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Combining ability and genetic architecture studies in maize

Ravi Kumawat, Amit Dadheech and Heera Lal Barupal

Abstract
Combining ability is the genotype's ability to pass the desired character or superior performance to its progenies. Thus, the present investigation was undertaken to assess the combining ability of 45 hybrids developed using 15 inbred and 3 tester parents in line x tester design during *Rabi*, 2017-18. These hybrids and parents were evaluated in randomized block design with three replications in three environments as two location during *Kharif*, 2019 (E1 and E2 environments) and one location during *Rabi*, 2019-20 (E3 environment). The mean sum of squares due to crosses and line x testers interaction were found significant for all the traits in all the environment as well as pooled over the environments indicating significant differences among the hybrids. The variance due to gca was found lower than variance due to sca for all the traits under indicating preponderance of non-additive component. The parents EI-2159, EI-2176-3, EI-2505, EI-2525-2, EI-2639 and EI-2653 were good general combiners for grain yield per plant. The parents EI-2653 (line) and EI-670 (tester) was found good general combiner for yield contributing traits as ear length, ear girth, grain rows per ear and 100-grain weight, whereas parent EI-102 was found good general combiner for quality traits. Thus, these parents had favorable alleles to improve the yield and yield contributing traits as well as quality traits in maize. Among the 45 hybrids, hybrids EI-2178 x EI-102, EI-2525-2 x EI-03, EI-2176-3 x EI-03, EI-2188-1 x EI-102, EI-2172 x EI-670 and EI-2159 x EI-670 was found good specific combiners for grain yield per plant. Thus, the above parents with desirable gca effects and cross combinations with desirable sca effects for grain yield and yield related traits could be used as useful genetic material for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

Keywords: Combining ability, gene action, genetic architecture, maize

1. Introduction

Maize (*Zea mays* L.; 2n = 20) is a versatile and multi utility grain crop and model genetic plant (Hake and Ross-Ibarra, 2015) [17]. It has enormous diversity at genetic level and both nucleotide polymorphisms and structural variations contributed in its phenotypic variation (Dooner and He, 2008) [12]. It was domesticated from Teosinte (*Zea mays* L. spp. *Parviglumis),* a closest living relative about 10,000 years ago in the Balsas River Basin of South Western Mexico (Schnable *et al.* 2009) [36]. In India, it was introduced by the Portuguese during the 17th century (Mangelsdorf, 1974) [24]. Maize is a diclinous, allogamous species, belongs to the monocot family Poaceae, Genus *Zea* and Species *mays* (Piperno and Flannery, 2001) [31]. It is a monoecious, protandrous plant and leafy stalk of the plant produces pollen inflorescences and separate ovuliferous inflorescences called ears that yield kernels or seeds (Poehlman, 1977) [32]. It is cultivated in both irrigated and rainfed regions, around the word and third important food crop after rice and wheat in terms of area and production (Gerpacio and Pingali, 2007) [15]. It is a important staple food crop for 4.5 billion people of the word (CGIAR, 2015) [7]. The crop is a key source of calorie, protein, vitamins and minerals to billions of people world-wide, particularly in Africa, South America and Asia. It is widely used for food, feed, fuel and fiber in many parts of the world and particularly for poultry and pigs, in industry, it is currently used for ethanol production (Moro and Fritsche-Neto, 2015) [27]. The nutritional composition is comprised of about 71.88 gram of carbohydrates, 8.84 gram of protein, 4.57 gram of fat and 2.15 gram of fiber per 100 gram of kernels (Prasad *et al.* 2016) [33]. It is grown in 196.76 M ha area, with a total production of 1162.38 MMT, and average productivity of 5.91 metric t/ha around the word (USDA, 2020) [42]. In India context, it is grown in 9.20 M ha area with a total production of 28.00 MMT, and average productivity of 3.04 metric t/ha (USDA, 2020) [42]. The major producing states are Andhra Pradesh, Karnataka, Maharashtra, Bihar, Tamil Nadu, Madhya Pradesh and Rajasthan. In Rajasthan, it is cultivated an area of 9.34 lakh ha with production of 17.64 lakh tonnes and productivity of 1889 kg/ha (Anonymous, 2020-21) [5].

