0.33	0.50	-2.84	-2.22	-0.80	-0.46	-0.39	0.06
17	L_6XT_2	-82.53	19.30	-3.81**	1.00	0.29	0.95	19.14	12.93**	3.53	-2.94**	-3.75**	-0.80*
18	L_6XT_3	-662.73*	-14.10	-0.80	-0.48	-0.63**	-1.46*	-16.29	-10.71**	-2.72	3.41**	4.14**	0.73*
19	L_7XT_1	324.32	11.50	0.51	-0.09	0.11	0.44	3.63	2.52	0.86	-0.79	-0.94	-0.15
20	L_7XT_2	-846.39**	-20.48	-0.68	-0.55	-0.54*	-1.60*	-19.09	-9.12**	-2.80	2.38**	3.35**	0.97**
21	L_7XT_3	522.07	8.97	0.16	0.64	0.43*	1.15	15.46	6.60*	1.94	-1.59*	-2.41**	-0.82*
22	L_8XT_1	1792.44**	48.14**	1.20	0.82	1.15**	2.63**	29.16*	19.90**	6.53	-6.46**	-8.50**	-2.04**
23	L_8XT_2	-2072.27**	-47.50**	-0.62	-1.63**	-0.97**	-2.80**	-25.77*	-16.40**	-5.13	5.38**	7.13**	1.75**
24	L_8XT_3	279.83	-0.63	-0.57	0.80	-0.17	0.16	-3.39	-3.50	-1.39	1.07	1.36	0.29
25	L_9XT_1	-1215.61**	-27.44*	-0.22	-0.95	-0.49*	-0.82	-1.03	-2.87	-0.58	1.76*	1.82*	0.06
26	L_9XT_2	336.15	55.89**	-8.26**	0.55	0.04	-0.23	-5.88	-1.43	-0.24	-0.39	-0.19	0.19
27	L_9XT_3	879.46**	-28.44**	8.48**	0.40	0.44*	1.06	6.91	4.30	0.82	-1.36	-1.63	-0.26
28	$L_{10}XT_1$	548.20	5.18	-0.38	0.76	0.26	0.94	9.45	4.97	1.75	-1.46	-2.17*	-0.70
29	$L_{10}XT_2$	-1047.37**	3.10	-7.40**	0.33	-0.46*	-1.61*	-13.83	-7.03*	-2.58	2.05*	3.13**	1.08**
30	$L_{10}XT_3$	499.16	-8.28	7.79**	-1.09	0.19	0.67	4.37	2.05	0.82	-0.59	-0.96	-0.37
31	$L_{11}XT_1$	-870.38**	-12.17	-1.86	-0.41	-0.34	-0.78	-8.33	-5.01	-0.69	1.42	2.05*	0.62
32	$L_{11}XT_2$	911.00**	-8.45	3.62**	0.67	0.31	0.59	2.02	1.66	-0.03	-1.060	-1.308	-0.248
33	$L_{11}XT_3$	-40.62	20.63	-1.75	-0.26	0.03	0.18	6.31	3.35	0.71	-0.368	-0.744	-0.376
34	$L_{12}XT_1$	-1747.43**	-43.80**	-1.13	-1.19*	-0.95**	-3.23**	-29.04*	-16.25**	-5.69	6.53**	8.16**	1.62**
35	$L_{12}XT_2$	502.32	38.10**	-5.53**	2.34**	0.31	2.11**	11.66	-1.17	2.30	-2.61**	-2.86**	-0.24
36	$L_{12}XT_3$	1245.10**	5.70	6.67**	-1.15	0.63**	1.12	17.38	17.42**	3.38	-3.92**	-5.29**	-1.37**
37	$L_{13}XT_1$	-366.57	-7.13	-1.07	0.12	-0.12	-0.09	3.07	2.04	0.41	-0.23	-0.39	-0.15
38	$L_{13}XT_2$	1175.16**	18.74	4.38**	-0.29	0.37	0.78	2.99	1.20	0.08	-1.06	-1.08	-0.02
39	$L_{13}XT_3$	-808.58**	-11.61	-3.31**	0.17	-0.24	-0.69	-6.07	-3.24	-0.50	1.29	1.47	0.17
	CD 5%	592.97	21.20	2.29	1.16	0.42	1.29	24.49	6.37	7.30	1.56	1.74	0.71

