Int. J. Pure Appl. Sci. Technol., 21(1) (2014), pp. 17-30

International Journal of Pure and Applied Sciences and Technology

ISSN 2229 - 6107

Available online at www.ijopaasat.in

Research Paper

Combining Ability, Gene Action and Heterosis in Some Inbred Lines of Maize at Two Sowing Dates Using Factorial Mating Design

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(Received: 29-11-13; Accepted: 17-2-14)

Abstract: *Combining ability, gene action and heterosis was studied for no. of days to 50% tasseling, no. of days to 50% silking, flag leaf area, plant height, no. of rows/ear, no. of grains/row, 300-grain weight and grain yield/plant in a Factorial Mating in Randomized Completely Randomized Design conducted separately in spring and autumn sowing dates, 2013 through hybridization between three parents of maize as female named [K-122 (1), Dkc (6418) (2), Dh(13×14) (3) and four parents as male named [HA-cross (4), Tietar (5) and Hvp-9433 (6) and H-1040 (7)]. The comparison of values revealed that the variability among hybrids was more than that among parents and the grand mean of all characters at autumn sowing date is better than the spring sowing date. Parents 1, 2, 3, 5 and 7 were the best general combiner for most characters at both sowing dates. The results of SCA effects revealed that the hybrids [3×7], [2×6] and [1×6] had a best specific combiner in desirable direction for most characters at both sowing dates. The values of dominance genetic variance were greater than additive genetic variance for all studied characters at both sowing dates, which depicts the importance of dominant gene effect for controlling these characters. Average degree of dominance, was greater than unity for all of the characters at both sowing dates. These results indicated that these characters were affected by over-dominance effects of some genes controlling the characters under study which is reflected in the low narrow-sense heritability. The high heterosis were exhibited by the following hybrid combinations [1×6, 2×6, 3×4, 3×5 and 3×7] for most studied characters at both sowing dates might be utilized for developing high yielding hybrid varieties.*

Keywords: Combining ability, gene action, heterosis, sowing dates, maize.

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1. Introduction:

Maize (*Zea mays* L.) plays a greater role in human and livestock nutrition world-wide. In Iraq it is ranks third position after wheat and barley. Increased grain yield mainly concerned to maize breeders, which have been utilizing the available genetic resources which is needed to search out the genetic material having potential of growth characters, grain yield and its components. , temperature, irrigation and soil fertility are three major limiting factors affecting maize growth and productivity (Hefny, 2010). Experts agree that temperatures will increase and that there will be more year-to-year variability due to climate change (Maton *et al.,* 2007), which depends largely on the geographical location (IPCC, 2001). So, the sowing dates have modifying effects on the growth, yield and its components of maize. In this case, it is essential to get information on the nature of combining ability of parents, their genetic behavior and heterosis in there hybrid combinations. There are various biometrical tools helps plant breeders in ascertaining the genetic information. Factorial Mating Design suggested by (Comstock and Robinson, 1952) including all the possible crosses between two different sets of parents: group (A) used as male parents (m) and group (B) used as females (f) parents. Plant breeders used this system of mating to insert a greater number of parents to get less number of crosses between them compared to another systems of mating such as diallel cross as it doesn't required equal number of males and females. By statistical genetic analysis it could be found there the components of genetic variation using parent's information of (Males) and (Females) either both separately, As well as to estimate the average degree of dominance, heritability in the narrow sense, expected genetic advance and heterosis, and give the breeder identify of the genetic behavior and the ability of the characteristics in order to identify the best parents and hybrids (Ali, 2012). Exploitation of hybrid vigor and selection of parents based on combining ability has been used as an important breeding approach in crop improvement. Developing of high yielding F1s along with other favorable traits is receiving considerable attention. For developing desirable hybrids, information about combining ability of the parents and the resulting crosses is essential (Uddin *et al.,* 2006). The combining ability and gene effects of yield components were studied by more researchers using various mating designs. (Basbag *et al.,* 2007) suggested that combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene action controlling quantitative traits. (Choukan, 1999) indicated that GCA effects were highly significant for grain yield and 1000-grain weight and highly significant of SCA for grain yield and conducted that both additive and non-additive effects were found to be important in genetically control of these traits. (Amiruzzaman *et al.*, 2013) reported that variance due to GCA and SCA were highly significant for the characters studied of yield components, indicating both additive and non-additive type of gene action were important for controlling the traits. **(**Sinsawat *et al.*, 2004) found that grain yield/plant and 100-grain weight were to be under non-additive gene control, while additive gene action was responsible for the genetic expression for days to 50% tasseling and rows/ear. However (Irshad-El-Haq *et al.*, 2010) reported that non-additive gene action was more important in the inheritance grain yield and other agronomic traits in maize. (While, Hefny, 2010) reported that both additive and non-additive gene effects were important in the genetic expression of maize yield and its components. The results obtained by (Hussain and Ali, 2010) indicated that narrow sense heritability were moderate for silking and tasseling date, grain yield/plant, number of kernels/row, 100- grain weight and low for plant height, leaf area, number of rows/ear, ear length and number of grains/ear and the expected genetic advance from selection was high for grain yield/plant and 100- grain weight. On the other hand higher parent heterosis is usually taken into cognizance especially when the goal is to identify a better hybrid superior to either of the parents (Kurawa, 2012). For grain yield/plant, heterosis over better parent was found in the range of 8.23 to 25.78 percent (Uddin *et al.* 2006).