The demand for maize is expected to double by 2050 and in Indian context the projected demand is expected to be 42 million tonnes by the year 2025 (Dass *et al.* 1987) [10]. Thus, improving maize productivity is urgent and challenging also due to limited crop land and a growing population. Furthermore, global crop yields were stagnant across 24-39 per cent of the main growing areas. The climate change is projected to reduce maize production globally by 3-10 per cent by 2050 (Rosegrant *et al.* 2009) [35]. The hybrid maize play a crucial role in increased maize production (Aslam *et al.* 2017) [6] and food security especially single-cross hybrids from superior inbreds. The production potential of inbreds can only be identified by testing the combining capacity of inbred lines. The combining ability analysis is one of the powerful tool in identifying the better combiners which may be hybridized to exploit heterosis and to select better crosses for direct use or further breeding work (Nigussie and Zelleke, 2001) [29]. The concept of combining ability in plant breeding as a measure of gene action was introduced by Sprague and Tatum in 1942[38]. The combining analysis also helps to understand the genetic architecture of yield and other component traits and the gene action involved in the expression of these traits that enable breeders to design effective breeding plans. Selection of parents on the basis of *per se* performance with good GCA effect is the breeders best approach to assess the nature of gene action involved in the inheritance of characters. The information on this aspect is necessary for selection of suitable parents (general combining ability) in hybridization and identification of promising hybrids (specific combining ability) for development of improved varieties for diverse agro-ecological conditions (Alabi *et al.* 1987) [3]. The objective of the maize breeder should thus not be to find the best pure line, but to find and maintain the best hybrid combination. Therefore, it is meaningful for maize breeders or researchers to assess the inbred lines over the seasons and locations to select superior parental inbred lines which are suitable for future breeding programmes.

2. Materials and Methods

The 45 hybrids of maize were developed by using line x tester mating design consisting of 15 lines and 3 testers during *Rabi*-2017-18. These 45 hybrids, 18 parents (15 lines and 3 testers) and two checks PHM-3 and PM-9 were evaluated in three environments *viz.,* E1 (*Kharif*-2019, Instructional Farm, RCA, Udaipur), E2 (*Kharif*-2019, ARSS Vallabhnagar) and E3 (*Rabi*-2019, Instructional Farm, RCA, Udaipur) in randomized block design with three replications at each environment. The each treatment was sown in single row plot of 4.0 m length with geometry of 60 x 20 cm row to row and plant to plant spacing, respectively. The Udaipur district is located in the Aravalli Hill Ranges of Southern part of the Rajasthan with latitude 24°35'31.5" longitudes 73°44'18.2" with an altitude of 582.17 m above mean sea level. The Vallabhnagar is a village in Vallabhnagar tehsil of Udaipur district of Rajasthan. The soil of both experimental fields were clay loam, deep, well drained, alluvial in origin and have good moisture holding capacity. All the recommended package of practices of zone IV-A (Sub-Humid Southern Plains of Rajasthan) were used to raise a healthy crop. The data were recorded for 14 traits including phonological, grain yield and other component traits on ten competitive plants selected from each plot in each replication. The estimation of quality traits *viz.,* starch content, protein content and oil content were carried out using anthrone reagent method, micro kjeldahl's method (Lindner, 1944) [23] and soxhlet's ether extraction method (A.O.A.C., 1965) [1], respectively. The data obtained on all the 14 traits were subjected to appropriate statistical analysis to carry out analysis of variance for each environment and on pooled basis as per method suggested by Panse and Sukhatme, (1985) [30]. The GCA effects (general combining ability) of parents (lines and testers) and SCA effects (specific combining ability) of hybrids were estimated as per method suggested by Kempthorne, (1957) [21] for each of the environment as well as for over the environments in the same manner as for individual environments except the number of environments was an additional divisor for pooled basis. The significance of GCA and SCA effects were performed computing the standard error for lines, testers and crosses and then tested against t-test by taking the degree of freedom of pooled error mean square (Singh and Chaudhary, 1979) [37] (Dabholkar, 1999) [8].

