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COMBINING ABILITY ANALYSIS FOR YIELD TRAITS IN DIALLEL CROSSES OF MAIZE

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ABSTRACT

Development of single cross maize hybrids significantly boosted up the grain yield potential. Estimation of combining ability is key step in the development and evaluation of hybrids. A total six maize accessions viz. A556, OH-41, WFTMS, Q67, 82Pi and L7-2 were hybridized following Griffing's Method 1, Model 1 in a complete diallel fashion (parental, direct and reciprocal combinations). Seeds from parental lines and all single and reciprocal crosses (30 F_{1s}) were sown during autumn 2013 using randomized complete block design with three replications. Mean squares due to general combining ability (GCA), specific combining ability (SCA) and reciprocal effects for all characters were significantly different. The SCA Variance components were higher for ear diameter, ear length, grain rows per ear and grains per ear than GCA effects. However, GCA variance for seedling emergence and 100-grain weight were greater than variance due to SCA effects. Results revealed that inheritance of ear diameter, grain rows per ear and grains per ear was governed by non-additive type of gene action. WFTMS for seedling emergence, ear length and grain rows per ear, L7-2 for ear diameter, Q67 for grains per row, OH-41 for grains per row and 100-grain weight had higher GCA effects. Crosses A556 × 82Pi for seedling emergence, Q67 × L7-2 for ear diameter, WFTMS × Q67 for ear length, OH-41 × WFTMS for grain rows per ear, OH-41 × L7-2 for grains per row, 82Pi × L7-2 for grains per ear, A556 × WFTMS for 100-grain weight had higher SCA values.

Keywords: Maize, Griffing's combining ability, GCA, SCA effects, gene action, yield components.

INTRODUCTION

Maize is a short duration high yielding cereal crop and has key importance in assuring the world food security (Saeed *et al*., 2000). Being a C_4 plant, it has good photosynthetic ability. It could be cultivated from coastal areas to high latitude because of high level of adaptability. Maize is highly polymorphic crop carrying high level of genetic variability. Grain yield and its components are complex traits and are the outcome of genetic and environmental effects and their interactions (Aslam *et al.,* 2006; Iqbal *et al.,* 2012; Aslam *et al.,* 2015a; Maqbool *et al.,* 2015).

Development of hybrid cultivars had accelerated the increase in productivity of maize across the world. Inbred lines are used for hybrid development and their worth is considered by their performance in combination with different other inbred lines. Ability of a line to transfer its performance to others is described as combining ability of inbred line. Combining ability of inbred lines gives information about genetic nature of quantitative traits and also conducive for selection of most appropriate parents to be used for heterosis breeding. Breeding value of an accession based on mean performance is regarded as general combining ability (GCA). Predominance of GCA is conducive for improvement of selection efficiency in segregating populations (Bocanski *et al*., 2009). Specific combining ability is cumulative performance of any two accessions in their specific hybrid combination. Variance due to general combining ability (GCA) is indicator for extent of additive gene action whereas; variance due to specific combing ability (SCA) shows the extent of non-additive gene action. Additive and non-additive types of gene actions were very important for genetic expression of yield and related traits. The majority of yield related traits are controlled by additive genes. The additive genes are more important than dominant genes for higher grain production (Aliu *et al.,* 2010). Selection of appropriate breeding program for maximum genetic improvement is based on relative values of general and specific combining ability (Hayman, 1954; Griffing, 1956). Dominance and additive gene actions are effectively used for improvement of hybrids (Kumar *et al*., 2012).

Diallel crossing technique provides the information about inheritance pattern of gene action in early filial generations to breeders for development of hybrid (Hayman, 1954; Jinks, 1954). Diallel mating design is helpful for obtaining the genetic information about the traits of interest through random and fixed selection sets of parental lines in short time (Hayman, 1954; Griffing, 1956). Diallel is very important for identification of desired lines to increase the frequency of targeted alleles in hybrids. Relative importance of additive and non-additive type of gene actions is also determined by diallel analysis.

Griffing's diallel approach (1956) is very prominently used for estimation of combining ability of inbred lines and to make the selection easier. It was reported that yield and yield components have very complex mode of inheritance (Bocanski *et al*., 2009) and economic value of a genotype is determined by its yield components thus, different yield components were used in current study for evaluation of parents. Purpose of this study was to determine gene action involvement in control of different yield components of maize accessions. This research experiment was also intrigued for estimation of combining abilities (general combining ability and specific combining ability) of different maize inbred lines for yield components due to their economic importance.

