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Combining ability analysis for yield and yield contributing traits in Popcorn (*Zea mays everta L.*) under temperate conditions.

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Abstract

The present study was aimed to investigate combining ability effects for yield and yield related traits in pop corn using line × tester analysis. Eight inbred lines, three testers and resulting 24 crosses were evaluated at two locations during *kharif* 2016 in a complete randomized block design.. ANOVA for combing ability revealed significant mean squares of GCA and SCA for all the traits. The estimates of variance due to dominance component was higher than due to additive component for traits viz., plant height, kernel rows cob^{-1}, grain depth, 100 grain weight, shelling percentage, grain yield plant^{-1} and protein content. The parent KDPI-8 was identified as best combiner for grain yield plant^{-1} and for most of its contributing traits followed by KDPI-4 and KDPI-6. Among the crosses, KDPI-6 × WIN POP, KDPI-8 × VL POPCORN-1 and KDPI-1 × VL POPCORN-1 exhibited highly significant and desirable SCA effects for grain yield plant^{-1}. Therefore, these crosses could be utilized in heterosis breeding to achieve a quantum jump in maize improvement.

Keywords: combining ability, gca, sca, line × tester, maize, yield.

1. Introduction

Maize (*Zea mays* L.) is the world's third leading cereal crop after rice and wheat but ranks first with respect to its production and productivity. At global level maize is cultivated over an area of 168.4 million hectares with an annual production of about 854.6 million tonnes and average productivity of 5.07 tonnes per hectare (Anonymous, 2015) [7]. Maize is not only of worldwide importance as a food, feed and as a source of diverse industrially important products, but is also a model genetic organism with immense genetic. In Jammu and Kashmir, maize ranks 3rd in production among cereals. At State level maize is cultivated over an area of 0.308 million hectares with an annual production of 0.560 million tonnes and an average productivity of 1.80 tonnes per hectare (Anonymous, 2015a) [7]. Very little work has been done to understand the combining ability in Popcorn. And the present study is a first of its kind in temperate conditions of Kashmir

Combining ability is an important prerequisite for developing a good economically viable hybrid maize variety. Proper choice of parents is an important criterion in order to exploit hybrid vigour. This key step depends on factors like per se performance of the parents and their combining ability. Combining ability is a potent tool in identifying the good combiners for hybridization especially, when a large number of parental lines are available and promising ones are to be selected on the basis of their ability to give superior cross combinations. Besides pin pointing the promising parents to be used in the development of advanced hybrids particularly when the production of such hybrids is not feasible due to some inherent problems in economic hybrid seed production, combining ability analysis has a momentous role in crop improvement as it helps in characterizing the nature and magnitude of genetic effects governing yield and its component traits. The hybrid breeding is imperative to select the cross combinations with high degree of SCA as well as parents with high general combining ability (Singh *et al.*, 2012) [24].General and specific combining ability are due to genes which are largely additive and dominance or epistatic effects respectively (Sprague and Tatum, 1942) [25]. In maize, combining ability analysis was also carried out by Iqbal *et al.* (2007) [18], Shahidhara (2008) [23], Kanagarasu *et al.*(2010) [12] Shanthi *et al.* (2010) [22], Premlatha *et al.* (2011) [20], Abuali *et al.*, (2012) [1]; Singh *et al.* (2012) [24], Haddabi *et al.* (2013) [10] Krupakar *et al.* (2013) [16], Dar *et al.* (2015) [9], Khan and Dubey (2015) [14] and many others.

A wide array of biometrical tools are available to breeders for characterizing value of genetic control governing economically important traits, especially line × tester mating design is one of them which provides reliable information on combining ability of parents and their cross combinations within affordable resources. This technique was developed by Kempthorne in 1957 [15]. The present study, was therefore, undertaken with a view to estimate general combining ability of parents and specific combining ability of their crosses for yield and its component traits in maize which can be exploited directly as single cross hybrids.

