

Combining ability analysis for yield and quality traits in medium maturing yellow seeded maize (*Zea mays* L.) hybrids using line x tester

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Abstract Thirty six hybrids of maize were developed through Line x Tester design using three male tester lines and twelve female inbred lines as parental material along with four standard checks Vivek-H-43, Pratap Hybrid Maize-3, Pratap Makka-9 and HM-11, to study combining ability in maize (*Zea mays* L.). The parents, hybrids and four standard checks were evaluated during *kharif* season 2016 for 15 characters in randomized block design with three replications. The mean squares due to genotypes, parents, crosses and parents v/s crosses were significant for all characters except for days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk, number of leaves per plant, cob girth and number of grain rows per cob. The ratio of $\sigma^2_{sca} / \sigma^2_{gca}$ was greater than over for all the traits except anthesis-silking interval, number of leaves per plant, harvest index, grain yield per plant and quality traits like oil content and starch content. This indicated that the preponderance of non-additive gave effects in the expression of these traits. Among female inbred line L10 was found good general combiners for grain yield per plant and yield component traits like, cob girth, number of grain rows per cob, harvest index and quality traits like, oil content and starch content. whereas the testers T3 was good general combines for yield and majority of traits viz., grain yield per plant, harvest index, oil content, protein content and starch content. The general combining ability due to additive and

additive x additive gene effects. Which are the fixable component of genetic variation. Twelve hybrids showed significant positive sca effects for grain yield per plant. The maximum significant positive sca effects for grain yield per plant was depicted by hybrid L12 x T3, followed by hybrids L1 x T2, L11 x T2, L7 x T1 and L4 x T2. This was cross between average x good gca effects parents for grain yield per plant. They produced significant and desirable SCA effects for most of the traits studied indicating potential for exploiting hybrid vigour in breeding programme.

Key words: General combining ability · Specific combining ability · Maize

Introduction

Combining ability analysis is one of the most powerful tool in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate productive genes. It also helps to understand the genetic architecture of various characters that enable to breeder to design effective breeding plan for other improvement of the existing breeding material. Maize (*Zea mays* L.) is an important multipurpose, cross pollinated crop belonging to family *Gramineae* and tribe *Maydeae*. It is the third most widely distributed crop of the world being grown in diverse seasons and ecologies with highest production and productivity among food cereals. It is used worldwide for feed, food and also serves as source of basic raw material for a number of industries viz., oil, starch, protein, food, alcoholic beverages, sweeteners, cosmetics and bio-fuels etc. It was grown in 202 m ha worldwide with production of 1162 mt with a productivity of 5.8 t/ha (FAOSTAT,

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2022). In India during 2020-21, 9.9 m ha of maize were cultivated and producing 30 mt of maize with a productivity of over 3 t/ha despite the challenging *kharif* season environment over 82 per cent of the land. While at Rajasthan level, it occupied 891115 ha area and 1155671 tonnes production with productivity level of 1.30 t/ha, (Anonymous, 2020). The productivity level of maize in India is very low then worlds productivity. Maize has high yield potential owing to its efficient carboxylation mechanism, suggesting tremendous scope to increase the yield potential through proper breeding strategy. In breeding of high yielding hybrids/varieties, the breeder often faces the problem of selecting the desirable parents. Information on combining ability provides guidelines to the plant breeder in selecting the elite parents and desirable cross combinations to be used in the formulation of systematic breeding programme and at the same time reveals the nature of gene action involved in the inheritance of various traits, combining ability analysis also provide the requisite information on the magnitude of gca and sac variances and effects, to formulate an efficient breeding methodology.

The concept of general and specific combining ability was proposed by Sprague and Tatum (1942). They defined

general combining ability as “an average of a line in hybrid combination” and used specific combining ability to designate “deviation of certain crosses from expectation on the basis of the average performance of the line involved”. Their studies in a set of F₁ crosses of maize revealed that general combining ability is the function of additive gene effect whereas, specific combining ability results from intra – allelic interaction (dominance) and inter – allelic interaction (epistasis). Comstock *et al.*, (1949) designated breeding procedure to make maximum use of both general and specific combining ability. The present study was, therefore, undertaken with a view to estimate general and specific combining ability variances and effects to identify superior maize hybrids for good yield potential and quality traits.