3. Results and Discussion

The ANOVA for combining ability in all three environments as well as over the environments revealed that the mean sum of squares due to crosses and line x testers interaction were found significant for all the traits in all the environments as well as pooled over the environment indicating significant differences among the hybrids (Table 1). On pooled basis, the variance due to lines were found significant for plant height, ear height, ear length, ear girth, grain yield per plant, harvest index and oil content, whereas variance due to testers were found significant for plant height, harvest index and starch content (Table 1). The mean squares due to environments x crosses interaction were also found significant for all the traits except grain rows per ear, 100-grain weight and oil content on pooled basis indicating significant role of environment on character expression (Table 1).

Table 1: ANOVA for combining ability for grain yield and its components in maize based on data pooled over the three environments

Sources	d.f.	Mean sum of squares													
		Days to 50 per cent tasseling	Days to 50 per cent silking	Days to 75 per cent brown husk	Plant Height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	Grain rows per ear	100-grain weight (g)	Grain yield per plant (g)	Harvest index (%)	Starch content (%)	Protein content (%)	Oil content (%)
Replication	2	8.29	5.66	3.82	132.73	54.31	2.04	1.16	3.19	7.83	75.84	1.71	1.94	0.47	0.21
Rep. x Env.	4	0.24	4.24	1.46	112.6*	35.7	1.41	0.66	0.63	7.69	9.4	3.86	7.11	0.25	0.02
Environments	2	206746.12**	222936.14**	242026.46**	8342.03**	1792.61**	189.78**	96.64**	92.25**	339.64**	9214.63**	557.04**	234.75**	10.3**	2.67**
Crosses	44	56.28**	47.89**	52.96**	1453.77**	404.23**	11.32**	8.1**	10.02**	47.63**	1131.89**	80.11**	55.91**	5.12**	1.3**
Line effect (L)	14	11.05	13.43	30.02	3248.64**	910.98**	18.38*	13.04*	14.32	42.24	1988.55**	178.27**	60.69	7.12	2.02*
Tester effect (T)	2	44.34	35.62	113.39	1807.17*	98.51	19.93	13.08	2.49	10.63	1490.22	202.86**	187.26*	2.51	2.75
L x T effect	28	79.75**	66**	60.12**	531.09**	172.69**	7.18**	5.27**	8.4**	52.97**	677.96**	22.26**	44.14**	4.31**	0.83**

Env. x crosses	88	9.23**	9.47**	12.29**	162.56**	77.45**	1.33*	1.74**	1.17	2.08	112.8**	6.47**	11.52**	0.5**	0.08
Error	372	3.12	2.32	2.56	44.67	18.57	1	0.66	1.08	4.07	25.86	4.46	7.74	0.24	0.07

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

Table 2: Estimates of combining ability variances, genetic components and proportional contribution of lines, testers and their interactions to total variance (%) for grain yield and its components based on data pooled over the three environments

Particulars	**Days to 50 per cent tasseling**	**Days to 50 per cent silking**	**Days to 75 per cent brown husk**	**Plant Height (cm)**	**Ear height (cm)**	**Ear length (cm)**	**Ear girth (cm)**	**Grain rows per ear**	**100-grain weight (g)**	**Grain yield per plant (g)**	**Harvest index (%)**	**Starch content (%)**	**Protein content (%)**	**Oil content (%)**
σ^2gca	0.3	0.27	0.85	30.66	6	0.22	0.15	0.09	0.28	21.15	2.3	1.44	0.06	0.03
σ^2sca	8.51	7.08	6.4	54.05	17.12	0.69	0.51	0.81	5.43	72.46	1.98	4.04	0.45	0.08
σ^2gca/σ^2sca	0.04	0.04	0.13	0.57	0.35	0.32	0.29	0.11	0.05	0.29	1.16	0.36	0.13	0.38
σ^2 A	0.61	0.55	1.71	61.31	12	0.45	0.31	0.18	0.55	42.31	4.6	2.87	0.11	0.06
σ^2 D	8.51	7.08	6.4	54.05	17.12	0.69	0.51	0.81	5.43	72.46	1.98	4.04	0.45	0.08
σ^2 A/σ^2 D	0.0713	0.0775	0.2669	1.1345	0.701	0.6528	0.5977	0.2224	0.1016	0.5839	2.3234	0.7096	0.2498	0.6769
Proportional contribution of lines, testers and their interactions to total variance (%)														
Lines (L)	6.25	8.92	18.03	71.1	71.71	51.66	51.22	45.5	28.22	55.9	70.81	34.54	44.22	49.55
Testers (T)	3.58	3.38	9.73	5.65	1.11	8	7.34	1.13	1.01	5.98	11.51	15.22	2.23	9.61
L x T	90.17	87.7	72.24	23.25	27.19	40.33	41.44	53.37	70.77	38.12	17.68	50.24	53.55	40.84