MATERIALS AND METHODS

A total six maize accessions (A556, OH-41, WFTMS, Q67, 82Pi and L7-2) were used as parents in 6 × 6 complete diallel crossing scheme at the University of Agriculture Faisalabad, Pakistan. Seeds were sown in the field by keeping plant to plant and row to row distances 30 cm and 75 cm respectively. At maturity all the parents were crossed following full diallel mating design, resultantly 30 F_{1s} were generated. Seeds harvested from F_{1s} and parents were sown by following randomized complete block design (RCBD) with three replications. All the agronomic practices were taken for establishment of proper stand in field. Data were recorded for following yield components i.e. seedling emergence, ear diameter (cm), ear length (cm), grain rows per ear, grains per row, grains per ear and 100- Grains weight (g).

Statistical Analysis: Griffing analysis of variance was used for estimation of GCA, SCA and reciprocal effects for studied quantitative traits of maize inbred lines. The data were analyzed using diallel technique for analysis of general and specific combining ability and components of variance (Griffing, 1956; Method 1, Model 1)

$$G_i=1/2\ (Xi. + X.i) – 1/P^2\ X..$$

Whereas, G_i = general combining ability effects for line ith, P = number of parents / lines, Xi. = total mean values of F_1's resulting from crossing between jth and ith inbreds, X.i = total mean values of F_1's resulting from crossing between jth and ith inbreds, X.. = grand total of all the mean values.

$$S_{ij}= 1/2(Xij+Xji) – 1/2P\ (Xi.+X.i+Xj.+X.j) + 1/P2X..$$

Where S_{ij} = specific combining ability between ith and jth inbreds, X_{ij} = mean values of F_1 resulting from crossing between ith and jth inbreds, X_{ji} = mean values of F_1 resulting from crossing between jth and ith inbreds, P = number of parents / varieties, X_i. = total mean values of F_1's resulting from crossing between jth and ith inbreds, $X._i$ = reciprocal values of X_i , X_j. = total mean values of F_1's resulting from crossing between ith and jth inbreds, $X._j$ = reciprocal values of $X_{j,}$ X.. = Grand total of all the mean values.

$$R_{ij} =1/2\ (X_{ij} - X_{ji})$$

Whereas, R_{ij} = reciprocal effects of the ith and jth inbreds, X_{ij} = mean values of F_1 resulting from crossing between ith and jth inbreds, X_{ji} = mean values of F_1 resulting from crossing between jth and ith inbred.

RESULTS

Combining ability analysis: GCA, SCA and reciprocal effects were found significant ($p\leq0.05$) for all the studied maize traits. GCA/SCA ratio was greater than unity (1) for all studied quantitative maize traits except for grains per ear (Table 1). Parental genotype WFTMS was found as good general combiner for seedling emergence, ear length and grain rows per ear. Genotype L7-2 showed good GCA effects for ear diameter. Accession OH-41 had higher GCA value for grains per ear and 100-grain weight (Table 2).

Highest SCA effects were observed in F_1 hybrid A556 × 82Pi for seedling emergence (Table 3). Accession Q67 had maximum and A556 had minimum mean values for seedling emergence. The cross OH-41 × WFTMS had maximum while hybrid A556 × 82Pi had minimum mean values for seedling emergence in direct crosses. In case of indirect crosses, the hybrid L7-2 × WFTMS had maximum while L7-2 × Q67 had minimum mean values for seedling emergence (Table 5).

Regarding ear diameter, the cross Q67 x L7-2 showed the highest SCA effects in direct crosses (Table 3) whereas, A556 × OH-41 had highest SCA effects in reciprocal crosses (Table 4). The F_1 hybrid OH-41 × WFTMS had highest mean value in direct crosses and L7-2 × WFTMS had maximum mean value in reciprocal crosses for ear diameter. Parental line 82Pi and crosses A556 × OH-41 and Q67 × WFTMS had minimum mean value for ear diameter (Table 5).

For ear length, WFTMS × Q67 had highest value of direct SCA effects (Table 3) whereas; WFTMS × L7-2 had maximum SCA effects in reciprocal crosses for ear length (Table 4). OH-41 × Q67 had maximum mean value in direct crosses and L7-2 × WFTMS had maximum mean value in reciprocal crosses for ear length. A556 (Parent), A556 × 82Pi (direct cross), 82Pi × OH-41 (reciprocal cross) had minimum mean value for ear length (Table 5). Cross OH-41 × WFTMS showed highest direct SCA effects (Table 3) and maximum reciprocal effects were observed in case of WFTMS × 82Pi for number of grain rows per ear (Table 4). OH-41 × WFTMS had maximum mean value for number of grain rows per ear in direct crosses, L7-2 × WFTMS had maximum mean value for number of grain rows per ear in reciprocal crosses. 82Pi (parent), A556 × 82Pi (direct cross), Q67 × OH-41 (reciprocal cross) had minimum mean value for number of grain rows per ear (Table 5).