Material and methods

The present investigation was carried out in analysis of combining ability in yellow seeded late maturing maize (*Zea mays* L.)” Hybrids at Instructional farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India during *kharif*, 2016. The experimental material consisting of 12 female

Table 1. Details of Inbred lines used as Parents and Checks

S.No	Inbred line	Symbol (Code)	Stage of level of inbred line	Source (Origin)
1.	EI-2522	L1	S5	AICRP on maize, Udaipur
2.	EI-2531	L2	S5	AICRP on maize, Udaipur
3.	EI-2533	L3	S5	AICRP on maize, Udaipur
4.	EI-2535	L4	S5	AICRP on maize, Udaipur
5.	EI-2536	L5	S5	AICRP on maize, Udaipur
6.	EI-2538	L6	S5	AICRP on maize, Udaipur
7.	EI-2540	L7	S5	AICRP on maize, Udaipur
8.	EI-2541	L8	S5	AICRP on maize, Udaipur
9.	EI-2542	L9	S5	AICRP on maize, Udaipur
10.	EI-2544	L10	S5	AICRP on maize, Udaipur
11.	EI-2550	L11	S5	AICRP on maize, Udaipur
12.	EI-2552	L12	S5	AICRP on maize, Udaipur
13.	EI-586-2	T1	S6	AICRP on maize, Udaipur
14.	EI-1158	T2	S6	AICRP on maize, Udaipur
15.	BML-6	T3	S6	AICRP on maize, Udaipur
16.	Pratap Hybrid Maize-3		Hybrid variety	AICRP on maize, Udaipur
17.	Vivek-Hybrid-43		Hybrid	VPKAS, Almora
18.	Pratap Makka-9		Composite	AICRP on maize, Udaipur
19.	HM-11		Hybrid	CCSHAU, Karnal

Where, AICRP – All India Coordinated Research Project.

CCS HAU - Chaudhary Charan Singh Haryana Agriculture University, Hisar

VPKAS - Vivekand Parvatiya Krishi Anusandhan Shala, Almora

parents (Lines) and 3 male parents (Tester) presented in (Table 1). In this experiment, 12 inbred lines were crossed with three testers *viz.*, EI-586-2, EI-1155 and BML-6 during Rabi -2015-16 to develop a total of 36 hybrids. These 36 F1 hybrids along with 15 parents and 4 checks *viz.*, Vivek-H-43, Pratap Hybrid Maize-3, Pratap Makka-9, HM-11 were evaluated in randomized block design with three replications during *kharij* 2016. The experimental material consisting of a total of 55 entries (36 F1 hybrids, 15 parents and 4 checks) were sown in randomized block design with three replications with a single row plot of four meter length, maintaining crop geometry of 60 x 25 cm. Observations for all traits were recorded on five randomly selected competitive plants of each entry in each replication except for days to 50 per cent tasseling, days to 50 per cent silking and days to 75 per cent brown husk where observations were recorded on plot basis. Data recorded were subjected to analysis of variance according to Panse and Sukhatme (1985) to determine significant differences among genotypes. Combining ability analysis for line x tester mating design was performed as per method suggested by Kempthorne (1957). Estimation of oil content, starch content and protein content were done as per method suggested by Soxhlet's Ether Extraction method developed by A.O.A.C. (1965), Anthrone Reagent method and Micro kjeldahl's method given by Lindner (1944), respectively.

Results and discussion

The mean square values for fifteen traits are presented in Table 2. Combining ability analysis provides estimates of variance due to general combining ability and specific combining ability. It also leads to identification of parents with good combining ability effects and in allocating cross combinations, sowing high specific combining ability effects. Analysis of variance for combining ability indicated that the mean square due to lines and testers were significant for all the characters except anthesis-silking interval, days to 75 per cent brown husk and number of leaves per plant due to the lines, anthesis-silking interval, days to 75 per cent brown husk, number of leaves per plant, plant height, cob girth and number of grain row per cob due to tester. The mean square due to line x tester interactions were significant for all characters except anthesis-silking interval, days to 75 per cent brown husk, number of leaves per plant and number of grain row per

Table 2. Analysis of variance for combining ability for fifteen traits in maize

	d.f.	Days to 50% silking	Anthesis silking interval	Days to 75% brown husk	Plant height	Ear height	No. of leaves per plant	Cob girth	No. of grains rows per cob	100 grain weight	Harvest index	Grain yield (g/plant)	Oil content	Protein content	Starch content
Replication	2	19.98**	10.85	1.77*	58.93	61.07	0.23	1.81	4.06	4.95	0.68	20.77	0.09	0.10	0.09
Crosses	35	13.48**	12.46**	0.56	241.82**	141.55**	1.11	2.07**	2.60**	9.22**	28.97**	1149.30**	1.03**	1.72**	15.82**
Lines	11	22.65**	21.84**	0.47	587.92**	213.53**	1.15	2.75**	4.07**	10.58**	18.13**	597.83**	0.81**	1.93**	11.98**
Testers	2	20.70**	14.73*	0.48	59.32	494.60**	0.54	1.01	0.47	23.59**	13.28**	907.41**	0.69**	0.21**	7.03**
Lines x Testers	22	8.23**	7.56*	0.61	85.37*	73.46**	1.13	1.83**	2.06	7.24**	35.81**	1447.03**	1.17**	1.76**	18.54**
Error	108	3.44	4.47	0.53	51.24	26.24	1.31	0.78	1.40	1.66	1.60	27.60	0.07	0.05	0.49
Variance															
σ^2_L	1.60	1.59	-0.02	-0.02	55.84	15.56	0.00	0.10	0.22	0.37	-1.96	-94.35	-0.04	0.02	-0.73
σ^2_t	0.35	0.20	-0.00	-0.00	-0.72	11.70	-0.02	-0.02	-0.04	0.45	-0.63	-14.99	-0.01	-0.04	-0.32
σ^2_{SCA}	1.60	1.03	0.03	0.03	11.38	15.56	-0.06	0.35	0.22	1.86	11.40	473.14	0.37	0.57	6.02
σ^2_{GCA}	0.33	0.31	-0.00	-0.00	9.85	4.29	-0.00	0.02	0.03	0.13	-0.43	-18.75	-0.01	-0.00	-0.17
$\sigma^2_{SCA/GCA}$	4.48	4.19	-	-	1.15	3.62	-	17.5	7.33	1.23	-26.51	-25.23	-37	-	-35.41

