RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
46 (2) 256-264, 2014

COMBINING ABILITY IN LOCAL AND CIMMYT INBRED LINES OF MAIZE (*Zea mays* L.) FOR GRAIN YIELD AND YIELD COMPONENTS USING LINE × TESTER ANALYSIS

U. CHANDEL* and B. S. MANKOTIA

CSK Himachal Pradesh Agricultural University,
Shivalik Agricultural Research and Extension Centre, Kangra-176001, India
*Corresponding author's email: uttam_chandel@yahoo.co.in

SUMMARY

Test cross evaluation is used to determine the relative potential of maize inbred lines in a hybrid breeding program. The choice of testers is important for efficient selection among lines for their potential in hybrid development. This study was carried out to determine the combining ability, type of gene action and genetic variance of yield and yield components in local and CIMMYT germplasm. Highly significant differences were found between the 2 environments i.e. irrigated and rainfed for the studied traits. The results exhibited that the inbred lines L_3 and L_6, L_{11} and L_{15} had negative and significant GCA effects for plant height whereas lines L_2, L_3, L_6 and L_{15} showed highly significant GCA effects for ear height. The inbred lines L_1, L_2, L_3, L_8, L_9 and L_{11} had a positive and significant GCA effects for ear length, L_5, L_8, L_{10}, L_{11}, L_{12} and L_{13} exhibited positive significant GCA effects for ear diameter, L_2, L_4, L_5, L_{10}, L_{11} and L_{13} showed positive and significant GCA effects for number of rows/ear and L_9 and L_{11} had positive significant GCA effects for grain yield. In addition, tester T_1 was the best general combiner for ear position, ear length and grain yield, while T_2 as a tester was the best combiner for plant height, ear diameter and number of rows/ear. Positive significant SCA effects were obtained in the test crosses $L_6 \times T_1$ and $L_8 \times T_2$ for grain yield, $L_4 \times T_1$, $L_5 \times T_1$, $L_8 \times T_2$ and $L_{11} \times T_2$ for plant height, $L_7 \times T_1$ for ear height, $L_1 \times T_2$, $L_{10} \times T_1$ and $L_{13} \times T_1$ for ear length, $L_2 \times T_2$, $L_5 \times T_1$ and $L_{10} \times T_1$ for ear diameter and $L_1 \times T_2$ and $L_7 \times T_1$ for number of rows/ear. General combining ability variance components σ^2 GCA was larger than that σ^2SCA for ear length and grain yield indicating that additive gene action played the major role than non-additive gene action in the inheritance of these traits, while σ^2 SCA was larger than σ^2 GCA for plant height, ear height and ear diameter and number of rows/ear indicating that non-additive gene action was important than additive gene action in the inheritance of these traits. Combined data revealed that the variance σ^2 GCA × environment interaction was smaller than the variance of σ^2 SCA × environment interaction for almost studied traits indicating, non-additive type of gene action was more affected by environmental conditions than additive effects. Three test crosses *viz.*, $L_5 \times T_1$ (6412 kg/ha), $L_9 \times T_1$ (6684 kg/ha) and $L_{11} \times T_1$ (6162 kg/ha) gave significantly superior yield over the best check Pro-Agro 4640 (5554 kg/ha). These test crosses have to be evaluated in the advanced stage for release as new commercial hybrids in maize research program.

Keywords: Maize, test cross, combining ability, gene action and genetic components

Manuscript received: April 11, 2014; Decision on manuscript: July 5, 2014; Manuscript accepted: September 1, 2014.

Communicating Editor: Bertrand Collard

INTRODUCTION

Maize is an important cereal crop of the world. Its cultivation extends over a wide range of geographical and environmental conditions ranging from 58°N to 40°S. It is the staple food of over 200 million people in developing countries in Asia, Latin America and Africa. In India, maize is grown over an area of 8.67 m ha with production of 22.25 million tons and productivity of 2566 kg/ha (Anonymous, 2013).