Highest SCA effects were exhibited by the cross OH-41 x L7-2 (Table 3) and maximum reciprocal effects were observed in case of L7-2 x OH-41 for number of grains per row (Table 4). WFTMS × L7-2 showed maximum mean value in case of direct crosses whereas; OH-41 × A556 had maximum mean value in case of reciprocal crosses for number of grains per rows. 83Pi (parent), OH-41 × L7-2 (direct cross), L7-2 × 82Pi (reciprocal cross) had minimum mean value for number of grains per row (Table 5). 82Pi x L7-2 had highest SCA effects (Table 3) and maximum reciprocal effects were observed in case of cross L7-2 x WFTMS for number of grains per ear (Table 4). WFTMS × L7-2 had maximum mean value in direct crosses while Q67 × OH-41 had maximum mean value in reciprocal crosses for number of grains per ear. A556 (parent), A556 × 82Pi (direct cross), 82Pi × OH-41 (reciprocal cross) had minimum mean value for number of grains per ear (Table 5). Cross A556 x WFTMS showed highest SCA effects (Table 3) and maximum reciprocal effects were observed in L7-2 × Q67 (Table 4). Cross OH-41 × WFTMS had maximum mean value in direct crosses whereas, L7-2 × WFTMS had maximum mean values in reciprocal crosses for 100-grains weight. L7-2 (parent), A556 × L7-2 (direct cross), Q67 × OH-41 (reciprocal cross) had minimum mean value for 100-grains weight (Table 5).

Estimates of variance components: Variance components were calculated to estimate relative importance of additive and non-additive types of gene action. The variance component for seedling emergence, number of grains per row, number of grains per ear and 100-grains weight had higher values of GCA variance relative to other maize yield components. Ear diameter, ear length, number of grain rows per ear and number of grains per ear had higher SCA variance relative to other studied maize yield components. Seedling emergence, ear diameter, number of grains per ear and 100-grains weight had higher variance due to reciprocal effects relative to other maize yield components. Degree of dominance had more than unit value for seedling emergence, number of grains per row and 100-grains weight. Variance due to additive gene effects was predominant for seedling emergence, number of grains per rows and 100-grains weight. Variance due to non-additive gene effects was predominant for ear diameter, ear length, number of grain rows per ear and number of grains per ear (Table 6).

Table 1. Analysis of variance for combining ability of different maize inbred lines based on different yield components.

SOV	DF	Mean squares						
		Seedling emergence (%)	Ear diameter (cm)	Ear length (cm)	Grain rows per ear	Grains per row	Grains per ear	100-Grain Weight (g)
GCA	5	57.61*	12.84*	45.51*	17.91*	59.88*	23.99*	48.35*
SCA	15	34.65*	6.94*	16.73*	1.59*	4.53*	31.23*	2.71*
RECI	15	10.08*	8.56*	7.32*	11.03*	2.57*	19.55*	6.40*
GCA/SCA		1.66	1.85	2.72	11.22	13.22	0.77	17.86
ERROR	70	1.44	0.85	0.24	7.88	0.52	212.05	0.77

*: Significant at 5% level of significance,

Table 2. General combining ability analysis of six maize inbred lines for different quantitative traits.

	Seedling emergence (%)	Ear diameter (cm)	Ear length (cm)	Grain rows per ear	Grains per row	Grains per ear	100-Grain weight (g)
A556	-0.39	-0.91*	-1.07*	-0.18	-0.79	-17.07*	-0.05
OH-41	-0.22	0.85*	-0.70*	0.05	0.019	22.76*	2.29*
WFTMS	0.34	0.005	1.43*	0.65*	-0.93	11.82	1.65*
Q67	0.08	-0.46	-0.15	-0.27	3.19*	6.87	-0.72
82Pi	0.14	-0.90*	-0.37	-0.019	-0.95	-32.51*	-2.59*
L7-2	0.05	1.42*	0.86*	-0.23	-0.55	8.14	-0.58

Table 3. Specific combining ability analysis of six maize inbred lines for different quantitative traits.