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

cob, which indicates that the experimental material possessed considerable variability and that both gca and sca were involve in the genetic control of various characters.

Combining ability analysis

The combining ability analysis for line x tester mating design was performed as per method suggested by Kempthorne (1957). The analysis of variance for combining ability through line x tester mating design.

Estimates of combining ability variance

Combining ability analysis provides estimates of variance due to general combining ability and specific combining ability. It also leads to identification of parents with good combining ability effects and in allocating cross combinations, sowing high specific combining ability effects. The analysis of variance for combining ability and estimation of variance components for various traits was done as per line x tester analysis following the procedure suggested by Kempthorne (1957). The data on 36 crosses were analysed and the total variance was partitioned into component *viz.*, variance due to lines, testers and line x

testers. The data on crosses were further analysed to determine the lines and testers (gca) and line x testers (sca) variance components for all the traits (Table 2)

The mean squares value for hybrids were significant for all the characters except anthesis-silking interval, days to 75 per cent brown husk and number of leaves per plant. The mean square of its further partition *viz.*, due to lines, testers and line x tester were significant for all the characters except for anthesis-silking interval, days to 75 per cent brown husk and number of leaves per plant due to lines, anthesis-silking interval, days to 75 per cent brown husk, plant height, number of leaves per plant, cob girth, number of grain row per cob due to tester and anthesis-silking interval, days to 75 per cent brown husk, number of leaves per plant and number of grain row per cob due to line x tester indicated significant contribution lines and testers towards general combining ability variance components for these traits. The significant line x tester indicated significant contribution of hybrids for specific combining ability variance components.

Comparison of the magnitude of unbiased estimates of variance due to lines and testers indicated that the contribution lines (female) was higher than that of testers (male) for all the characters except for anthesis-silking interval, ear height, 100-grain weight, grain yield per plant

Table 3. Estimates gca and sca effects for days to 50 per cent tasseling days to 50 per cent silking, anthesis-silking interval, days to 75 per cent brown husk, plant height, ear height, number of leaves per plant and gob girth in maize

SN	Genotype	Days to 50 per cent tasseling	Days to 50 per cent silking	Anthesis silking interval	Days to 75 per cent brown husk	Plant height (cm)	Ear height (cm)	Number of leaves per plant	Cob girth (cm)
1	T1	-0.13	-0.16	-0.04	0.03	-0.55	-2.79**	-0.13	0.09
2	T2	0.81*	0.70	-0.09	-0.25	-0.91	-1.42	0.01	-0.19
3	T3	-0.69	-0.55	0.13	0.22	1.47	4.21**	0.12	0.10
4	L1	0.26	0.43	0.16	-0.56	-5.48*	-5.59**	0.01	-0.19
5	L2	0.81	0.98	0.16	1.33	14.79**	4.48*	0.38	-0.13
6	L3	-0.19	-0.02	0.16	0.89	-5.30*	-4.25*	-0.38	-0.34
7	L4	-1.19	-0.91	0.27	0.22	-6.42*	-3.43	-0.36	-0.26
8	L5	-0.96	-0.91	0.05	-1.00	0.56	-2.28	0.04	-0.57
9	L6	-1.74**	-2.13**	-0.40	-1.11	-9.16**	-6.41**	-0.50	-0.32
10	L7	-2.07**	-2.13**	-0.06	1.00	1.76	4.68*	-0.05	-0.10
11	L8	-0.63	-0.80	-0.18	-0.33	8.89**	-1.97	0.30	-0.65*
12	L9	3.26**	2.76**	-0.40	0.22	6.30*	3.70*	-0.27	0.49
13	L10	2.15**	2.09**	-0.06	0.78	-11.56**	-0.17	0.29	1.30**
14	L11	1.04	1.31	0.27	-0.78	-1.94	1.70	0.69	0.52
15	L12	-0.74	-0.69	0.05	-0.67	7.57**	9.55**	-0.16	0.27
16	L1 x T1	-2.31	-2.29	0.04	-0.69	1.78	-0.08	-0.03	-1.18
17	L2 x T1	-0.20	-0.51	-0.30	-0.25	-2.18	0.59	-0.06	0.62

Table 3 contd...