Maize possesses enormous genetic and biological diversity which justifies the attention it continues to enjoy from geneticists and plant breeders. In fact, maize has been subjected to extensive genetic studies than any other crop (Hallauer and Miranda, 1988). Combing ability is the relative ability of a genotype to transmit its desirable performance to its progeny. Combining ability analysis is not only the quickest method of understanding the genetic nature of quantitatively inherited traits, but also gives essential information about the selection of parents which produces better segregants. The concept of general and specific combining ability was introduced by Sprague and Tatum (1942). Estimation of combining ability and genetic variance components are important in the breeding programs for hybridization (Fehr, 1993). In any breeding program, the choice of the correct parents is the secret of the success. One of the most important criteria in breeding programs for identifying hybrids with high yield is knowledge regarding parent's genetic structure and information regarding their combining ability (Ceyhan, 2003). Maize breeders have used several biometrical techniques to study the genetic architecture of quantitative traits including grain yield. Amongst a large array of biometrical procedures for relative estimation of genetic components, line × tester is an efficient procedure as it allows the inclusion of a large number of lines and provides reliable estimates of combining ability and gene action governing a complex trait. Therefore, the present study was carried out to determine estimates of combining ability for local and CIMMYT inbreds of normal yellow maize, to determine the gene action of the traits under study and define the superior test crosses to be used for developing high yielding hybrids in maize.

MATERIALS AND METHODS

The material for the present investigation was developed during k*harif*, 2011 at Research Farm of SAREC, Kangra (32° 09' N latitude, longitude 76° 22' E, 700 m above mean sea level). The soil of the experimental field was loamy in texture and slightly acidic having pH 6.4. Fifteen normal yellow maize female inbreds (Mentioned L_1 to L_{15} in Table 1) including 3 local inbred i.e. KI_{16}, KI_{18} and KI_{25} and 12 exotic CIMMYT inbreds *viz.*, CML_{161}, CML_{166}, CML_{169}, CML_{172}, CML_{224}, CML_{226}, CML_{337}, CML_{338}, CML_{359}, CML_{411}, CML_{439} and CML_{502} were crossed with 2 male testers HKI $_{1105}$ (T_1) and CM $_{212}$(T_2) in a line× tester mating design. Elite inbreds of the released hybrids having high frequency of favorable alleles that allows identifying the best progenies, the ones with the highest specific combing ability may be used as tester. So, new lines identified in superior crossings could become parents directly of commercial hybrids. In *kharif* 2012, the 30 tests crosses along with 2 checks *viz.*, Pro-Agro 4640 and HQPM-1 were evaluated under irrigated (irrigation provided was provided at every crop growth stage *viz.*, knee high stage, flowering and grain filling) and rainfed (under natural rainfall) conditions in RCBD with 3 replications at the Experimental Farm of Shivalik Agricultural Research and Extension Centre, Kangra representing sub-tropical climate conditions of North-Western Himalayas. Each genotype was planted in 2 rows of 2m length with inter and intra-row spacing of 60cm and 20cm, respectively. All recommended agronomic field practices were applied to raise successful crop. Data were recorded for plant height (cm), ear height(cm), ear length (cm), ear diameter (cm), number of rows/ear and grain yield kg/ha) at 15.5% moisture content.

Statistical analysis were performed for each environment then combined over environments according to Steel and Torrie (1980). The combining ability analysis was estimated using line × tester procedure suggested by Kempthorne (1957) using software SPAR 3.0. Combined analysis among the 2 environments was done on the basis of homogeneity test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Analysis of variances for all the studied traits, i.e., plant height, ear height, ear length, ear diameter, number of rows/ear and grain yield combined over both environments are presented in Table 1. Results revealed that environments mean squares were highly significant for all the studied traits. Mean squares due to crosses, lines (L), testers (T) and L × T interactions were significant for all studied traits except lines for plant height, ear length and grain yield; testers for ear height and ear diameter. Variance due to interaction effects of lines and testers were significant for all the characters. Obviously due to diverse nature of lines and testers, the crosses between them were also found to be significant for all the characters. The significant variance of L × T interaction indicated the importance of specific combing ability. Test crosses evaluation is used to determine the relative potential of maize inbred lines in a hybrid breeding program. The mean squares due to testers were of a larger magnitude than those of lines and L × T interaction for all the characters except ear height and ear diameter indicating greater diversity among the testers than the lines. Mean squares due to L× T interactions were significant for all the studied traits suggested that inbred lines may have different combining ability patterns and performed differently in crosses depending on type of tester used. Similar results were reported earlier in maize (Aly and Amer, 2008; Parveez *et al.,* 2007). The interactions between crosses and environment were significant for plant height, ear height, ear diameter, number of rows/ear and grain yield indicating that test crosses presented differential performance in the testing environments.