	Seedling emergence (%)	Ear diameter (cm)	Ear length (cm)	Grain rows per ear	Grains per row	Grains per ear	100-Grain weight (g)
OH-41×A556	-0.043	3.15*	0.51*	-0.52	0.87	26.40*	-1.65*
WFTMS ×A556	0.00	0.75	-0.10	0.812*	-0.18	27.35*	1.00*
Q67 ×A556	-0.002	-5.55*	-0.04	-0.57	-0.30	22.00*	-0.20
82Pi × A556	-0.23	-1.02*	-1.68*	0.30	-0.05	-0.30	1.00*
L7-2 ×A556	-0.42	0.14	0.17	-0.45	0.05	72.75*	0.15
WFTMS× OH-41	0.085	0.09	-0.57*	-1.62*	0.20	-47.00*	-2.55*
Q67× OH-41	-0.58	2.39*	0.45*	-0.22	-0.03	43.35*	-0.50
82Pi × OH-41	-0.17	-0.39	0.48*	-0.60*	-0.30	-23.00*	1.00*
L7-2× OH-41	-0.08	0.63	1.44*	-0.28	2.75*	45.85*	-0.35
Q67 ×WFTMS	-0.25	-0.023	0.38	0.10	-0.27	30.12*	0.27
82Pi ×WFTMS	-0.42	-0.88*	0.73*	0.87*	-0.38	37.40*	-0.95*
L7-2 ×WFTMS	-0.34	0.75	2.54*	0.70*	0.67	115.95*	2.72*
82Pi ×Q67	0.24	0.88*	0.00	-0.13	-0.37	22.50*	1.68*
L7-2 ×Q67	0.086	1.73*	-0.36	-0.62*	0.73	11.90	2.83*
L7-2 ×82Pi	-0.25	-1.049*	-0.24	-0.47	0.15	-27.50*	2.25*

Table 4: Indirect or reciprocal effects of six maize inbred lines for different quantitative traits

	Seedling emergence (%)	Ear diameter (cm)	Ear length (cm)	Grain rows per ear	Grains per row	Grains per ear	100-Grain weight (g)
A556× OH-41	-0.06	1.59*	-1.41*	0.04	0.23	52.66*	-1.11*
A556× WFTMS	-0.09	0.07	-0.07	-0.49	-0.37	6.75	1.28*
A556× Q67	0.001	0.14	-1.02*	0.04	-0.37	25.95*	-0.36
A556×82Pi	0.69	-0.88*	1.75*	0.09	0.75	-62.67*	-0.58
A556× L7-2	0.29	1.23*	1.38*	0.16	-0.88	38.43*	-0.05
OH-41× WFTMS	-0.02	0.71	0.89*	0.28	-0.87	21.57*	-0.31
OH-41× Q67	0.41	0.46	1.33*	-0.20	0.51	-24.23*	1.20*
OH-41×82Pi	-0.23	1.75*	1.01*	-0.23	-0.65	54.81*	0.68
OH-41× L7-2	0.11	-1.48*	-1.06*	0.00	2.34*	-36.60*	0.51
WFTMS× Q67	0.18	1.89*	2.19*	0.25	1.26	43.28*	0.11
WFTMS×82Pi	-0.04	0.55	-0.26	-0.38	-0.002	22.85*	0.06
WFTMS× L7-2	0.47	-0.07	0.12	0.28	0.17	34.14*	0.48
Q67×82Pi	-0.09	-1.21*	-0.35	0.15	1.04	9.10	-0.20
Q67× L7-2	0.47	2.57*	0.91*	-0.08	0.18	29.84*	1.13*
82Pi× L7-2	0.26	-0.05	-0.27	0.12	-0.96	59.43*	0.69

Table 5. Mean performance of parents, direct and reciprocal crosses of different yield components

	Seedling emergence (%)	Ear diameter (cm)	Ear length (cm)	Grain rows per ear	Grains per row	Grains per ear	100-Grain weight (g)
Parents							
A556	0.610	42.47	16.26	21.00	41.00	229.40	23.20
OH-41	1.930	40.64	15.29	26.30	36.30	409.80	21.93
WFTMS	3.200	42.91	12.61	28.10	38.10	383.90	21.21
Q67	7.600	44.34	17.70	30.60	43.60	387.10	27.60
82Pi	1.200	37.53	11.85	21.80	29.80	265.40	20.60
L7-2	1.215	43.90	12.45	30.00	30.00	418.10	21.20
Direct Crosses							
A556× OH-41	1.510	38.60	13.85	22.30	32.30	410.90	21.51