SN	Genotype	Days to 50 per cent tasseling	Days to 50 per cent silking	Anthesis silking interval	Days to 75 per cent brown husk	Plant height (cm)	Ear height (cm)	Number of leaves per plant	Cob girth (cm)
18	L3 x T1	1.80	1.82	0.04	0.19	6.81	9.59**	0.59	-0.16
19	L4 x T1	1.13	1.05	-0.07	2.19	2.98	1.30	-0.83	-0.78
20	L5 x T1	-0.76	-0.95	-0.19	1.75	-6.73	-7.26*	0.10	-0.74
21	L6 x T1	0.35	-0.06	-0.41	1.19	0.24	1.21	-0.59	0.59
22	L7 x T1	0.69	0.94	0.26	-0.25	-1.32	1.99	-0.07	0.30
23	L8 x T1	-0.43	-0.73	-0.30	-0.25	2.44	0.17	0.45	0.91
24	L9 x T1	-1.98	-0.95	0.93	-3.47	5.23	-0.43	0.41	0.88
25	L10 x T1	1.80	1.71	-0.07	-1.36	-5.10	-0.70	0.06	-0.00
26	L11 x T1	-0.43	-0.51	-0.07	1.19	-2.37	-3.90	-0.61	-0.22
27	L12 x T1	0.35	0.49	0.15	-0.25	-1.78	-2.48	0.57	-0.21
28	L1 x T2	2.07	2.85	0.76	2.58	-1.40	-1.58	-0.20	-0.40
29	L2 x T2	-0.15	-0.04	0.09	0.69	0.04	2.68	-0.06	-0.30
30	L3 x T2	-2.15	-2.04	0.09	-1.19	-4.52	0.62	-0.61	-0.04
31	L4 x T2	-1.48	-1.48	-0.02	-1.19	-0.87	-0.34	0.97	0.64
32	L5 x T2	0.30	0.52	0.20	1.03	9.33	7.04	0.64	0.08
33	L6 x T2	-0.59	-0.26	0.31	0.47	-8.89	-7.89*	0.31	-0.09
34	L7 x T2	-0.59	-0.93	-0.35	1.36	-2.09	-4.52	-0.81	-0.52
35	L8 x T2	-0.37	-0.26	0.09	-2.64	-0.20	3.06	-0.55	0.23
36	L9 x T2	4.07**	2.85	-1.02*	1.47	-6.37	0.79	-0.05	-0.91
37	L10 x T2	-2.15	-2.48	-0.35	2.58	7.55	-0.01	-0.47	-0.18
38	L11 x T2	1.30	1.30	-0.02	-2.86	2.88	-1.27	0.73	0.59
39	L12 x T2	-0.26	-0.04	0.20	-2.31	4.52	1.42	0.10	0.90
40	L1 x T3	0.24	-0.56	-0.80	-1.89	-0.38	1.66	0.23	1.58*
41	L2 x T3	0.35	0.55	0.20	-0.44	2.14	-3.27	0.13	-0.32
42	L3 x T3	0.35	0.21	-0.13	1.00	-2.29	-10.21**	0.01	0.20
43	L4 x T3	0.35	0.44	0.09	-1.00	-2.11	-0.96	-0.14	0.14
44	L5 x T3	0.46	0.44	-0.02	-2.78	-2.60	0.22	-0.74	0.65
45	L6 x T3	0.24	0.32	0.09	-1.67	8.64	6.68	0.27	-0.49
46	L7 x T3	-0.09	-0.01	0.09	-1.11	3.41	2.53	0.88	0.22
47	L8 x T3	0.80	0.99	0.20	2.89	-2.25	-3.23	0.10	-1.14
48	L9 x T3	-2.09	-1.90	0.09	2.00	1.14	-0.36	-0.36	0.03
49	L10 x T3	0.35	0.77	0.43	-1.22	-2.45	0.71	0.41	0.19
50	L11 x T3	-0.87	-0.79	0.09	1.67	-0.51	5.17	-0.12	-0.37
51	L12 x T3	-0.09	-0.45	-0.35	2.56	-2.74	1.06	-0.67	-0.69
Standard error									
	Ti	0.36	0.41	0.14	0.83	1.38	1.00	0.22	0.17
	Lj	0.64	0.73	0.25	1.50	2.48	1.80	0.40	0.31
	Sij	1.29	1.47	0.50	3.01	4.97	19	0.80	0.61
	Ti-j	0.44	0.50	0.17	1.02	1.69	1.22	0.27	0.21
	Li-j	0.87	1.00	0.34	2.04	3.37	2.44	0.54	0.42
	Ti-Lj	0.69	0.79	0.27	1.61	2.67	1.93	0.43	0.33
	STi-Tj	1.58	1.80	0.62	3.68	6.08	4.40	0.97	0.75
	SiL-jL	1.75	1.99	0.69	4.09	6.75	4.88	1.08	0.83
	Sij-kl	1.80	2.05	0.71	4.21	6.96	5.03	1.11	0.86