The objective of the present study were to investigate combining ability for yield and its components in some maize inbred lines using factorial mating design to identify parents with desirable GCA effects and cross combinations with desirable SCA effects and to study the nature of gene action which controlled these traits under two sowing dates.

2. Materials and Methods:

Grains of twelve F_1 generation of maize produced by using Factorial Mating Design in autumn, 2012 through hybridization between three parents as female named [K-122 (1), Dkc (6418) (2), Dh(13×14) (3) and four parents as male named [HA-cross (4), Tietar (5) and Hvp-9433 (6) and H-1040 (7)]. The 19th genotypes were cultivated on two sowing dates (spring and autumn, 2013) with two experiments separately at the Field of Faculty of Agriculture, Duhok University/Iraqi Kurdistan Region using Randomized Complete Block Design with three replications. Each replication consists of 19 rows (beside that 2 rows as a guard), one row for each genotype; 3.0 m long, with 75 cm row to row and 25 cm plant to plant distance. The following measurements were recorded: No. of days to 50% tasseling, no. of days to 50% silking, flag leaf area (cm^2), plant height (cm), no. of rows/ear, no. of grains/row, 300-grain weight (g) and grain yield/plant (g). Data was analyzed according to both R.C.B.D. and Factorial Mating Design (Comstock and Robinson, 1952) which statistical model is:

$$yijk = \mu + mi + fj + mf(ij) + Rk + eijk \quad \left[\begin{array}{l} i = 1,2,3.....m \\ j = 1,2,3.....f \\ k = 1,2,3.....r \end{array} \right.$$

Estimation of effects:

Effect of GCA for males $\hat{g}i$

$$\hat{g}i = \bar{y}i.. - \bar{y}...$$

Effect of GCA for females $\hat{g}j$

$$\hat{g}j = \bar{y}.j. - \bar{y}...$$

Effect of SCA for any hybrid $\hat{S}ij$

$$\hat{S}ij = \bar{y}ij. - \bar{y}i.. - \bar{y}.j. + \bar{y}...$$

In order to estimate the standard error between effects of general combining ability for parents (males and females), the following equation were conducted: $S.E.(gi \,\&\, gj') = \sqrt{\frac{2\sigma^2 E}{r}}$; while the following equation were conducted to estimate the standard error between effects of specific combining ability for hybrids: $S.E.(Sij - Sij') = \sqrt{\frac{4\,\sigma^2 E}{r}}$.