Material and methods

The basic material for the present investigation comprised of eight diverse maize inbred lines viz., KDPI-1, KDPI-2, KDPI-3, KDPI-4, KDPI-5, KDPI-6, KDPI-7 and KDPI-8 and three testers viz., WinPop, SPC-1 and VLPopcorn-1. Twenty four crosses were obtained from the set of parents using the methodology of line × tester mating design.as suggested by Kempthorne (1957) [15] during *rabi* 2015-16 at Winter Nursery Centre, Hyderabad. Twenty four crosses along with their parents were evaluated at two locations during *Kharif* 2016 in a complete randomized block design with two replications at both the locations. The experimental plot comprised of two rows each of 4 metre length with a planting geometry of 75 × 20 cm. All the Recommended agronomic practices were followed to raise a good crop. Observations on various traits viz., plant height (cm), ear height (cm), grain depth, number of kernel rows ear^{-1}, number of kernels row^{-1}, shelling percentage (%), 100-grain weight (g), prolificacy index, grain yield plant^{-1} (g) and protein content (%) were recorded on five randomly selected competitive plants except for maturity traits (days to 50 per cent tasseling and days to 50 per cent silking) where data were recorded on plot basis. Combining ability analysis was carried out according to model as suggested by Kempthorne (1957) [15] using statistical software package of Windostat version 9.1.

Results and Discussion

Analysis of variance for the traits under study in pooled analysis is presented in Table 1. Perusal of the results revealed significant differences among parents (lines), crosses and line × testers for all traits under study, indicating that the material selected was diverse for all the traits under study. Significant LxT suggested presence of high SCA among hybrids. It was`also found that mean squares due to lines were larger when compared to testers for all the traits indicating greater diversity among lines. This was in confirmation with the results reported by Abauli *et al.* (2012) [1]. Analysis of variance for combining ability revealed significant mean squares for GCA and SCA for all the traits studied which indicated importance of both additive and non additive gene action in the inheritance of these traits. Similar results were observed Kumar *et al*. (2013) [16], Krupakar *et al*. (2013) [16], Amiruzzaman *et al*. (2013) [6], Izhar and Chakraborty (2013) [11] and Dar *et al*. (2015) [9]. The knowledge of combining ability effects of parents and crosses together with *per se* performance is of paramount importance to a breeder for isolating desirable lines and selection of an appropriate methodology for handling the segregating generations. Non additive gene action played a major role in the expression of the traits viz., plant height, kernel rows cob^{-1}, kernels row^{-1}, grain depth, 100 grain weight, shelling percentage, grain yield plant^{-1} and protein content after comparing the GCA and SCA variances to assess the relative importance of the genetic variance components (Table 2). These results are in accordance with earlier findings of Pavan *et al*. (2011) [21], Singh *et al*. (2012) [24] for number of Kernels row^{-1}, number of kernels ear^{-1}, 100-grain weight and grain yield plant^{-1} and Dar *et al*. (2015) [9]. Average degree of dominance was greater than unity (over dominance range) for most of the traits that included plant height, kernel rows cob^{-1}, grain depth,100 grain depth, shelling percentage, grain yield plant^{-1} and protein content, indicating that the present study of materials was diverse and contained contrasting in most of the cases in dispersion phase, which on combination through hybridization increased heterozygositycob^{-1}, grain depth,100 grain depth, shelling percentage, grain yield plant^{-1} and protein content, indicating that the present study of materials was diverse and contained contrasting in most of the cases in dispersion phase, which on combination through hybridization increased indicating prevalence of dominance variance in controlling these traits. Greater contribution of non additive gene action suggested exploitation of the gene action through heterosis breeding. The general and specific combining ability of the parents and crosses respectively were estimated and discussed below