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

and oil content. The contribution of lines (female) towards σ^2_{gca} was greater. Variance due to testers was of higher magnitude than that of lines for, anthesis-silking interval, ear height, 100-grain weight, and grain yield per plant. This indicated greater the contribution of testers for these traits towards σ^2_{gca} . The ratio of $\sigma^2_{\text{sca}} / \sigma^2_{\text{gca}}$ was greater than one for all the traits except anthesis-silking interval, number of leaves per plant, harvest index, grain yield per plant, oil content, starch content, protein content. This indicated that the preponderance of non-additive gene effects in the expression of these traits.

Estimates of combining ability effects

The combining ability analysis was performed to obtain information on selection of better parents and crosses for their further use in breeding programme. The estimates of gca effects of the parents and sca effects of the hybrids for different traits are presented in Table 3 and Table 4.

1. Days to 50 per cent tasseling: Four inbred lines showed significant gca effect out of which two inbred lines viz., L_7 (-2.07) and L_6 (-1.74) expressed negative significant gca effects for days to 50 per cent tasseling. None of the testers and hybrids showed significant negative gca and sca effects, respectively (Table 3).

2. Days to 50 per cent silking: Two inbred lines viz., L_6 and L_7 (-2.13) expressed negative significant gca effect for this trait. These lines were also showed negative significant gca effect for 50 per cent tasseling. None of the testers and hybrids showed significant negative gca and sca effects, respectively for this trait (Panwar *et al.*, 2013) (Table 3).

3. Anthesis-silking interval: None inbred line and tester expressed significant gca effects. Only one hybrid $L_9 \times T_2$ (-1.08) showed significant negative sca effects for Anthesis-silking interval (Table 3).

4. Days to 75 per cent brown husk: None of the inbred lines, tester and hybrid showed significant gca and sca effects, respectively for this trait (Table 3).

5. Plant height: Out of twelve inbred lines, five inbred lines expressed negative significant gca effects with magnitude varied from -11.56 (L_{10}) to -5.30 (L_3). None of the testers and hybrids showed significant gca and sca effects, respectively for plant height (Table 3).

6. Ear height: Out of twelve inbred lines, 7 inbred lines showed significant gca effect out of which three inbred lines viz., L_6 (-6.41), L_1 (-5.59) and L_3 (-4.25). Among the testers, only one tester T_1 (-2.29) showed significant negative gca effects for this trait. Three hybrids viz., $L_3 \times T_3$ (-10.21), $L_5 \times T_1$ (-7.26) and $L_6 \times T_2$ (-7.89) showed significant and negative sca effect for ear height (Table 3).

7. Number of leaves per plant: None of the inbred lines, tester and hybrid showed significant gca and sca effects, respectively for this trait (Table 3).

8. Cob girth: Only one inbred line L_{10} (1.30) showed positive significant gca effects. None of the tester showed significant gca effects. Only one hybrid $L_1 \times T_1$ (1.58) showed significant positive sca effects for this trait (Table 3).

9. Number of grain rows per cob: Out of twelve inbred lines only three inbred lines viz., L_{10} (1.20), L_9 (1.0) and L_{11} (0.98) showed significant and positive gca effect. Among the tester and hybrids none of tester and hybrid showed significant positive gca and sca effects, respectively for this trait (Table 4).

10. 100-grain weight: The estimates of positive significant gca effects for 100-grain weight revealed that out of twelve inbred lines, only two inbred lines viz., L_8 (1.35) and L_2 (1.13) showed positive and significant gca effects. Among the three testers, only one tester T_2 (0.85) showed significant gca effect, whereas only one hybrid $L_5 \times T_1$ (2.98) depicted positive and significant sca effect for 100-grain weight (Table 4).

11. Harvest index: Nine inbred lines showed positive significant gca effects out of which four inbred lines depicted significant and positive gca effect with ranged from 1.15 (L_{10}) to 2.11 (L_2). Among the testers, only one tester T_3 (0.63) showed significant gca effect. 24 hybrid showed significant sca effects ranged from -3.92 ($L_9 \times T_2$) to 6.19 ($L_{12} \times T_3$). 12 hybrids showed positive significant sca effects for this trait. The maximum significant and positive sca effects expressed by hybrid $L_{12} \times T_3$ (6.19), followed by $L_1 \times T_2$ (4.46), $L_7 \times T_1$ (4.24), $L_4 \times T_2$ (3.90) and $L_{11} \times T_2$ (3.39) (Table 4).