Table 1. Experimental material.

Lines	Genotype name	Source
L_1	KI_{16}	Inbred line developed at SAREC, Kangra
L_2	KI_{18}	Inbred line developed at SAREC, Kangra
L_3	KI_{25}	Inbred line developed at SAREC, Kangra
L_4	CML_{161}	CIMMYT
L_5	CML_{166}	CIMMYT
L_6	CML_{169}	CIMMYT
L_7	CML_{172}	CIMMYT
L_8	CML_{224}	CIMMYT
L_9	CML_{226}	CIMMYT
L_{10}	CML_{337}	CIMMYT
L_{11}	CML_{338}	CIMMYT
L_{12}	CML_{359}	CIMMYT
L_{13}	CML_{411}	CIMMYT
L_{14}	CML_{439}	CIMMYT
L_{15}	CML_{502}	CIMMYT
Testers		
T_1	HKI_{1105}	Elite inbred line developed at CCS HAU, Maize Research Station, Karnal
T_2	CM_{212}	Elite inbred line developed at VPKAS, Almora

Table 2. Analysis of variance pooled over environments of all the studied traits.

Source of variation	Df	Plant Height (cm)	Ear Height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	Grain Yield (kg/ha)
Environment (E)	1	6401.7**	33850.5**	428.5**	4.58**	16.5*	8031.6**
Replications/Env.	4	604.5	220.5	0.25	0.05	3.7	20
Crosses (C)	29	650.4**	260.6**	18.5**	0.18**	12.0**	60.9**
Lines (L)	14	805	402.8*	5.4	0.27**	11.3**	27.8
Tester (T)	1	2010.1*	1.5	408.7**	0.2	161.5**	962.6**
L × T	14	420.2**	148.7**	3.1**	0.09**	2.0**	43.1**
C × E	29	150.6*	104.2*	0.92	0.08**	1.3*	27.4**
L × E	14	171.6	105.5	0.84	0.12**	1	33.3*
T × E	1	504.5	205.7	2.2	0.21**	0.2	104.5*
L × T × E	14	125.7	81.6	0.83	0.05	1.2*	15.9*
Pooled Error	186†	83.91	50.16	0.9	0.025	0.71	8.91

* Refers to 0.05 significance probability level, ** Refers to 0.01 significance probability level.
† included checks

Table 3. Mean performances of the test crosses and the 2 checks for all studied traits combined over the 2 environments.