General combining ability effects

The GCA effects represent the additive nature of the gene action. In the present study, the general combining ability of parents (8 lines) were estimated to know their genetic worth for use in production of superior progenies. The estimates of GCA effects are listed in Table 3 and close examination of the results revealed that none of the parents showed significant GCA effects in the desired direction simultaneously for all the traits studied. For grain yield plant^{-1} KDPI-8 was identified as best combiner followed by KDPI-4 and KDPI-6. These can be used directly as parents for developing high yielding single cross hybrids. KDPI-8 was also accompanied with significant gca in desired direction for 100 grain weight, grain depth, shelling percentage, protein content kernels row^{-1}, flowering traits viz., days to 50 per cent tasseling, days to 50 per cent silking. Similar results significant were reported for yield and yield related traits by Pavan *et al*. (2011) [21] and Singh *et al.* (2012) [24]. Estimates of GCA effects for flowering traits indicates that among parents, KDPI-2, KDPI-8, and KDPI-6 were having highly significant negative GCA effects indicating the potential advantage of inbred lines for development of early maturing hybrids. These findings are in conformity with earlier results of Singh *et al.* (2012) [24], Amiruzzaman *et al.* (2013) [6], Khan *et al.* (2014) [13], and Alamerew and Warsi (2015) [3].

For morphological traits like plant height and ear height KDPI-1, KDPI-2 and KDPI-5 showed the desirable GCA effects. Similar results for ear height were reported by Aminu *et al.* (2014) and Alamerew and Warsi (2015) [3] implying the tendency of the lines to reduce ear height.

Specific combining ability effects

The SCA effect is an important criterion to determine the potential and effectiveness of hybrids. The estimates of specific combining ability effects of the twenty-four crosses for various traits, given in Table 4, revealed that none of the cross combination possessed high SCA effects for all the traits. However, crosses which exhibited highly significant and desirable SCA effects included KDPI-6 × WIN POP, KDPI-8 × VL POPCORN-1 and KDPI-1 × VL POPCORN-1 for grain yield plant^{-1}. The perusal of the SCA effects along with per se performance revealed that some of the crosses showing high desirable specific combining ability effects were also having high per se performance for most of the traits under study. Similar results were found by Mosa (2010)

[19] and Dar *et al.* (2015) [9]. While assessing the performance of parents on the basis general combining ability, it was observed that most of the specific cross combinations were the result of crosses between low × high or low × low or low × medium or high × high or high × medium general combiners. Among these crosses, KDPI-6 × WIN POP which showed the highest positive SCA effect for yield had high × medium combiners; KDPI-8 × VL POPCORN-1 had high × high combiners; KDPI-1 × VL POPCORN-1 had low × high combiners suggesting that involvement of one good general combiner appears to be essential to get the better specific combination. The results are in general agreement with the findings of several workers (Aguiar *et al.,* 2003; Iqbal *et al.,* 2007 and Ali *et al.,* 2007) [2, 18, 4]. Thus the superiority of crosses involving high × high and high × medium combiners as parents might have possibly resulted from the concentration and interaction of favourable alleles contributed by parents. The case of high SCA between high x low combiners could produce good segregants on the basis of interaction between positive alleles from good combiners and negative alleles for the poor combiners as parents. Similar results were reported by Izhar and Chakraborty (2013) [11]. The high yield of such crosses would be non fixable and thus could be exploited through heterosis breeding.

Table 1: Analysis of variance for different traits in Pop corn

Source of variation	d.f.	Days to 50% tasselling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Prolificacy	Kernel rows cob^{-1}
Environments	1	1327.593**	1335.041**	50592.360**	18869.237**	0.001	1.181**
Replications	1	0.010	0.375	17.543	8.230	0.002	0.077
Rep× env	1	1.260	1.500	0.339	4.725	0.005	0.003
Crosses	23	30.640**	28.521**	1368.560**	735.382**	0.037**	6.911**
Lines	7	91.166*	98.375**	2702.331*	1338.545*	0.086**	23.501*
Testers	2	31.343	28.690	618.567	1305.800	0.030	0.203
Line × tester	14	21.642**	18.458*	808.817**	352.312**	0.013**	8.116**
Crosses × env	23	0.550	0.563	26.901**	32.055**	0.001	0.032
Lines × env	7	0.712	1.113*	42.697	26.094	0.001	0.037
Testers × env	2	0.875	0.541	2.198	0.173	0.002	0.040
L× T × env	14	0.874*	1.2300*	22.532**	39.589**	0.004	0.112**
Error	46	0.396	0.524	4.620	2.061	0.003	0.034