A556× WFTMS	1.870	40.35	15.10	23.00	33.00	284.40	21.87
A556× Q67	2.340	40.96	15.64	27.50	37.50	338.90	22.43
A556×82Pi	1.229	38.35	12.89	21.90	31.90	266.20	21.23
A556× L7-2	5.930	43.62	16.53	28.20	38.20	385.50	25.93
OH-41× WFTMS	8.400	44.92	20.17	32.10	38.10	446.00	28.40
OH-41× Q67	7.100	43.73	17.21	33.60	37.60	406.80	27.10
OH-41×82Pi	1.530	38.85	14.03	22.80	32.80	269.00	21.53
OH-41× L7-2	2.900	43.76	16.22	29.10	31.10	409.90	22.90
WFTMS× Q67	2.330	43.83	15.61	31.70	38.70	417.50	22.33
WFTMS×82Pi	1.900	40.63	15.25	25.60	35.60	316.10	21.90
WFTMS× L7-2	6.170	47.56	16.54	32.20	45.20	462.70	26.17
Q67×82Pi	2.776	41.08	15.69	27.60	37.60	340.00	22.77
Q67× L7-2	7.630	46.62	19.07	31.90	44.90	440.50	27.63
82Pi× L7-2	2.900	42.23	16.15	28.00	38.00	352.10	22.90
Indirect Crosses							
OH-41×A556	7.530	44.19	17.55	30.50	43.50	434.70	27.53
WFTMS ×A556	6.700	43.71	16.75	28.40	38.40	400.00	26.77
Q67 ×A556	2.900	41.72	15.76	27.70	37.70	342.70	22.90
82Pi × A556	2.300	40.75	15.61	27.20	36.20	334.70	22.30
L7-2 ×A556	1.970	40.73	15.40	26.60	35.60	326.40	21.97
WFTMS× OH-41	7.400	44.40	17.21	30.90	32.90	436.70	27.40
Q67× OH-41	1.230	43.01	13.05	31.20	37.20	548.00	21.23
82Pi × OH-41	1.800	40.20	14.68	22.90	32.90	282.70	21.80
L7-2× OH-41	1.600	43.77	14.35	33.70	35.70	415.70	21.60
Q67 ×WFTMS	1.770	39.16	14.35	22.90	38.90	273.00	21.77
82Pi ×WFTMS	7.500	44.10	17.40	30.20	37.20	426.70	27.50
L7-2 ×WFTMS	7.600	45.54	18.30	39.10	41.22	481.10	27.60
82Pi ×Q67	4.170	42.84	16.84	28.00	35.67	371.70	24.17
L7-2 ×Q67	1.570	43.96	14.20	30.10	37.77	480.20	21.57
L7-2 ×82Pi	1.870	40.61	15.20	24.60	31.22	298.60	21.87

Table 6. Estimates of relative proportion of variance components for GCA, SCA and reciprocal effects for quantitative traits in maize under field condition.

Traits	б^{2}GCA	б^{2}SCA	б^{2}Reci	Degree of dominance	б^{2}A	б^{2}D
SE	2.89	0.28	6.55	10.27	5.78	0.28
ED	0.436	2.95	3.23	0.15	0.872	2.95
EL	0.589	2.20	0.76	0.267	1.18	2.20
RE	0.107	2.72	0.39	0.039	0.21	2.72
GR	2.38	1.06	0.40	2.25	4.77	1.06
GE	-110.7	3722.4	197	0.03	-221.6	3722.39
100-GW	2.93	0.763	2.08	3.84	5.86	0.673

Note: б^{2}GCA: variance due to general combining ability, б^{2}SCA: variance due to specific combining ability, б^{2}Reci: variance due to reciprocal combining ability, б^{2}A: variance due to additive gene action, б^{2}D: variance due to dominance gene action.

DISCUSSION

Griffing's analysis of variance showed significant GCA and SCA effects for quantitative maize traits among diallel crosses which showed that both additive and non-additive gene effects were important for inheritance of these traits in maize inbred lines. It was reported that estimates of SCA were more predictive than mean productivity (MP) estimates regarding the performance of inbred lines for hybrid development (Estakhr and Heidari, 2012). Efficiency of hybrid improvement is increased by SCA based selection. GCA effects of inbred lines showed that prerequisite genetic variation was present which is required for development of advanced maize inbred lines. In crop improvement program, selection is dependent on parents with superior combining ability which help in selection of suitable breeding program. Analysis of variance for combining ability showed significant differences among general, specific and reciprocal effects of all studied maize traits which depicted that heterotic effects were present in parents for studied traits. Additive gene action is effectively responsive to selection whereas, non-additive gene action (dominance and epistatic) enhances the hybrid vigor in cross combination of inbred lines. It was reported that both additive and non-additive gene actions were observed for various yield and related traits (days to flowering, plant height, ear height, leaf area and number of ears, cob size, grains per row and grain weight) of maize (Malik *et al.,* 2004; Borghi *et al.,* 2012; Bertoia and Aulicino, 2014) were contributors in genetic control of different quantitative traits of maize.