These findings were in corroboration with Aly and Hassan (2011) [4], Mohammad *et al.* (2013) [26], Dar *et al.* (2015) [9] in maize. The variance due to gca (σ^2gca) was found lower than variance due to sca (σ^2sca) for all the traits under consideration except for the trait harvest index (%) on pooled basis indicating preponderance of non-additive component (Table 2). Similarly, the ratio of variances due to gca to sca (σ^2gca/(σ^2sca) was found less than unity for all the traits under study except for the trait harvest index on pooled basis indicating non-additive component have predominant role in character expression under study. The magnitude of additive variance (σ^2_A) was lower than dominance variance (σ^2_D) for most of the traits under study except for plant height and harvest index on pooled basis. The ratio due to additive variance to dominance variance (σ^2_A/(σ^2_D) were also found less than unity for most of the traits under study on pooled basis indicating importance of both additive and non-additive gene action in character expression under study (Table 2). The results are in corroboration with Joshi *et al.* (2002) [19], Abdel-Moneam *et al.* (2009) [2], Murtadha *et al.* (2018) [28] who also reported importance of both additive and non-additive gene action in maize. The contribution of lines was found greater than testers, whereas the overall contribution was found greater for L X T towards total variance (%) for all the traits under study on pooled basis (Table 2). In case of proportional contribution of lines, tester and lines x testers, the maximum variance for lines was found for the traits plant height followed by ear height and grain yield per plant, whereas for testers, starch content followed by harvest index and oil content contributed maximum portion toward total variance (%). The traits days to 50 per cent tasseling followed by days to 50 per cent silking and 100-grain weight contributed maximum proportion for line x tester towards total variance (%) (Table 2). These findings are in corroboration with Tefera *et al.* (2020) [41] and Sun *et al.* (2018) [39] who also reported greater contribution of lines than testers and overall maximum contribution for L X T towards total variance (%).

GCA and SCA effects

The genotypes (lines, testers and hybrids) having only significant values for both GCA and SCA effects were considered desirable for all the traits under the study and genotypes with non-significant values were no considered. The significant negative effects (both gca and sca) were considered desirable for the traits days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk, plant height and ear height, whereas significant positive effects were considered desirable for the remaining traits under the study. The best performing hybrids and parents (lines and tester) for grain yield and other related traits was given in the Table 3.The hybrids having significant and positive SCA effects for grain yield per plant and with their desirability for other traits under the study are presented in Table 4. The negative gca effect was divulged only by the line EI-2507 (-0.91) and tester EI-670 on pooled basis for days to 50 per cent tasseling. The 16 hybrids recorded negative sca effects for this trait on pooled basis and among them hybrids EI-2522 x EI-03 (-4.55) possessed highest values succeeded by EI-2188 x EI-03 (-4.25), EI-2188-1 x EI-670 (-3.55), EI-2403 x EI-102 (-3.32), EI-2653 x EI-670 (-3.32) and EI-2507 x EI-102 (-2.72) on pooled basis for the trait days to 50 per cent tasseling. For days to 50 per cent silking, lines EI-2403 (-0.97), EI-2507 (-0.89) and EI-2642 (-0.63) and tester EI-670 (-0.43) displayed negative gca effects for days to 50 per cent silking on pooled basis. The 15 hybrids recorded negative sca effects on pooled basis and the top most hybrids were EI-2522 x EI-03 (-3.90), EI-2188 x EI-03 (-3.72), EI-2188-1x EI-670 (-3.42), EI-2403 x EI-102 (-3.16), EI-2653x EI-670 (-3.16) and EI-2639 x EI-03 (-2.83) for days to 50 per cent silking. Similar negative effects for days