*, **: level of significance at 5% and 1%, respectively

Significantly positive *SCA* effects were observed for 1000-kernels weight, kernel rows per ear, kernels per row, ear length and ear diameter. The best specific combiners were, $L_1 \times T_3$, $L_9 \times T_2$, $L_8 \times T_1$, $L_{12} \times T_2$, $L_4 \times T_1$, $L_3 \times T_1$, $L_5 \times T_2$ and $L_2 \times T_2$ for 1000 kernels weight; $L_{12} \times T_4$, $L_4 \times T_1$ and $L_1 \times T_3$ for kernel rows per ear; $L_4 \times T_2$, $L_9 \times T_3$, $L_{10} \times T_3$, $L_{12} \times T_3$, $L_5 \times T_2$, $L_6 \times T_1$, $L_{13} \times T_2$, $L_{11} \times T_2$ and $L_2 \times T_2$ for kernels per row; the lines $L_5 \times T_2$ followed by $L_1 \times T_3$, $L_8 \times T_1$, $L_2 \times T_2$, $L_{12} \times T_2$, $L_3 \times T_1$ and $L_4 \times T_1$ for ear length; $L_1 \times T_3$, $L_8 \times T_1$, $L_5 \times T_2$, $L_2 \times T_2$, $L_3 \times T_1$, $L_{12} \times T_3$, $L_4 \times T_1$, $L_9 \times T_3$ and $L_7 \times T_3$ for ear diameter showed significant positive SCA effects. This result is in conformity with findings of Shashidhara (2008) [27]; Dar *et al.*, (2017) [11]; Ejigu *et al.*, (2017) [13] for kernel rows per year. This trait contributes directly to maize grain yield, thus crosses with positive and significant SCA effects are preferred. Uddin *et al.*, (2006) [30] reported significant SCA effects in maize inbred lines assessed in line × tester for 1000-kernels weight, which is consistent with the current findings.

For grain yield, both negative and positive significant *SCA* effects were observed among the crosses. A very low proportion *i.e.*, 33.33 per cent of the crosses were good specific combiners for grain yield. The 13 crosses *viz.*, $L_1 \times T_3$, $L_5 \times T_2$, $L_8 \times T_1$, $L_2 \times T_2$, $L_3 \times T_1$, $L_4 \times T_1$, $L_9 \times T_3$, $L_{13} \times T_2$, $L_{11} \times T_2$, $L_9 \times T_3$, $L_6 \times T_2$, $L_3 \times T_3$ and $L_4 \times T_2$ were good specific combiners for grain yield because of significant positive SCA effects. This finding is in line with the result reported by Chemada *et al.*, (2015) [8]; Ahmed *et al.*, (2017) [4], Natol (2017) [22]; who reported both positive and negative significant *SCA* for grain yield. Highly significant *SCA* effects of the crosses indicate that significant deviation from what would have been predicted based on their parental performances. These crosses with highly positive and significant estimations of SCA effect could be chosen for use in maize improvement programmes because of their specific combining ability. The results of the current study are in agreement with the findings of Iqbal *et al.*, (2007) [14], Shams *et al.*, (2010) [26]; Devi and Singh (2011) [12]; Akula *et al.*, (2016); Dar *et al.*, (2017) [11]; Chiuta and Mutengwa (2020) [9] who reported significant to highly significant level of *SCA* effects in most of the crosses they studied for grain yield in maize.

Some of the hybrids of characters under studied, exhibited non-significant SCA effect (absence of dominance) for respective traits but their parents showed significant estimates of GCA effect (presence of additive gene action) for that traits this could be useful in identification of superior segregates. The results of the current study are in agreement with the findings of Nadarajan and Gunsekarn (2008) [21].

Conclusions

Based on the results, grain yield was significantly influenced by non-additive gene action. The breeding strategy to improve yield must consist of inbreeding followed by cross-breeding to generate superior hybrids. Single cross hybrids *viz.*, $L_1 \times T_3$, $L_5 \times T_2$, $L_8 \times T_1$, $L_2 \times T_2$, $L_3 \times T_1$, $L_4 \times T_1$, $L_9 \times T_3$, $L_{13} \times T_2$, $L_{11} \times T_2$, $L_9 \times T_3$, $L_6 \times T_2$, $L_3 \times T_3$ and $L_4 \times T_2$ exhibited high SCA effects for grain yield. These hybrids were therefore the highest yielders. As such, these hybrids can be recommended for further evaluation, such as in intermediate variety trials. They can also be used as parents when generating three-way and four-way hybrids in breeding programs. On the other hand, inbred lines L_6 followed by L_{12}, L_9, L_3, L_8, L_4 and tester T_2 exhibited high GCA effects for grain yield and thus can be very useful source materials in hybridization breeding programs.

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