Crosses	Plant height (cm)	Ear Height (cm)	Ear Length (cm)	Ear diameter (cm)	No. of Rows/ear	Grain Yield (kg/ha)
$L_1\times T_1$	250.88	128.25	19.93	4.71	15.3	5826
$L_1\times T_2$	252.5	133.75	18.73	4.89	18.35	5334
$L_2\times T_1$	244.88	121.38	20.03	4.71	17	5502
$L_2\times T_2$	250	126.38	18.24	5	18.1	5426
$L_3\times T_1$	242.88	119	20.04	4.78	15.46	5386
$L_3\times T_2$	238.25	122.75	17.95	4.89	17.5	4782
$L_4\times T_1$	244.13	129.88	19.29	4.98	17.2	5920
$L_4\times T_2$	253.63	138.25	17.7	4.9	19.75	5414
$L_5\times T_1$	245.88	124.5	19.64	5.1	17.15	6412
$L_5\times T_2$	254.25	128.88	17.14	4.86	18.05	4938
$L_6\times T_1$	249.25	123.25	19.79	4.58	15	6100
$L_6\times T_2$	232.5	119.38	16.2	4.63	16.95	4042
$L_7\times T_1$	252.88	125.75	19.51	4.8	16.45	6000
$L_7\times T_2$	248.63	139.25	16.86	4.74	16.75	4426
$L_8\times T_1$	272.25	133.75	20.64	4.9	16.4	5590
$L_8\times T_2$	252	127.88	17.93	5.04	17.9	5828
$L_9\times T_1$	249.13	128.5	20.59	4.71	15.5	6684
$L_9\times T_2$	252.25	127.88	17.44	4.79	17.85	5074
$L_{10}\times T_1$	257.5	133.25	20.83	5.11	17.1	6080
$L_{10}\times T_2$	249.5	127.63	16.73	4.93	18.5	5134
$L_{11}\times T_1$	255.25	131.63	19.1	4.75	15.45	6152
$L_{11}\times T_2$	229.88	125.13	16.21	4.8	16.4	4976
$L_{12}\times T_1$	257.75	136.25	19.2	4.89	16.6	5744
$L_{12}\times T_2$	248	129.88	15.9	5.03	18.25	4994
$L_{13}\times T_1$	264	136.5	20.18	4.96	18.25	5458
$L_{13}\times T_2$	260.88	135.88	16.1	5.2	19.48	5458
$L_{14}\times T_1$	257	132.13	19.81	4.91	16.4	5490
$L_{14}\times T_2$	248.5	130.38	17.93	4.94	17.9	4966
$L_{15}\times T_1$	245.88	123.63	19.21	4.66	15.45	5292
$L_{15}\times T_2$	230.75	116.75	17.1	4.81	17.6	4760
HQPM-1	288.75	150.88	18.18	4.75	14.38	5218
Pro-Agro 4640	289.88	155.75	21.48	4.7	14.68	5554
LSD 0.05	9.50	7.34	0.93	0.15	0.82	5.84
0.01	12.48	9.65	1.23	0.2	1.08	7.68

Furthermore, the L × E and T × E interactions were significant for ear diameter and grain yield indicated that inbred lines performed differently as reflected in their respective test crosses from one environment to another. The interactions for L × T × E were significant only for ear diameter, number of rows/ear and grain yield. These results are in agreement with those by Mosa (2010), who reported significant interaction of (L x E), (T x E) for grain yield and ear diameter and (L x T x E) for plant height and grain yield. These findings indicated that these are different ranks of interaction of inbred lines in their test crosses from one environment to another that appeared in grain yield.

Mean performance of test crosses and the 2 checks for all the studied traits combined over the environments are presented in Table 3. The results showed that only 3 test crosses i.e. $L_5 \times T_1$ (6412 kg/ha), $L_9 \times T_1$ (6684 kg/ha) and $L_{11} \times T_1$ (6152 kg/ha) were significantly superior to best hybrid check Pro-Agro 4640 (5554 kg/ha) well adapted to the mid hill conditions of North Western Himalayas. Results indicated that these test crosses for plant height towards shorter plants, ear height towards lower ear placement, ear length, ear diameter and number of rows/ear were also significantly superior to the best check Pro-Agro 4640.

The GCA effects for 15 inbred lines and the 2 testers combined over both environments are shown in Table 4. The results exhibited that the inbred lines L_{3}, L_{6}, L_{11} and L_{15} gave significant negative values of GCA effects

Table 4. Pooled Estimates of GCA effects for the 15 inbred lines and 2 testers.

Parents	Plant Height (cm)	Ear Height (cm)	Ear Length (cm)	Ear Diameter (cm)	No. of ear/row	Grain Yield (Kg/ha)
L_1	1.9	2.4	0.80**	-0.07	-0.29	0.7
L_2	-1.25	-4.71*	0.60*	-0.12**	0.44*	0.12
L_3	-7.14**	-6.71**	0.46	-0.14**	-1.65**	-2.78**
L_4	-0.83	5.48**	-0.9	-0.07	1.34**	1.14
L_5	-1.37	-1.9	-0.84**	0.12**	0.47*	1.17
L_6	-8.83**	-7.28**	-0.64**	-0.27**	-1.16**	-1.84*
L_7	1.8	3.91*	-0.39	-0.10**	-0.53*	-2.13**
L_8	12.43**	2.23	0.75**	0.10**	0.02	1.35
L_9	0.99	-0.4	0.48*	-0.12	-1.46**	2.20**
L_{10}	3.8	-1.85	0.25	0.15**	0.67**	0.84
L_{11}	-7.14**	-0.21	0.87**	0.09*	1.42**	1.62*
L_{12}	3.18	4.48*	-0.98**	0.09*	0.29	-0.35
L_{13}	12.74**	7.60**	-0.39	0.22**	1.73**	0.09
L_{14}	3.05	2.66	0.34	0.06	0.02	-1.06
L_{15}	-11.39**	-8.40**	-0.37	-0.13**	-1.24**	-1.07
LSD (L) 0.05	4.7	3.6	0.47	0.08	0.41	1.46
0.01	5.24	4.83	0.61	0.1	0.54	1.92
T_1	2.93	-0.08	1.32	-0.03	-0.82	2.01
T_2	-2.93	0.08	-1.32	0.03	0.82	-2.01
LSD (T) 0.05	1.7	1.34	0.17	0.03	0.15	0.53
0.01	2.25	1.76	0.22	0.04	0.2	0.7