Table 3: Best performing parental lines, testers and hybrids on the basis of GCA and SCA effects pooled over the environments

S.N.	**Characters**	**Parents**		**Hybrids**
		Lines (L)	**Testers (T)**	
1.	Days to 50 per cent tasseling	1. EI-2507	1. EI-670	1. EI-2522 x EI-03 2. EI-2188 x EI-03 3 EI-2188-1 x EI-670

2	Days to 50 per cent silkling	1. EI-2403 2. EI-2507 3. EI-2642	1. EI-670	1. EI-2522 x EI-03 2. EI-2188 x EI-03 3. EI-2188-1x EI-670
3	Days to 75 per cent brown husk	1. EI-2188-1 2. EI-2642 3. EI-2188	1. EI-670	1. EI-2525-2 x EI-102 2. EI-2403 x EI-102 3. EI-2522 x EI-03
4	Plant height (cm)	1. EI-2188 2. EI-2159 3. EI-2639	1. EI-03	1. EI-2172 x EI-03 2. EI-2525-2 x EI-102 3. EI-2188 x EI-670
5	Ear height (cm)	1. EI-2159 2. EI-2188 3. EI-2178	1. EI-03	1. EI-2188-1 x EI-670 2. EI-2522 x EI-670 3. EI-2176-3 x EI-102
6	Ear length (cm)	1. EI-2525-2 2. EI-2507 3. EI-2403	1. EI-670	1. EI-2505 x EI-102 2. EI-2653 x EI-03 3. EI-2642 x EI-102
7	Ear girth (cm)	1. EI-2507 2. EI-2653 3. EI-2525-2	1. EI-670	1. EI-2505 x EI-102 2. EI-2639 x EI-670 3. EI-2522 x EI-03
8	Grain rows per ear	1. EI-2642 2. EI-2639 3. EI-2653	None	1. EI-2188 x EI-102 2. EI-2507 x EI-670 3. EI-2448 x EI-670
9	100-grain weight (g)	1. EI-2403 2. EI-2172 3. EI-2653	None	1. EI-2178 x EI-102 2. EI-2639 x EI-03 3. EI-2448 x EI-102
10	Grain yield per plant (g)	1. EI-2188 2. EI-2653 3. EI-2525-2	1. EI-670	1. EI-2178 x EI-102 2. EI-2525-2 x EI-03 3. EI-2176-3 x EI-03
11	Harvest index (%)	1. EI-2188 2. EI-2176-3 3. EI-2403	1. EI-670	1. EI-2522 x EI-03 2. EI-2188-1 x EI-102 3. EI-2159 x EI-102
12	Starch content (%)	1. EI-2507 2. EI-2505 3. EI-2525-2	1. EI-102	1. EI-2505 x EI-03 2. EI-2525-2 x EI-670 3. EI-2639 x EI-670
13	Protein content (%)	1. EI-2178 2. EI-2176-3 3. EI-2642	1. EI-102	1. EI-2639 x EI-670 2. EI-2188 x EI-03 3. EI-2505 x EI-670
14	Oil content (%)	1. EI-2639 2. EI-2448 3. EI-2172	1. EI-102	1. EI-2505 x EI-03 2. EI-2176-3 x EI-102 3. EI-2522 x EI-102