The components of phenotypic variation (Dominance variance $\sigma^2 D$, Additive variance $\sigma^2 A$ and environmental variance $\sigma^2 E$) have been estimated based on expected mean square (Table, 1).

Table (1): ANOVA Table of factorial mating design (Fixed model)

SOV	*df*	*SS*	*MS*	*EMS*
$\mathrm{Re}\,pl.$	$r-1$	$\frac{\Sigma Y..k^2}{mf}-\frac{Y...^2}{mfr}$		
Females	$m-1$	$\frac{\Sigma Yi..^2}{fr}-\frac{Y...^2}{mfr}$	MSf	$\sigma^2 e+mr\sigma^2 f$
Males	$f-1$	$\frac{\Sigma Y.j.^2}{mr}-\frac{Y...^2}{mfr}$	MSm	$\sigma^2 e+fr\sigma^2 m$
$M.\times F.$	$(m-1)(f-1)$	$\frac{\Sigma Yij.^2}{r}-\frac{\Sigma Yi..^2}{fr}-\frac{\Sigma Y.j.^2}{mr}+\frac{Y...^2}{mfr}$	$MSmf$	$\sigma^2 e+r\sigma^2 mf$
Error	$(mf-1)(r-1)$	$\Sigma yijk^2-\frac{\Sigma Yij.^2}{r}-\frac{\Sigma Y..k^2}{mf}+\frac{Y...^2}{mfr}$	MSe	$\sigma^2 e$
Total	$mfr-1$	$\Sigma yijk^2-\frac{Y...^2}{mfr}$		

Applying the following equations according to the fixed model:

$$\sigma^2 m=\frac{MSm-MSe}{fr}=\sigma^2 G.C.A.=\frac{1}{2}\sigma^2 A$$

$$\sigma^2 f=\frac{MSf-MSe}{mr}=\sigma^2 G.C.A.=\frac{1}{2}\sigma^2 A$$

$$\sigma^2 m\times f=\frac{MSmf-MSe}{r}=\sigma^2 S.C.A.=\sigma^2 D$$

Where,

$\sigma^2 E=MSe$

$\sigma^2 m$ and $\sigma^2 f$ = variance of GCA for males and females, respectively.

$\sigma^2 m\times f$ = variance of SCA for hybrids.

And considering that the parents used in the study is pure (F=1) then:

$$\sigma^2 Am=2\sigma^2 m$$
$$\sigma^2 Af=2\sigma^2 f$$

Therefore, the additive variance equal to:

$$\sigma^2 A = \frac{2\sigma^2 m + 2\sigma^2 f}{2} = \frac{\sigma^2 Am + \sigma^2 Af}{2}$$

And dominance variance equal to:

$$\sigma^2 D = \sigma^2 m \times f$$

Therefore, the total genetic variation can be calculated by the following equation:

$$\sigma^2 G = \sigma^2 A + \sigma^2 D$$

And phenotypic variance:

$$\sigma^2 P = \sigma^2 G + \sigma^2 E$$

Variance of $\sigma^2 A$, $\sigma^2 D$ and $\sigma^2 E$ was estimated by applying the following equations (Kempthorne, 1969):

$$V(\sigma^2 A)_{as \quad male} = \frac{4}{r^2 f^2}\left[\frac{2(MSm)^2}{K+2} + \frac{2(MSe)^2}{K+2}\right]$$

$$V(\sigma^2 A)_{as \quad female} = \frac{4}{r^2 m^2}\left[\frac{2(MSf)^2}{K+2} + \frac{2(MSe)^2}{K+2}\right]$$

$$V(\sigma^2 D) = \frac{4}{r^2}\left[\frac{2(MSmf)^2}{K+2} + \frac{2(MSe)^2}{K+2}\right] , \qquad V(\sigma^2 E) = \left[\frac{2(MSe)^2}{K+2}\right]$$

Where K= d. f. for each source of variation.