* Refers to 0.05 significance probability level, ** Refers to 0.01 significance probability level

for plant height and L_2, L_3 and L_8 had a negative and significant GCA effects for ear height. Inbred lines L_1, L_2, L_3, L_8, L_9 and L_{11} showed positive significant GCA effects for ear diameter whereas L_2, L_4, L_5, L_{10}, L_{11} and L_{13} showed positive and significant GCA effects for number of rows/ear and L_9 & L_{11} has similar GCA effects for grain yield. In addition, the obtained results in the same table showed thatT_1 was the best general combiner for ear length and grain yield, whereas the T_2 was the best combiner for plant height, ear diameter and number of rows/ear. The best SCA effects were obtained in L_6× T_1 and L_8× T_2 for grain yield, L_4× T_1, L_4× T_1, L_8× T_2 and L_{11}× T_2 for plant height, L_7× T_1 for ear height, L_1× T_2, L_{10}× T_1 and L_{13}× $T_1$for ear length, L_2× T_2, L_5× T_1 and L_{10}× T_1 for ear diameter and L_1× T_2& L_7× T_1 for number of rows/ear (Table 5).

Table 5. Specific combining ability (SCA) effects for 30 test crosses for all the studied traits as a combined over all the 2 environments.

Crosses	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	Grain Yield (kg/ha)
$L_1\times T_1$	-3.746	-2.671	-0.721*	-0.058	-0.705*	-0.782
$L_1\times T_2$	3.746	2.671	0.721*	0.058	0.705*	0.782
$L_2\times T_1$	-5.496	-2.421	-0.427	-0.115*	0.27	-1.824
$L_2\times T_2$	5.496	2.421	0.427	0.115*	-0.27	1.824
$L_3\times T_1$	-0.621	-1.796	-0.277	-0.027	-0.198	-0.503
$L_3\times T_2$	0.621	1.796	0.277	0.027	0.198	0.503
$L_4\times T_1$	-7.683*	-4.108	-0.527	0.067	-0.455	-0.749
$L_4\times T_2$	7.683*	4.108	0.527	-0.067	0.455	0.749
$L_5\times T_1$	-7.121*	-2.108	-0.071	0.148*	0.37	1.673
$L_5\times T_2$	7.121*	2.108	0.071	-0.148*	-0.37	-1.673
$L_6\times T_1$	5.442	2.017	0.473	0.004	-0.155	3.128*
$L_6\times T_2$	-5.442	-2.017	-0.473	-0.004	0.155	-3.128*
$L_7\times T_1$	-0.808	-6.671*	0.004	0.06	0.670*	1.923
$L_7\times T_2$	0.808	6.671*	-0.004	-0.06	-0.670*	-1.923
$L_8\times T_1$	7.192*	3.017	0.035	-0.04	0.07	-2.610*
$L_8\times T_2$	-7.192*	-3.017	-0.035	0.04	-0.07	2.610*
$L_9\times T_1$	-4.496	0.392	0.254	-0.008	-0.355	2.01
$L_9\times T_2$	4.496	-0.392	-0.254	0.008	0.355	-2.01
$L_{10}\times T_1$	1.067	2.892	0.729*	0.123*	0.12	0.353
$L_{10}\times T_2$	-1.067	-2.892	-0.729*	-0.123*	-0.12	-0.353
$L_{11}\times T_1$	9.754*	3.329	0.123	0.004	0.345	0.923
$L_{11}\times T_2$	-9.754*	-3.329	-0.123	-0.004	-0.345	-0.923
$L_{12}\times T_1$	1.942	3.267	0.329	-0.04	-0.005	-0.138
$L_{12}\times T_2$	-1.942	-3.267	-0.329	0.04	0.005	0.138
$L_{13}\times T_1$	-1.371	0.392	0.717*	-0.09	0.208	-2.016
$L_{13}\times T_2$	1.371	-0.392	-0.717*	0.09	-0.208	2.016
$L_{14}\times T_1$	1.317	0.954	-0.377	0.017	0.07	-0.704
$L_{14}\times T_2$	-1.317	-0.954	0.377	-0.017	-0.07	0.704
$L_{15}\times T_1$	4.629	3.517	-0.265	-0.046	-0.255	-0.683
$L_{15}\times T_2$	-4.629	-3.517	0.265	0.046	0.255	0.683
LSD 0.05	6.716	5.193	0.659	0.11	0.583	2.068
0.01	8.826	6.862	0.866	0.144	0.766	2.718