Variability in mean values of different yield components of maize showed that further improvement could be brought about by hybridization of parents. To initiate the breeding program for the improvement of maize there is dire need of genetic differences. Mean differences among different traits of maize lines were also reported by Malik *et al.* (2004); Melani and Carena (2005); Lázaro *et al.* (2010); Borghi *et al.* (2012).

Combining ability analysis provides information regarding potential of parents. Line × tester (Kempthorne, 1957) and diallel analysis (Hayman, 1954; Jinks, 1954; Griffing, 1956) are conducted for estimation of various components i.e. GCA and SCA, additive (D) and dominance components (H_1, H_2) etc. Combining ability analysis was previously carried out by several researchers to explore the parental potential of yield and yield components of maize germplasm (Malik *et al.,* 2004; Melani & Carena, 2005; Lázaro *et al.*, 2010; Borghi *et al.,* 2012; Iqbal *et al.,* 2012 and Aslam *et al.,* 2015b). More than unity, GCA/SCA ratio means additive effects were prevailing for genetic control of maize parameters whereas, dominance gene effects (non-additive) were found less important for these studied traits. It was also reported that GCA/SCA ratio may depict the similar picture or different for quantitative traits either due to differential combining ability of inbred lines or due to complex interaction of genes and genotype by environment under diverse environmental conditions in maize genotypes (Iqbal *et al.,* 2012; Aslam *et al.,* 2015b). Significant positive SCA was the result of parental combination of lines having significant positive and negative GCA in F-206 maize inbred line (Iqbal *et al.,* 2012). Contradictory results were also reported which mentioned that higher SCA was not necessary for the lines that had higher GCA for same characters. Combining ability was also used for classification of maize in different heterotic groups (Borghi *et al.,* 2012).

Additive variance was predominant for seedling emergence in current research whereas, Moterle *et al.* (2011) reported the preponderance of non-additive genetic effects for final count of germination, seedling vigor classification, seedling emergence in sand seedbed, speed of emergence in sand seedbed and speed of emergence index in tropical maize lines. Ear diameter, ear length, number of grain rows per ear and number of grains per ear had higher SCA variance and non-additive genetic effects in current research study. However, Rezaei *et al.* (2005) and Iqbal *et al*. (2012), Aliu *et al.* (2010) reported the similar results for these yield related traits of maize. Number of grains per row, number of grains per ear and 100-grains weight of maize genotypes studied in current research were found under the control of additive gene action whereas, El-Badawy, (2012) reported the preponderance of additive and additive × additive genetic effects for number of grains per row, number of grains per ear and grain yield. Saeed *et al.* (2000) reported that number of kernels per row, 100-grain weight and grain yield per plant were governed by non-additive gene action. However, Saeed *et al.* (2000) found the number of kernel rows per ear under the control of additive gene action. Pswarayi and Vivek, (2008) reported the overwhelmness of additive gene action for grain yield. Aslam *et al.* (2015b) reported the preponderance of non-additive gene action for early growth stages of maize. Unay *et al.* (2004) reported the grain yield under control of dominant genes.

Moterle *et al.* (2011) reported the predominance of the non-additive genetic effects for grain yield in tropical maize inbred lines. Flash, Dekalb 350 and P 30F80 were reported to be high combiner for yield. Dekalb 350 × CD 3121-2, Speed × CD 3121-2, CD 3121-1 × P 30F80 and Dow 8330 × AG 8080 specific cross combinations were found to be best for yield in tropical maize inbred lines (Moterle *et al.,* 2011).

High and significant GCA value of OH-41 was observed for most of the quantitative traits. This line (OH-41) also had high SCA value for different quantitative traits in following crosses; A556 × OH-41, OH-41 × WFTMS, OH-41 × Q67 and OH-41 × 82Pi. These results showed that additive and non-additive genetic effects were acting in the same direction in different crosses for improvement of maize traits. Kumar *et al*., (2012) reported non-addtive gene action for yield per plant, additive gene effects for maize flowering traits. Kenga *et al*., (2004) reported the non-additive gene action for most of the yield and related traits. Iqbal *et al*., (2012) reported the "F-206" genotype to be best general combiner for flowering and grain yield among the studied maize germplasm. F-192×F-189, F-110×F-206, and F-110×S-42 were the F1 hybrids with maximum SCA effects.