Contd……..Table-1

Source of variation	d.f.	Kernels row^{-1}	Grain depth (cm)	100 grain weight (g)	Shelling percentage (%)	Grain yield plant^{-1} (g)	Protein content (%)
Environments	1	149.675**	0.002**	9.519**	1.680*	309.350**	0.181**
Replications	1	2.100	0.002	0.968	0.860	26.001	0.021
Rep× env	1	0.974	0.004	0.457	0.255	3.884	0.0003
Crosses	23	92.341**	0.035**	43.047**	56.440**	4083.823**	0.789**
Lines	7	190.000*	0.064*	164.001**	109.000*	9102.700*	1.966*
Testers	2	23.20**	0.044**	24.679	93.014	181.286	0.262
Line × tester	14	65.000**	0.021**	38.776**	36.782**	3169.133**	0.670**
Crosses × env	23	1.059**	0.001	0.646**	0.332	27.945**	0.043
Lines × env	7	1.426	0.001	0.736	0.428	77.530**	0.052
Testers × env	2	0.009	0.001	0.388	0.109	12.649	0.003
L× T × env	14	1.026**	0.006**	0.638**	0.315	19.675**	0.044*
Error	46	0.272	0.001	0.248	0.244	6.666	0.017

Table 2: Estimates of genetic components of variance, degree of dominance for different traits in Pop corn

Components of variance	Days to 50% tasselling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Prolificacy	Kernel rows per cob	Kernels per row	Grain depth (cm)	100 grain weight (g)	Shelling percentage (%)	Grain yield per plant (g)	Protein content (%)
σ^2 lines	2.581* ±1.391	2.351* ±1.251	181.035* ±87.4894	111.370** ±53.620	0.002 ±0.001	0.530* ±0.350	8.870** ± 5.040	0.004 ±0.002	0.004 ±0.002	7.090* ±3.520	418.460** ±232.621	0.091* ±0.050
σ^2 lines × environments	0.060 ±0.060	0.092 ±0.091	-	4.000 ±3.101	-0.002 ±0.001	0.011 ±0.011	0.190 ± 0.120	0.002 ±0.001	0.002 ±0.001	0.030 ±0.040	11.811 ±6.090	0.010 ±0.010
σ^2testers	2.840 ±2.030	3.06 1 ±2.181	20.409 ± 16.110	40.740 ±29.120	0.002 ±0.001	0.010 ±0.100	0.720 ±1.170	0.001 ±0.001	0.001 ±0.001	2.891 ±2.091	5.451 ±46.203	0.010 ±0.010
σ^2 testers × environments	0.030 0.041	0.012 0.021	-	-0.120 ±0.870	0.002 ±0.001	0.010 ±0.010	-0.020 ±0.020	0.001 ±0.001	0.001 ±0.001	-0.011 ±0.011	0.370 ±0.570	-0.010 ±0.011
σ^2gca	2.760* ±1.520	2.860* ±1.620	64.216** ±26.5822	60.000** ±25.73	0.002 ±0.001	0.151** ±0.120	2.940** ±1.620	0.002* ±0.001	0.002* ±0.001	4.040** ±1.800	118.090** ±71.800	0.030* ±0.010
σ^2gca × environments	0.040 ±0.010	0.02 2 ±0.031	-	1.012 ±1.062	-0.001 ±0.002	0.010 ±0.010	0.041 ±0.040	0.002 ±0.001	0.002 ±0.001	0.010 ±0.010	3.490* ±1.710	0.011 ±0.010
σ^2sca (lines × testers)	5.310** ±1.910	4.480** ±1.631	158.035** ±56.150	87.560** ±31.330	0.002* ±0.001	2.02** ±0.72	23.680** ±8.390	0.006* ±0.001	0.006* ±0.001	9.130** ±3.250	1040.611** ±368.500	0.161* ±0.060
σ^2sca × environments (L× T ×E)	0.010 ±0.080	-0.121 ±0.072	-	18.760** ±7.000	-0.001 ±0.001	-0.011 ±0.010	0.371 0.180	0.001 0.001	0.001 0.001	0.030 ±0.06	-0.660 1.160	0.010 0.011
σ^2E	0.090	0.131	0.786	0.510	0.001	0.011	0.061	0.001	0.001	0.060	1.660	0.001
σ^2A	5.531	5.720	128.433	120.001	0.010	0.292	5.880	0.01	0.01	8.080	236.180	0.060
σ^2D	5.311	4.480	158.035	87.560	0.002	2.021	23.680	0.006	0.006	9.130	1040.610	0.160
σ^2A/σ^2D	0.971	0.880	1.109	0.851	0.710	2.601	2.010	1.434	1.434	1.060	2.090	1.590
Degree of dominance	0.9798	0.8847	1.1552	1.2080	0.7067	2.6042	2.0066	1.0662	1.6172	1.0631	2.0990	1.5983