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

Genetic variance components for all the studied traits over the environments and their interaction with environments are shown in Table 6. Results revealed that estimates of $\sigma^2GCA_{(L)}$ were higher in magnitude than those of σ^2 $GCA_{(T)}$ for plant height, ear height and ear diameter, indicated that most of the total GCA variances were due to the inbred lines and contribution of lines were higher than the contribution of testers for these traits.

General combining ability variance components, σ^2GCA was larger than $\sigma^2SCA$for ear length and grain yield. These results indicated preponderance of additive gene action than non-additive gene action in the inheritance of these traits, whereas σ^2SCA was larger than σ^2GCA for plant height, ear height, ear diameter and number of rows/ear indicated that non-additive gene action was important than additive gene action in the inheritance of these traits. Similar results have been reported earlier in maize (Kumar *et al*., 1998; Joshi *et al*., 1998; Paul and Debanth, 1999; Zelleka, 2000; Betran *et al*., 2003; Aly, 2004 and Kumar *et al*., 2005). Moreover, the results showed that variance interactions of $\sigma^2GCA_L\times$ environment was higher than $\sigma^2SCA_T\times$ environment for plant height, ear height, ear diameter and grain yield indicating that the σ^2GCA for lines was affected more by environment than by testers for these traits. Combined data revealed that the variance of $\sigma^2GCA\times$ environment interaction was either smaller or negligible than the variance of $\sigma^2SCA\times$ environment interaction for almost studied traits. These results indicated that non-additive type of gene action was more affected by environmental conditions than additive effects. Similar results have been reported earlier in maize (Matzinger, 1953; Silva and Hallauer, 1975).

A number of parental lines *viz.,* L_5 (CML_{166}), L_6 (CML_{169}), L_8 (CML_{224}), L_9 (CML_{226}) and L_{11} (CML_{338}) which not only had good GCA but also entered into specific cross combinations exhibiting superior mean performance and SCA effects for grain yield and related traits. These inbreds in future could be used in hybridization program to broaden the genetic base of local germplasm.

Table6. Estimates of genetic variance components for all studied traits over the 2 environments and their interaction with environment.

Genetic parameters	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	Grain Yield (kg/ha)
$\sigma^2L = \sigma^2$ GCA (Lines)	23.053	15.317	0.135	0.011	0.578	-0.972
$\sigma^2T = \sigma^2$ GCA (Testers)	13.574	-1.31	3.463	0.001	1.329	7.747
$\sigma^2GCA = \sigma^2GCA$ (av.)	14.689	0.646	3.072	0.0022	0.124	6.721
$\sigma^2L\times T = \sigma^2SCA$ (av.)	42.782	12.823	0.277	0.008	0.169	4.302
$\sigma^2GCA/ = \sigma^2GCA$ av./σ^2SCA av. σ^2SCA	0.343	0.05	11.082	0.284	0.733	1.562
$\sigma^2L \times E = \sigma^2GCA$ (L) × E	8.24	2.234	0.002	0.009	-0.016@	2.17
$\sigma^2T\times E = \sigma^2GCA$ (T) × E	6.315	1.989	0.021	0.003	-0.018	1.518
$\sigma^2GCA \times E = \sigma^2GCA$ av. × E	6.542	2.018	0.019	0.004	-0.017	1.588
$\sigma^2L \times T \times E = \sigma^2SCA$ av. × E	7.943	8.858	0.006	0.006	0.113	1.756
Contribution of Lines	57.97	71.767	13.794	72.533	45.409	19.757
Contribution of Tester	10.622	0.019	78.057	3.949	46.317	49.429
Contribution of L × T	31.409	28.214	8.149	23.518	8.274	30.813