Additive gene action was found to have main control in number of kernels per row and plant height while dominance was prevailing in 100-grain weight, seed yield, time to maturity, ear length and ear height in subjected maize genotypes (Konak *et al.,* 1999; Aslam *et al.,* 2015b). Additive genetic variances were found for number of grains per row and number of grain rows per ear under high density plantation (Borghi *et al.,* 2012). In maize, dominant and additive gene actions were reported for grain yield but dominance effects were mentioned to be more important. Negative variance for genetic components might be due to improper statistical and genetic model, lack of proper sampling from population, unsuitable experimental design and sampling error (Mather and Jinks, 1982; Roy, 2000). Additive gene effects were found to be more prominent than dominance gene effects in controlling forage characters of maize (Abadi *et al.,* 2011).

Additive gene effects were found for 1000 grain weight and day to heading in bread wheat (Fellahi *et al.,* 2013) whereas, additive and non-additive gene actions were reported for grain yield, plant height, grains per spike, fertile tillers and spike length. So for as, self-pollinated crops are concerned, SCA is only useful for improvement if heterosis is exploited and transgressive segregants are obtained. Suitable SCA and one parent with higher GCA are useful for increase the concentration of more alleles for targeted traits (Kenga *et al.,* 2004).

Specific combining ability variance (σ^2sca) higher than general combining ability variance (σ2gca) showed that non-additive gene action is propounding to control the characters (Fellahi *et al.,* 2013). Degree of dominance greater than one and ratio of GCA over SCA variance less than unity showed that dominant genetic variance was larger than additive genetic variance for studied characters (Fellahi *et al.,* 2013). In case of preponderance of non-additive genetic effects, selection of superior plants for targeted traits must be postponed and selection should be made in lateral generations. In lateral generation, improvement in characters can be made by recombinant selection in segregating generations (Fellahi *et al.,* 2013).

It was concluded that promising cross combinations were present among different parents who could be exploited for the improvement of yield potential of maize crop. Vigour of hybrid is dependent on prevalence of additive, non-additive and epistatic effects. Non-additive (dominance and over-dominance) and epistatic genetic effects were responsible for production of hybrids having performance and vigour better than parents. So, cross combinations showing desired SCA value can be used for future breeding program. Q67 having high GCA values can be used for development of synthetic varieties. Parents involved in the cross OH-41 × WFTMS having high SCA value could be used for development of hybrids.

REFERENCES

Abadi, J.M., S.K. Khorasani, B.S. Sar, S. Movafeg and M. Golbashy (2011). Estimation of Combining Ability and Gene Effects in Forage Maize (*Zea mays* L.) Using Line × Tester Crosses. J. Plant Physiol. Breed. 1(1): 57-67.

Aliu, S., S. Fetahu and L. Rozman (2010). Variation of physiological traits and yield components of some maize hybrid (*Zea mays* L.) in agroecological conditions of Kosovo. Acta Agriculturae Slovenica. 95 (1): 35-41.

Aslam, M., I.A. Khan, M. Saleem and Z. Ali (2006). Assessment of water stress tolerance indifferent maize accessions at germination and early growth stage. Pakistan J. Bot.38: 1571–1579.

Aslam, M., M.A. Maqbool, M. Yaseen, Q.U. Zaman (2015a). AMMI Biplot analysis for comparative evaluation of maize genotypes under different saline environments. Pakistan J. Agric. Sci. 52(2): 339-347.

Aslam, M., Q. Sohail, M.A. Maqbool, Q.U. Zaman and Z. Ahmed (2015b). Combining ability analysis and genetic inheritance of salt tolerance indicators in maize (*Zeamays* L.) following diallel mating design. Int. J. Agric. Bio. 17: 523–530.

Bertoia, L.M. and M.B. Aulicino (2014). Maize forage aptitude: Combining ability of inbredlines and stability of hybrids. Crop J. 2: 407–418.

Bocanski, J., Z. Sreckov, and A. Nastasic (2009). Genetic and phenotypic relationship between grain yield and components of grain yield of maize (*Zea mays* L.). Genetika41(2): 145-154.

Borghi, M.L., M.A. Ibañez, N.C. Bonamico., M.V. Kandus., D.A. Gomar., E.A. Guillin, J.C. Salerno and M.A.D. Renzo (2012). Combining ability of flint corn inbred lines: Malde Río Cuarto disease tolerance and grain yield. Phyton: Int. J. Exp. Bot., 81:123-131.