Table 3: General combining ability effects of lines and testers for different characters in Pop corn

Parents	Days to 50% tasselling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Prolificacy	Kernel rows cob^{-1}
Lines						
KDPI-1	-0.260	0.667**	-17.967**	-15.595**	0.195**	0.359**
KDPI-2	-1.344**	-1.500**	-10.800**	-5.903**	-0.055**	-0.191**
KDPI-3	3.323**	3.333**	10.416**	7.389**	0.020	-0.741**
KDPI-4	0.740**	0.167	2.075**	1.930**	-0.055**	0.951**
KDPI-5	0.490**	0.833**	-21.472**	-12.511**	-0.055**	0.492**
KDPI-6	-1.283**	-0.917**	5.075**	2.689**	-0.055**	-1.266**
KDPI-7	0.073	-0.083	17.663**	15.397**	0.011	0.517**
KDPI-8	-1.427**	-1.167**	15.011**	6.605**	-0.005	-0.121*
S.E.g$_i$ (lines)	0.182	0.209	0.620	-0.414	0.016	0.053
Testers						
WIN POP	1.667**	1.688***	4.725**	3.730**	-0.021*	-0.072*
SPC-1	-1.708**	-1.813 ***	-3.970**	-7.376**	-0.015	-0.013
VL POPCORN-1	0.042	0.125	-0.756**	3.646**	0.035**	0.085*
S.E.g$_i$(testers)	0.113	0.128	0.380	0.254	0.010	0.033
High gca parents	4	5	4	4	2	5

*,** Significant at 5 and 1 percent levels, respectively

Parents	Kernels row^{-1}	Grain depth (cm)	100 grain weight (g)	Shelling percentage (%)	Grain yield plant^{-1} (g)	Protein content (%)
Lines						
KDPI-1	-0.335*	-0.081**	-1.062**	-4.290**	-6.079**	0.229**
KDPI-2	-4.143**	-0.062**	-3.337**	-2.128**	-30.814**	0.040
KDPI-3	-0.205	-0.037**	-2.672**	-0.243	-14.469**	-0.235**
KDPI-4	1.123**	0.057**	2.571**	2.451**	18.253**	-0268**
KDPI-5	-1.910**	0.037**	1.146**	-1.827**	2.613**	-0.518**
KDPI-6	1.312**	-0.046**	1.504**	3.632**	12.118**	0.073
KDPI-7	-1.773**	0.093**	-0.037	2.022**	-14.066**	0.357**
KDPI-8	5.931**	0.046**	1.888**	0.383*	32.444**	0.323**
S.E.g$_i$ (lines)	0.151	-0.081**	0.144	0.143	0.745	0.038
Testers						
WIN POP	-0.038	-0.044**	0.605**	-1.351**	-0.340	-0.076**
SPC-1	-0.832**	0.039**	0.402**	1.916**	-2.192**	0.100**
VL POPCORN-1	0.870**	0.003	-1.007**	-0.565**	2.532**	-0.025
S.E.g$_i$(testers)	0.092	0.001	0.088	0.087	0.456	0.023
High gca parents	4	5	6	5	5	4