to 50 per cent tasseling and silking were also reported by Sundararajan and Kumar (2011) [40] and Demissew, (2014) [11] in maize. The hybrids with negative sca effects for the above phenological traits are considered desirable as it indicate the earliness of the hybrids. On pooled basis 3 inbred parental lines EI-2188-1 (-1.93), EI-2642 (-1.82) and EI-2188 (-1.04), whereas tester EI-670 (-1.02) expressed negative gca effect within all three environments and on pooled basis for days to 75 per cent brown husk. The 13 hybrids had showed negative sca effects on pooled basis and among them, the top ranking hybrids were EI-2525-2 x EI-102 (-4.42), EI-2403 x EI-102 (-3.97), EI-2522 x EI-03 (-3.94), EI-2642 x EI-03 (-3.79) and EI-2639 x EI-03 (3.42) for days to 75 per cent brown husk. The 6 inbred lines *viz.*, EI-2188 (-14.60), EI-2159 (-13.98), EI-2639 (-13.71), EI-2653 (-11.51), EI-2172 (-9.92) and EI-2522 (-4.01) and tester EI-03 (-4.16) divulged negative gca effects in desirable direction within all three environments as well as on pooled basis except the inbred line EI-2522 for the trait plant height. Out of the 11 hybrids with negative sca effects on pooled basis, the top ranking five hybrids were EI-2172 x EI-03 (-12.68), EI-2525-2 x EI-102 (-11.96), EI-2188 x EI-670 (-9.33), EI-2188-1 x EI-670 (-9.10) and EI-2403 x EI-670 (-8.17) for the trait plant height. Out of the 6 inbred lines with negative gca effects on pooled basis, the top three lines were EI-2159 (-11.66), EI-2188 (-7.17) and EI-2178 (-4.71) for ear height. Similarly, the tester parent EI-03 displayed negative gca effects (-0.94) on pooled basis for ear height. Out of 8 hybrids with negative sca effects on pooled basis, the top ranking hybrids were EI-2188-1 x EI-670 (-10.31), EI-2522 x EI-670 (-7.80), EI-2176-3 x EI-102 (-4.64), EI-2639 x EI-102 (-4.36) and EI-2653 x EI-102 (-4.19) for the trait ear height. These results are in corroboration with Ji *et al.* (2006) [18] and Girma *et al.* (2015) [16] also reported that inbred lines with negative gca effect had tendency to reduce plant and ear height and concluded that shorter plant height with lower ear placement is desirable for lodging resistance in maize. Out of the 5 inbred lines with positive gca effects on pooled basis, the top three lines were EI-2525-2 (1.41), EI-2507 (1.30), EI-2403 (0.88) for the trait ear length. The only tester EI-670 had showed positive gca effects of 0.44 on pooled basis and across all three environments. The top ranking hybrids for the trait ear length were EI-2505 x EI-102 (1.72), EI-2653 x EI-03 (1.40), EI-2642 x EI-102 (1.10), EI-2522 x EI-03 (0.89) and EI-2639 x EI-03 (0.88) on the basis of sca effects on pooled basis for the trait ear length. Out of the 7 inbred lines with positive gca effects on pooled basis, the top ranking lines were EI-2507 (1.02), EI-2653 (1.01), EI-2525-2 (0.68), EI-2188 (0.68), on pooled basis for ear girth. Similarly, the only tester EI-670 (0.35) had showed positive gca effects on pooled basis for this trait. The top ranking hybrids were EI-2505 x EI-102 (1.43), EI-2639 x EI-670 (1.10), EI-2522 x EI-03 (0.78), EI-2172 x EI-102 (0.71) and EI-2176-3 x EI-03 (0.59) based on their positive sca effects on pooled basis for ear girth. The results are in general agreement with the findings reported by Premlatha and Kalamani (2010) [34], Estakhr and Heidari (2012) [14] and