El-Badawy, M.El.M. (2012). Heterosis and combining ability in maize using diallel crosses among seven new inbred lines. Asian J. Crop Sci. 1-13.

Estakhr, A., and B. Heidari (2012). Combining Ability and Gene Action for Maturity and Agronomic Traits in Different Heterotic Groups of Maize Inbred Lines and Their Diallel Crosses. J. Crop Sci. Biotech. 15 (3): 219 - 229.

Fellahi, Z.E.A., A. Hannachi, H. Bouzerzour, and A. Boutekrabt (2013). Line × Tester Mating Design Analysis for Grain Yield and Yield Related Traits in Bread Wheat (*Triticum aestivum* L.). Int. J. Agron. 1-9.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing system. Aust. J. Biol. Sci. 9:463–493.

Hayman, B.I. (1954).The theory and analysis of diallel crosses. Genetics 39: 789-809.

Iqbal, J., M. Saleem, M. Ahsan, and A. Ali (2012). General and specific combining ability analyses in maize under normal and moisture stress conditions. The J. Anim. Plant Sci., 22(4): 1048-1054.

Jinks, J.L. (1954). The analysis of heritable variation in a diallel cross of *Nicotiana rustica* varieties. Genetics 39: 767-788.

Kempthorne, O. (1957). An Introduction to Genetic Statistics. John Wiley, New York, pp.545.

Kenga, R., S.O. Alabi, and S.C. Gupta (2004). Combining ability studies in tropicalsorghum (*Sorghum bicolor* (L.) Moench). Field Crops Res. 88(2-3): 251–260.

Konak, C., A. Unay, E. Serter, and H. Basal (1999). Estimation of combining ability effects, heterosis and heterobeltiosis by line×tester method in maize. Turk. J. Field Crops 4:1-9.

Kumar, T.S., D.M. Reddy, V.S. Naik, S.I. Parveen, P.V. Subbaiha (2012). Gene action for yield and morpho-physiological traits in maize (*Zea mays* L.) inbred lines. J. Agric. Sci. 4(5): 30-35.

Lázaro, D.L.C., E.G.C. Najera, N.P.B. Manzano, A.G. Vázquez, V.R. Torres and A.J.L. delRío (2010). Heterosis y aptitud combinatoria de poblaciones de maíz tropical. Phyton: Int. J. Exp. Bot. 79: 11-17.

Malik, S.I., H.N. Malik, M.N. Minhas and M. Munir (2004). General and specific combining ability studies in maize diallel crosses. Int. J. Agric. Bio. 5: 856-859.

Maqbool, M.A., M. Aslam, H. Ali, T.M. Shah, B.M. Atta (2015). GGE biplot analysis based selection of superior chickpea (*Cicer arietinum* L.) inbred lines under variable water environments. Pakistan J. Bot. 47(5):1901-1908.

Mather, K., and J.L. Jinks (1982). Biometrical Genetics. The Study of Continuous Variation, 3rd Edi. Chapman and Hall, New York, pp. 396.

Melani, M.D. and M.J. Carena (2005). Alternative maize heterotic patterns for the northerncorn belt. Crop Sci. 45: 2186- 2194.

Moterle, L.M., A.L. Braccini, C.A. Scapim, R.J.B. Pinto, L.S.A. Gonçalves, A.T. do Amaral Júnior and T.R.C. Silva. (2011). Combining ability of tropical maize lines for seed quality and agronomic traits. Genet. Mol. Res. 10 (3): 2268-2278.

Pswarayi, A., and S.B. Vivek (2008). Combining ability amongst CIMMYT’s earlymaturing maize (*Zea mays* L.) germplasm under stress and non-stress conditions and identification of testers. Euphytica 162(3): 353-262.

Rezaei, A.H., B. Yazdisamadi, A. Zali, A.M. Rezaei, A. Tallei and H. Zeinali (2005). Anestimate of heterosis and combining ability in corn using diallel crosses of inbredlines. Iran. J. Agric. Sci. 36(2): 385-397.

Roy, D. (2000). Plant Breeding, Analysis and Exploitation of Variation. Alpha Science International Ltd, Pangbourne, UK.

Saeed, M.T., M. Saleem and M. Afzal (2000). Genetic analysis of yield and its components in maize diallel crosses (*Zea mays* L.). Int. J. Agric. Bio. 2(4): 376-378.

Unay, A., H. Basal, and C. Konak (2004). Inheritance of grain yield in a half diallel maize population. Turk. J. Agric. 28: 239-244.