@ Variance estimate proceeded by negative sign is considered zero (Robinson *et al.,* 1955) (T) Denote tester, (L) inbred lines and (E) Environment

Three crosses viz., $L_5 \times T_1$, $L_9 \times T_1$ and $L_{11} \times T_1$ have shown high SCA effects for grain yield involving parents of positive GCA effects can be exploited for the development of single cross hybrids. Since non-additive gene action for most of the traits was observed, further they can also be used for population Improvement through reciprocal recurrent selection.

REFERENCES

Aly AA (2004). Combining ability and gene action of new inbred maize lines (*Zea mays* L.) using line × tester analysis. *Egyptian J. Applied Sci*. 19: 492-518.

Aly RSH, Amer EA (2008). Combining ability and type of gene avtion for grain yield and some other traits using line × tester analysis in newly yellow maize inbred lines (*Zea mays* L.). *Journal of Agricultural Sciences* 33: 4993-5003.

Anonymous (2013). *Maize Statistics at a Glance*. US department of Agriculture. pp. 1.

BetranFD, Beck M, Banziger, Edmeads G (2003). Genetic analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. *Crop Sci.* 43: 807-817.

Ceyhan E (2003). Determination of some agricultural characters and their heredity through line x tester method in Pea parents and crosses. Selcuk Univ., Graduate School Nat. Applied Sci., pp.130.

Fehr WR (1993**).** Principles of Cultivar Development. MacMillan Publication Co. New York. pp.342.

Hallauer AR, Miranda JB (1988). Quantitative genetics in maize breeding. Lowa State, Ames. pp 468.

Joshi VN, Pandiya N, Dubey RB (1988). Heterosis and combining ability for yield and quality in early maturing single crosses of maize. *Indian J. Gene. Plant Breed.* 58: 519-524.

Kempthorne O (1957). An Introduction to Genetic Statistics. John Wiley Sons Inc. New York, U.S.A. pp. 545.

Kumar A, Gangashetti MG, Kumar N (1998). Gene effects in some metric traits in maize. *Annals Agricultural Biology Res.* 3: 139-143.

Kumar R, Singh M, Narwal M, Sharma S (2005). Gene effects for grain yield and its attributes in maize. *Natural J. Plant Improvement* 7: 105-107.

Matzinger, DF (1953). Comparisons of three types of testers for the evaluation of inbred lines of corn. *Agronomy J*. 45: 493-495.

Mosa HE (2010). Estimation of combining ability of maize inbred lines using top crosses mating design. *J. Agricultural Research* 36: 1-15.

Parvez AS, Rather AG, Dar Z (2007). Association of heterotic expression for grain yield and its components traits in maize (*Zea mays* L.) *International J. Agri. Res.* 2: 500-503.

Paul KK, Debanth SC (1999). Combining ability analysis in maize. *Pakistan J. Scientific and Industrial Res.* 42: 141-144.

Robinson JO, Comstock RE, Harvey PH (1955). Genetic variance in open pollinated varieties of corn. *Genetics* 40: 45-60.

Silva JC, Hallauer AR (1975). Estimation of epistatic variance in stiff stalk synthetic maize. *J. Heredity* 66: 290-296.

Sprague GF, Tatum LA (1942).General vs.specific combining ability in single crosses of corn. *J. Amer. Soc. Agron.* 34:923 – 932

Steel RG, Torrie JH (1980). Principal and Procedures of Statistics. McGraw Hill Inc. NewYork, U.S.A. pp.326.

Zelleka H (2000). Combining ability for grain yield and other agronomic traits in inbred lines of maize. *Ind. J. Genet. Plant Breed.* 60*:* 63-70.