*,** Significant at 5 and 1 percent levels, respectively

Table 4: Specific combining ability effects of lines and testers for different characters in Pop corn

Crosses	Days to 50% tasselling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Prolificacy	Kernel rows cob^{-1}
KDPI-1 × WIN POP	2.167 **	1.729**	-22.867**	-17.155**	0.046	0.697**
KDPI-1×SPC-1	0.042	0.979**	10.353**	4.626**	0.040	-1.687**
KDPI-1×VL POPCORN-1	-2.208 **	-2.708**	12.514**	12.529**	-0.085**	0.990**
KDPI-2 × WIN POP	-1.500**	-1.188**	11.466**	5.153**	0.021	2.073**
KDPI-2×SPC-1	0.625	-0.188	12.887**	10.109**	0.015	-1.287**
KDPI-2×KDM343A	0.875 **	1.375**	-24.353**	-15.263**	-0.035	-0.785**
KDPI-3× WIN POP	-1.417 ***	-1.771**	7.775**	12.986**	-0.054	-0.102
KDM2111×SPC-1	-2.042 **	-0.771*	-6.530**	-7.082**	-0.010	1.113**
KDPI-3×VL POPCORN-1	3.458**	2.542**	-1.244	-5.904**	0.065*	-1.010**
KDPI-4×WIN POP	3.167**	2.646**	6.291**	0.570	0.021	0.281**
KDM2113× SPC-1	-1.708**	-2.104**	-4.963**	-3.274**	0.015	1.246**
KDPI-4×VL POPCORN-1	-1.458**	-0.542	-1.328	2.704**	-0.035	-1.527**

Crosses	Days to 50% tasselling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Prolificacy	Kernel rows cob^{-1}
KDPI-5×WIN POP	1.417**	1.729**	-12.937**	-3.039**	0.021	-0.711**
KDPI-5×SPC-1	1.292**	0.729*	9.868**	4.993**	0.015	0.104
KDPI-5×VL POPCORN-1	-2.708**	-2.458**	3.069**	-1.954***	-0.035	0.606**
KDPI-6×WIN POP	-0.500	0.729*	12.616**	2.761**	0.021	0.598**
KDPI-6×SPC-1	0.375	-0.521	-19.763**	-6.782**	0.015	0.513**
KDPI-6×VL POPCORN-1	0.125	-0.208	7.147**	4.021**	-0.035	-1.110**
KDPI-7×WIN POP	-2.917**	-2.604**	-0.132	-2.172**	-0.046	-1.688**
KDPI-7×SPC-1	0.208	0.146	-6.227**	-0.766	-0.052	0.405**
KDPI-7×VL POPCORN-1	2.708**	2.458**	6.359**	2.938**	0.098*	1.282**
KDPI-8×WIN POP	-0.417	-1.271**	-2.212*	0.895	-0.929	-1.148**
KDPI-8×SPC-1	1.208**	1.729**	4.376**	-1.824*	-0.035	-0.407**
KDPI-8×VL POPCORN-1	-0.792*	-0.458	-2.164*	0.029	-0.065*	1.555**
S.E.(S_{ij})	0.315	0.362	1.075	0.718	0.028	0.092
High sca crosses	9	8	9	10	4	12