Girma *et al.* (2015) [16] for ear length and ear girth in maize. The 3 of the inbred lines EI-2642 (1.36), EI-2639 (1.16) and EI-2653 (0.95) had showed positive gca effects on pooled basis for the trait grain rows per ear. The positive sca effects was evident in the 6 number of hybrids and among them, hybrids EI-2188 x EI-102 (1.55), EI-2507 x EI-670 (1.31), EI-2448 x EI-670 (1.28), EI-2403 x EI-03 (1.24) and EI-2525-2x EI-03 (0.99) were the top ranking hybrids on pooled basis for grain rows per ear. For the trait 100-grain weight, three inbred lines EI-2403 (1.34), EI-2172 (1.24) and EI-2653 (1.22) divulged positive gca effects. The 12 hybrids possessed positive sca effects and among them the hybrids EI-2178 x EI-102 (3.32), EI-2639 x EI-03 (3.01), EI-2448 x EI-102 (2.79), EI-2507 x EI-670 (2.79), EI-2525-2 x EI-670 (2.62) and EI-2642 x EI-670 (2.58) were the top ranking hybrids based on positive sca effects on pooled basis for 100-grain weight. Out of the 6 inbred lines with positive gca effects on pooled basis, the inbred parent EI-2188 (13.13) was found best general combiner followed by EI-2653 (9.93) and EI-2525-2 (9.86). The only tester EI-670 (2.98) was found good general combiner for grain yield per plant. Out of 11 hybrids with positive sca effects on pooled basis, the top ranking hybrids were EI-2178 x EI-102 (18.13), EI-2525-2 x EI-03 (17.52), EI-2176-3 x EI-03 (11.01), EI-2188-1 x EI-102 (9.47) and EI-2172 x EI-670 (9.14) for grain yield per plant. The results are in corroboration with the findings of Matin *et al.* (2016) [25], Karim *et al.* (2018) [20], Sun *et al.* (2018) [40] who reported positive gca and sca effects in parents and hybrids for grain rows per ear, 100-grain weight and grain yield per plant in maize. The 4 inbred lines EI-2188 (5.22), EI-2176-3 (4.15), EI-2403 (1.40) and EI-2448 (0.89), whereas tester EI-670 (1.19) was found good general combiner (positive gca) on pooled basis for harvest index.

Table 4: Hybrid showing significant and positive specific combining ability effects for grain yield per plant and their per se performance with their desirability for other traits in maize.

S. N.	Hybrids	SCA effects	Grain yield per plant (g)	Trait showing desirable and significant SCA effects
1	EI-2178 x EI-102	18.13**	89.15	Days to 50 per cent tasseling, Days to 50 per cent silking, 100-Grain weight (g) and Oil content (%)
2	EI-2525-2 x EI-03	17.52**	109.22	Harvest index (%) and Oil content (%)
3	EI-2176-3 x EI-03	11.01**	106.00	Ear girth (cm), Grain rows per ear, 100-Grain weight (g) and Harvest index (%)
4	EI-2188-1 x EI-102	9.47**	76.89	Grain rows per ear, 100-Grain weight (g), Starch content (%) and Protein content (%)
5	EI-2172 x EI-670	9.14**	79.41	Grain rows per ear and Starch content (%),
6	EI-2159 x EI-670	8.30**	101.78	Days to 50 per cent tasseling, Days to 50 per cent silking
7	EI-2522x EI-03	8.17**	89.21	Days to 50 per cent tasseling, Days to 50 per cent silking, Days to 75 per cent brown husk, Ear length (cm) and Ear girth (cm)
8	EI-2448x EI-102	7.38**	80.06	100-Grain weight (g) and Protein content (%)
9	EI-2507x EI-03	6.50**	79.62	Protein content (%)
10	EI-2505x EI-670	6.49**	95.68	Protein content (%)
11	EI-2653x EI-102	5.13**	92.73	Ear height (cm)