12. Grain yield per plant: The gca effect for grain yield per plant ranged from -11.40 (L_7) to 11.60 (L_{11}) (Table 4). 11 inbred lines showed significant gca effect out of

Table 4. Estimates gca and sca effects for number of grains rows per cob, 100 -grain weight, harvest index, grain yield per plant, oil content, protein content and starch content (%) in maize

SN	Genotype	No. of grains rows per cob	100 grain weight	Harvest index	Grain yield per plant	Oil content	Protein content	Starch content
1	T1	0.05	-0.76**	-0.58*	-4.86**	-0.01	-0.05	-0.49**
2	T2	-0.13	0.85**	-0.06	-0.30	-0.13**	0.09*	0.13
3	T3	0.08	-0.09	0.63*	5.16**	0.14**	-0.04	0.36**
4	L1	-0.31	-0.87	-0.45	-4.95**	0.08	-0.26**	-0.95**
5	L2	-0.26	1.13*	2.11**	8.40**	-0.62**	0.57**	2.50**
6	L3	-0.40	-0.43	-1.52**	-9.40**	0.24**	-0.30**	-0.63*
7	L4	-0.31	-0.54	-0.29	-3.64*	0.05	-0.31**	0.22
8	L5	-0.64	0.91*	-0.89*	-5.22**	0.28**	-0.06	-0.29
9	L6	-0.31	-2.54**	-1.72**	-8.44**	0.07	-0.60**	-0.34
10	L7	-0.31	-0.54	-1.72**	11.04**	0.30**	0.49**	-0.86**
11	L8	-0.73	1.35**	0.86	6.49**	-0.20*	-0.04	1.45**
12	L9	1.00*	-0.20	1.79**	10.49**	0.16	-0.54**	0.45
13	L10	1.20**	0.69	1.15*	5.14**	0.24*	-0.20**	0.70**
14	L11	0.98*	0.57	1.55**	11.60**	-0.13	0.79**	-1.75**
15	L12	0.09	0.46	-0.87*	0.58	-0.47**	0.47**	-0.51*
16	L1 x T1	-0.94	-0.91	-2.82**	22.29**	0.29	0.05	-1.98**
17	L2 x T1	0.55	-0.91	1.76*	13.69**	0.05	-1.03**	-2.97**
18	L3 x T1	-0.12	0.98	2.31**	15.09**	-0.68**	-0.86**	0.28
19	L4 x T1	-0.74	-1.57	-3.04**	-16.34**	-0.62**	-0.55**	0.56
20	L5 x T1	-0.61	2.98**	2.69**	16.04**	0.61**	-0.08	-0.27
21	L6 x T1	0.53	-1.57	2.38**	15.06**	0.49**	0.30	1.54**
22	L7 x T1	0.59	-0.57	4.24**	24.60**	0.23	0.29	0.02
23	L8 x T1	1.08	0.54	0.67	2.86	-0.46*	0.81**	1.12*
24	L9 x T1	0.41	0.43	0.60	1.66	0.56**	0.38*	3.23**
25	L10 x T1	0.01	0.54	-2.96**	-15.38**	-0.07	-0.05	-0.81
26	L11 x T1	-0.63	0.31	-2.56**	-12.45**	-0.38*	-0.08	1.27*
27	L12 x T1	-0.14	-0.24	-3.27**	-22.56**	-0.03	0.81**	-1.99**
28	L1 x T2	-0.49	-0.52	4.46**	25.94**	-0.61**	-0.95**	-0.11
29	L2 x T2	-0.20	-0.52	-1.70	-8.28*	-0.09	0.29	1.59**
30	L3 x T2	-0.00	-1.63	-2.68**	-18.21**	0.32	0.66**	2.74**
31	L4 x T2	0.64	1.48	3.90**	21.50**	0.72**	0.36*	-1.03*
32	L5 x T2	0.04	-2.30*	-0.37	-1.99	0.40*	-0.10	-2.99**
33	L6 x T2	-0.09	0.15	-0.94	-3.70	0.34	-0.76**	0.55
34	L7 x T2	-0.36	1.48	-2.21*	-11.90**	0.54**	0.42**	1.97**
35	L8 x T2	0.33	0.26	2.81**	16.76**	-0.19	0.59**	2.45**
36	L9 x T2	-1.40	1.48	-3.92**	-20.64**	-0.74**	0.14	-1.69**
37	L10 x T2	-0.00	-1.74	0.19	-0.21	-0.33	-0.76**	-2.16**
38	L11 x T2	0.55	0.70	3.39**	24.59**	-0.45*	0.05	-1.08*
39	L12 x T2	0.98	1.15	-2.92**	-23.86**	0.09	0.07	-0.23
40	L1 x T3	1.43	1.43	-1.63	-3.65	0.32	0.90**	2.09**
41	L2 x T3	-0.35	1.43	-0.06	-5.41	0.04	0.74**	1.39**
42	L3 x T3	0.12	0.65	0.37	3.13	0.37*	0.21	-3.02**
43	L4 x T3	0.10	0.09	-0.86	-5.16	-0.10	0.19	0.47
44	L5 x T3	0.56	-0.69	-2.32**	-14.05**	-1.01**	0.18	3.26**

Table 4 contd....