Taking the square root of the variations above we then get the standard error (SE) for each variance for the test of significant of each one of these variances using statistical t-test.

Heritability in the broad $h^2{}_{B.S.}$ and narrow sense $h^2{}_{N.S.}$ was estimated by using the following equations:

$$h^2{}_{B.S.} = \frac{\sigma^2 G}{\sigma^2 P}$$

$$h^2{}_{N.S.} = \frac{\sigma^2 A}{\sigma^2 P}$$

Average degree of dominance $\bar{a}$: $\bar{a} = \sqrt{\frac{2\sigma^2 D}{\sigma^2 A}}$

Expected genetic advance EGA : $EGA = (h^2{}_{N.S.})(\sigma P)(i)$

Expected genetic advance as a percent of mean: $EGA\% = EGA / \bar{X} \times \%100$

Where,

i = Coefficient of selection which is 2.06 at 5% selection intensity.
σP = Phenotypic standard deviation.
$h^2_{N.S.}$ = Heritability in narrow sense.

Mid- parent heterosis over mid parents was computed according to the following equation: $Heterosis(H) = \overline{F}_2 - \left[\overline{p}i + \overline{p}j/2\right]$. Then, heterosis significant was tested using t-test for each hybrid: $t(H) = H/\sqrt{V(H)}$. The variance of heterosis were calculated from the following equation: $V(H) = (3/2)(Mse/r)$.

3. Results and Discussion:

[1] Parents and F1 Hybrids Performance

Preliminary analysis of variance showed significant genotype effects for all the studied characters, indicating variation among inbred lines and also their hybrids at two sowing dates and different responses and ranking of these genotypes to sowing dates. The mean performance of parents and hybrids for different characters are presented in Table (2). Earliest days to 50 % tasseling observed from parent [5] (66.667 day) and parent [1] (63 days) among parents and from [3 × 5] (68.667 day) and [2 × 7] (58.667 day) among hybrids in spring and autumn sowing dates, respectively. While the earliest days to 50 % silking observed from parent [7] (69.333 day) and (66.333 days) among parents and from [1× 5], [3× 5], [3× 7] (71.333 day) and [1 × 7] (61.333 day) among hybrids in spring and autumn sowing dates, respectively. The largest flag leaf area was found in parent [7] (384.933 cm^2) and [5] (908.267 cm^2) among parents, while the hybrid [3×7] gave the largest flag leaf area (589.617 cm^2) and (905.400 cm^2) among hybrids in spring and autumn sowing dates, respectively. The tallest parents were observed in parent [3] (206.333 cm) and [1] (275 cm^2) among parents, while maximum plant height was recorded in [2 × 7] (220 cm^2) and [2×6] (281.667 cm^2) among hybrids in spring and autumn sowing dates, respectively. Among all genotypes, the highest no. of row/ear at spring sowing date was observed for [3×7] (22.033) and at autumn sowing date the highest values were for [1×4] (18.433). Highest no. of grains/row was observed for [3×7] (48.467) at spring sowing date and for [3×5] (46.867) at autumn sowing date. [3×7 and 1×6] had the highest 1000-grain weight (68.507 and 85.443 g) at spring and autumn sowing date, respectively. Heaviest grain yield/plant was observed for [3×7] (146.510g) at spring sowing date and for [1×6] (182.260) at autumn sowing date. It can be concluded that parent [7] exceeded over the other parents in most characters; it was the earliest in days to 50% tasseling at autumn sowing date and better in flag leaf area and no. of row/ear at spring sowing date, however its better in days to 50% silking, no. of grains/ear and 300-grain weight at both sowing dates. Parent [1] was better in exceeded for no. of rows/ear and grain yield/plant at autumn sowing date. Parents [2] and [1] exceeded over the other parents in grain yield at spring and autumn sowing date, respectively. Regarding the hybrids, hybrid [3×5] was earlier to days to 50% tasseling at both sowing dates. Hybrid [3×7] and better in flag leaf area at both sowing dates and in no. of row/ear, no. of grains/row, 300-grain weight and grain yield at spring sowing date. While the hybrid [1×6] was better in 300-grain weight and grain yield at autumn sowing date. The comparison of values revealed that the variability among hybrids was more than that among parents and the grand mean of all characters at autumn sowing date is better than the spring sowing date due to preference environmental conditions, especially temperature during flowering and grain filling period in autumn sowing compared to the spring sowing. Such variability among maize genotypes for yield and its components were reported by more researchers (Akbar *et al.*, 2008, Abdel-Moneam *et al.,* 2009, Hefny, 2010, Hussain and Ali, 2010 and El-Badawy, 2013).