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

The EI-2522 x EI-03 (3.15), EI-2188-1 x EI-102 (3.04), EI-2159 x EI-102 (1.82), EI-2176-3 x EI-03 (1.75) and EI-2639 x EI-670 (1.55) were the top ranking hybrids on pooled basis based on their positive sca effects for harvest index. The inbred lines EI-2507 (2.31), EI-2505 (2.04), EI-2525-2 (1.91) and EI-2653 (1.39), whereas tester EI-102 (1.35) was found good general combiner (positive gca) on pooled basis for starch content. Among the 7 hybrids with positive sca effects on pooled basis, the hybrids EI-2505 x EI-03 (3.33), EI-2525-2 x EI-670 (3.12), EI-2639 x EI-670 (2.63), EI-2188-1 x EI-102 (2.55) and EI-2172 x EI-670 (2.44) were the top ranking hybrids for starch content. On pooled basis, the inbred lines EI-2178 (0.91), EI-2176-3 (0.68), EI-2642 (0.55), EI-2507 (0.39), EI-2505 (0.36) and EI-2639 (0.33), whereas tester EI-102 (0.16) was found good general combiners (positive gca) for protein content. Out of the 16 hybrids with positive sca effects on pooled basis, the EI-2639 x EI-670 (0.97), EI-2188 x EI-03 (0.95), EI-2505 x EI-670 (0.64), EI-2525-2 x EI-670 (0.59), EI-2176-3 x EI-670 (0.59) and EI-2188-1 x EI-102 (0.58) were the top ranking hybrids for protein content. The 6 inbred lines EI-2639 (0.36), EI-2448 (0.32), EI-2172 (0.29), EI-2505 (0.28), EI-2653 (0.28) and EI-2178 (0.12) and the only tester EI-102 (0.16) was found good general combiner for the trait oil content on pooled basis. The 11 hybrids had showed positive sca effects and among them hybrids EI-2505 x EI-03 (0.50), EI-2176-3 x EI-102 (0.44), EI-2522 x EI-102 (0.41), EI-2639 x EI-670 (0.41), EI-2403 x EI-03 (0.36) and EI-2172 x EI-102 (0.35) were the top ranking hybrids on pooled basis for oil content. These results are in corroboration with the findings of Dubey *et al.* (2009) [13], Khan and Dubey (2015) [22] who reported positive gca and sca effects for the traits starch content, protein content and oil content in maize.

4. Conclusion

The ratio of additive to dominance variance was found less than unity for all the traits except plant height and harvest index indicating involvement of non-additive gene action in character expression. Hence, population improvement or mass selection or one of the forms of recurrent selection may be rewarding to exploit additive gene action. The heterosis breeding may be adopted to improve those characters which have higher magnitude of non-additive gene action in their expression under the study. The inbred line EI-2507 was better parent (good general combiner) for early maturity type, whereas lines EI-2159, EI-2172, EI-2188, EI-2639 was found better for short plant stature. The lines EI-2188, EI-2403, EI-2507, EI-2525-2 and EI-2653 was found good general combiner lines for ear length and ear girth, whereas line EI-2642 and EI-2653 for ear girth and 100-grain weight. The tester parent EI-670 was found good general combiner for most of the yield contributing traits ear length, ear girth, grain yield per plant and harvest index. For grain yield per plant, inbred parents EI-2159, EI-2176-3, EI-2505, EI-2525-2, EI-2639 and EI-2653 was found good general combiner lines.

The inbred line EI-2653 was found good general combiner for most of the yield contributing traits as ear length, ear girth, grain rows per ear and 100-grain weight under the study. In case of quality traits, tester parent EI-102 was found good general combiner for all the three quality traits as protein content, starch content and oil content. Thus, these inbred lines and testers with good general combiners could be utilized in the improvement of traits of interest either during hybrid or synthetic variety development. Among the 45 hybrids for grain yield per plant, hybrids EI-2178 x EI-102, EI-2525-2 x EI-03, EI-2176-3 x EI-03, EI-2188-1 x EI-102, EI-2172 x EI-670 and EI-2159 x EI-670 were the top ranking hybrids. Among the above hybrids, hybrid EI-2176-3 x EI-03 had also showed their desirability (positive sca effects) for ear girth, grain rows per ear, 100-grain weight and harvest index, whereas hybrid EI-2188-1 x EI-102 for grain rows per ear, 100-grain weight, starch content and protein content. Finally, better performing inbred lines and testers with desirable gca effects and cross combinations with desirable sca effects for grain yield and yield related traits could be used as source of useful genetic material for future maize breeding.

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