SN	Genotype	No. of grains rows per cob	100 grain weight	Harvest index	Grain yield per plant	Oil content	Protein content	Starch content
45	L6 x T3	-0.44	1.43	-1.43	-11.36**	-0.84**	0.46**	-2.09**
46	L7 x T3	-0.24	-0.91	-2.03*	-12.70**	-0.76**	-0.71**	-1.99**
47	L8 x T3	-1.41	-0.80	-3.48**	-19.63**	0.65**	-1.40**	-17**
48	L9 x T3	0.99	-1.91*	3.32**	18.97**	0.18	-0.52**	-1.54**
49	L10 x T3	-0.01	1.20	2.77**	15.59**	0.40*	0.81**	2.97**
50	L11 x T3	0.08	-1.02	-0.83	-12.14**	0.83**	0.03	-0.19
51	L12 x T3	-0.84	-0.91	6.19**	46.41**	-0.06	-0.88**	2.22**
Standard error								
	Ti	0.23	0.25	0.24	1.01	0.05	0.04	0.13
	Lj	0.41	0.45	0.44	1.82	0.09	0.08	0.24
	Sij	0.82	0.89	0.88	3.65	0.18	0.15	0.48
	Ti-j	0.28	0.30	0.30	1.24	0.06	0.05	0.16
	Li-j	0.56	0.61	0.60	2.48	0.12	0.11	0.33
	Ti-Lj	0.44	0.48	0.47	1.96	0.10	0.08	0.26
	STi-Tj	1.00	1.09	1.08	4.46	0.22	0.19	0.59
	SiL-jL	1.11	1.21	1.19	4.95	0.25	0.21	0.66
	Sij-kl	1.15	1.25	1.23	5.11	0.25	0.22	0.68

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

which five inbred lines viz., L₁₁ (11.60), L₉ (10.49), L₂ (8.40), L₈ (6.49) and L₁₀ (5.14) depicted significant and positive gca effect for this trait. Whereas tester T₃ (5.16) had positive and significant gca effect for this trait. Among the hybrids sca effects ranged from -23.86 (L₁₂ x T₂) to 46.41 (L₁₂ x T₃). 27 hybrids depicted significant sca effect out of which twelve hybrids showed positive and significant sca effect for grain yield per plant. The maximum sca effects expressed by hybrid L₁₂ x T₃ (46.41) followed by L₁ x T₂ (24.60), L₁₁ x T₂ (24.59), L₇ x T₁ (24.60) and L₄ x T₂ (21.50). These hybrids were also expressed positive and significant sca effects for harvest index. These results are accordance with the findings of Reddy *et al.*, (2011).

13. Oil content: The gca effect for oil content in grain ranged from -0.62 (L₂) to 0.30 (L₇) (Table 4). 7 inbred lines showed significant gca effect out of which, four inbred lines expressed positive and significant gca effect. Among the testers only one tester T₃ (0.14) showed positive and significant gca effect tester T₃ also showed positive significant gca effect for harvest index, grain yield per plant and starch content. Among the hybrids 10 hybrids showed positive and significant sca effect for this trait. The maximum sca effects for oil content depicted by hybrid L₁₁ x T₃ (0.83) followed by L₄ x T₂ (0.72), L₈ x T₃ (0.65), L₅ x T₁ (0.61) and L₉ x T₁ (0.56).

14. Protein content: The perusal estimates of significant positive gca effects for protein content in grain revealed that out of twelve inbred lines four lines were significant ranged from 0.47 (L₁₂) to 0.79 (L₁₁) (Table 4). Among the three testers, only one tester T₂ (0.09) showed significant positive gca effects (Gautam *et al.*, 2013). The perusal of sca effects for this trait revealed that eleven hybrids expressed positive significant sca effects the range from 0.36 (L₄ x T₂) to 0.90 (L₁ x T₃).

15. Starch content: The gca effect for starch content ranged from -1.75 (L₁₁) to 2.50 (L₂) (Table 4). 8 inbred lines showed significant gca effect out of which as three inbred lines viz., L₂ (2.50), L₈ (1.45) and L₁₀ (0.70) showed positive and significant gca effect. Only tester T₃ (0.36) depicted positive and significant gca effect, sca effect for this trait ranged from -3.57 (L₈ x T₃) to 3.26 (L₅ x T₃). 26 hybrids showed significant sca effects out of which 13 hybrids expressed positive and significant sca effects. The maximum sca effects showed by hybrid L₅ x T₃ (3.26) followed by L₉ x T₁ (2.74), L₁₂ x T₃ (2.22), L₃ x T₂ (2.74) and L₁ x T₃ (2.09). Twelve hybrids showed significant positive sca effects for grain yield per plant (Table 5). The maximum significant positive sca effects for grain yield per plant L₁₂ x T₃ (46.41) followed by hybrids L₁ x T₂ (24.60), L₁₁ x T₂ (24.59), L₇ x T₁ (24.60), Hybrid L₄ x T₂