Crosses	Kernels row^{-1}	Grain depth (cm)	100 grain weight (g)	Shelling percentage (%)	Grain yield plant^{-1} (g)	Protein content (%)
KDPI-1 × WIN POP	-3.837**	-0.003	-1.697**	-2.784**	-10.806**	-0.254**
KDPI-1×SPC-1	2.057**	-0.024**	-1.219**	-1.942**	-16.459**	0.027
KDPI-1×VL POPCORN-1	1.780**	0.024**	2.916**	4.726**	27.265**	0.227**
KDPI-2 × WIN POP	-3.179**	0.032**	2.928**	1.561**	3.667**	-0.383**
KDPI-2×SPC-1	3.665**	0.013*	-0.669*	0.733**	13.359**	0.591**
KDPI-2×KDM343A	-0.487	-0.046**	-2.259**	-2.294**	-17.027**	-0.209**
KDPI-3× WIN POP	-1.152**	0.006	-3.392**	1.124**	-18.396**	0.717**
KDM2111×SPC-1	2.702**	0.005	3.416**	-1.222**	26.991**	-0.709**
KDPI-3×VL POPCORN-1	-1.550**	-0.012*	-0.024	0.099	-8.595**	-0.009
KDPI-4×WIN POP	-5.495**	-0.021**	2.270**	2.993**	-22.165**	-0.124
KDM2113× SPC-1	0.499	-0.063**	-3.002**	-1.443**	11.437**	-0.200**
KDPI-4×VL POPCORN-1	4.997**	0.083**	0.932**	-1.550**	10.728**	0.325**

Crosses	Kernels row^{-1}	Grain depth (cm)	100 grain weight (g)	Shelling percentage (%)	Grain yield plant^{-1} (g)	Protein content (%)
KDPI-5×WIN POP	2.513**	-0.050**	-0.105	-0.092	-0.180	0.251**
KDPI-5×SPC-1	1.882**	-0.010*	-0.177	-0.996**	14.429**	0.075
KDPI-5×VL POPCORN-1	-4.395**	0.061**	0.282	1.088**	-14.249**	-0.325**
KDPI-6×WIN POP	9.440**	0.130**	3.888**	0.780**	72.542**	-0.141*
KDPI-6×SPC-1	-6.941**	-0.095**	0.965**	4.431**	-24.828**	0.333**
KDPI-6×VL POPCORN-1	-2.500**	-0.003	-4.853**	-5.211**	-47.714**	-0.192**
KDPI-7×WIN POP	3.913**	-0.064**	-4.272**	-3.168**	-4.549**	-0.249**
KDPI-7×SPC-1	-2.031**	0.110**	2.206**	1.873**	-5.086**	0.025
KDPI-7×VL POPCORN-1	-1.882**	-0.044**	2.066**	1.294**	9.635**	0.225**
KDPI-8×WIN POP	-2.203**	-0.026**	0.378	-0.414	-20.114**	0.184**
KDPI-8×SPC-1	-1.834**	0.082**	-1.519**	-1.433**	-19.844**	-0.142*
KDPI-8×VL POPCORN-1	4.037**	-0.057**	1.141**	1.848**	39.957**	-0.042
S.E.(S_{ij})	0.261	0.005	0.249	0.247	1.291	0.066
High sca crosses	10	8	10	11	10	8

*,** Significant at 5 and 1 percent levels, respectively

Conclusion

Highly significant differences were observed among line and line × testers for all the traits which indicate the possibility of selection for improvement of yield and yield related traits. Among parents, KDPI-8, KDPI-4 and KDPI-6 showed highly desirable GCA effects for grain yield plant^{-1} and can be selected for the development of hybrids. Moreover, crosses KDPI-6 × WIN POP, KDPI-8 × VL POPCORN-1 and KDPI-1 × VL POPCORN-1 reflected high SCA effects for grain yield plant^{-1}. Thus these crosses can be used directly or exploited for future hybrid breeding programmes to achieve quantum jump in maize improvement.

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