Table 5. Inbred lines and hybrids possessing good gca and sca effects for fifteen traits in maize

S.No.	Characters	Inbred lines	Testers	Hybrids
1.	Days to 50 per cent tasseling	L ₆ , L ₇	-	-
2.	Days to 50 per cent silking	L ₆ , L ₇	-	-
3.	Days to 75 per cent brown husk	-	-	L ₉ x T ₂
4.	Anthesis silking interval	-	-	-
5.	Plant height	L ₁ , L ₃ , L ₄ , and L ₆	-	-
6.	Ear height	L ₁ , L ₃ , and L ₆	T ₁	L ₅ x T ₁ , L ₆ x T ₂ and L ₃ x T ₃
7.	Number of leaves per plant	-	-	-
8.	Cob girth	L ₁₀	-	L ₁ x T ₃
9.	Grain rows per cob	L ₁₀ , L ₁₁	-	-
10.	100 grain weight	L ₂ , L ₅ , and L ₈	T ₂	L ₅ x T ₁
11.	Harvest index	L ₂ , L ₉ , L ₁₀ and L ₁₁	T ₃	L ₂ x T ₁ , L ₃ x T ₁ , L ₅ x T ₁ , L ₆ x T ₁ , L ₇ x T ₁ , L ₁ x T ₂ , L ₄ x T ₂ , L ₈ x T ₂ , L ₁₁ x T ₂ , L ₉ x T ₃ , L ₁₀ x T ₃ and L ₁₂ x T ₃
12.	Grain yield per plant	L ₂ , L ₉ , L ₁₀ and L ₁₁	T ₃	L ₂ x T ₁ , L ₃ x T ₁ , L ₅ x T ₁ , L ₆ x T ₁ , L ₇ x T ₁ , L ₁ x T ₂ , L ₄ x T ₂ , L ₈ x T ₂ , L ₁₁ x T ₂ , L ₉ x T ₃ , L ₁₀ x T ₃ and L ₁₂ x T ₃
13.	Oil content	L ₃ , L ₅ , L ₇ and L ₁₀	T ₃	L ₅ x T ₁ , L ₆ x T ₁ , L ₉ x T ₁ , L ₄ x T ₂ , L ₅ x T ₂ , L ₇ x T ₂ , L ₃ x T ₃ , L ₈ x T ₃ , L ₁₀ x T ₃ and L ₁₁ x T ₃
14.	Protein content	L ₂ , L ₆ , L ₁₁ and L ₁₂	T ₂	L ₈ x T ₁ , L ₉ x T ₁ , L ₁₂ x T ₁ , L ₃ x T ₂ , L ₄ x T ₂ , L ₇ x T ₂ , L ₈ x T ₂ , L ₁ x T ₃ , L ₂ x T ₃ , L ₆ x T ₃ and L ₁₀ x T ₃
15.	Starch content	L ₂ , L ₈ and L ₁₀	T ₃	L ₆ x T ₁ , L ₈ x T ₁ , L ₉ x T ₁ , L ₁₁ x T ₁ , L ₂ x T ₂ , L ₃ x T ₂ , L ₇ x T ₂ , L ₈ x T ₂ , L ₁ x T ₃ , L ₂ x T ₃ , L ₅ x T ₃ , L ₁₀ x T ₃ and L ₁₂ x T ₃

(21.50) (Table 3). These above said cross are between average x good, poor x average, good x average, poor x poor and poor x average gca effects parents, respectively for grain yield per plant. For oil content ten hybrids viz., L₅ x T₁, L₆ x T₁, L₉ x T₁, L₄ x T₂, L₅ x T₂, L₇ x T₂, L₃ x T₃, L₈ x T₃, L₁₀ x T₃ and L₁₁ x T₃ showed significant positive sca effect for this trait. Whereas 11 and 13 hybrids depicted significant and positive sca effects for protein and starch content, respectively (Table 5).

Conclusion

The study under discussion finally revealed that some of inbred lines and testers used in the present investigation can be selected for the successful development of single cross hybrids since they possessed high to good *per se* performance with good general combining ability for grain yield per plant and other yield contributing and quality traits (Khan *et al.*, 2014). Characters inhibited through additive mode of inheritance can be improved by selection method. Some of the selected hybrids under study revealed good economic heterotic response to the tune of 11.56 to 26.17 per cent and good performance with high significant positive sca effects for grain yield per plant. Hence, these

hybrids may be concluded for commercial exploitation and could be recommended for testing in multi-location trials.

Conflict of interest

The authors declare no conflict of interest.

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