Table (2): Mean performance of parents and hybrids for the studied characters

	No. of days to 50% tasseling		No. of days to 50% silking		Flag leaf area (cm^2)		Plant height (cm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Females								
1	76.667	63.000	80.333	67.000	367.300	812.067	162.333	275.000
2	77.000	64.667	80.333	68.333	326.083	671.767	174.667	245.000
3	77.000	65.333	79.667	67.667	323.467	743.500	206.333	228.333
Mean	76.889	64.333	80.111	67.667	338.950	742.444	181.111	249.444
Males								
4	76.667	64.667	79.667	68.667	372.183	637.333	168.333	205.000
5	66.667	67.667	69.667	70.333	328.750	908.267	167.333	226.667
6	68.667	64.667	70.667	67.667	262.067	563.667	194.000	203.333
7	67.000	63.667	69.333	66.333	384.933	619.167	182.333	211.667
Mean	69.750	65.167	72.333	68.250	336.983	682.108	178.000	211.667
Hybrids								
1 × 4	69.000	62.333	71.667	64.667	401.183	908.500	170.667	223.333
1 × 5	69.000	62.333	71.333	65.000	283.000	746.567	200.333	225.000
1 × 6	73.000	62.667	75.333	66.000	416.950	732.333	219.000	241.667
1 × 7	73.000	59.333	76.333	61.333	373.667	844.433	206.000	253.333
2 × 4	73.333	62.333	76.333	65.667	358.483	749.433	216.667	256.667
2 × 5	73.667	63.000	76.000	67.333	282.500	742.667	215.667	250.000
2 × 6	73.333	62.333	77.333	65.000	436.183	736.500	210.000	281.667
2 × 7	73.000	58.667	75.667	62.333	335.983	725.833	220.000	253.333
3 × 4	75.333	62.000	77.000	64.667	470.100	719.167	204.333	238.333
3 × 5	68.667	58.333	71.333	60.333	482.267	764.900	191.000	241.667
3 × 6	78.333	66.667	80.333	69.333	273.903	814.400	189.000	206.667
3 × 7	70.000	65.333	71.333	67.667	589.617	905.400	185.667	235.000
Mean	72.472	62.111	75.000	64.944	391.986	782.511	202.361	242.222
G. M.	72.596	63.105	75.246	66.070	372.033	755.047	193.877	236.930
LSD $_{0.05}$	0.606	0.582	0.655	0.777	14.741	19.362	4.005	6.601

(Cont.)

	No. of rows/ear		No. of grains/row		300-grain weight (g)		Grain yield/plant (g)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Females								
1	15.233	18.167	26.500	36.333	41.363	70.980	37.023	145.480
2	13.467	16.500	31.300	38.767	45.440	67.970	73.000	143.000
3	19.133	14.400	36.833	30.733	58.377	65.390	49.857	86.740

Mean	15.944	13.356	31.544	35.278	48.393	68.113	53.293	125.073
Males								
4	20.500	13.167	24.700	32.033	38.970	76.790	62.683	85.660
5	17.000	16.333	30.167	31.667	32.953	77.393	36.493	104.013
6	15.567	13.267	33.233	25.000	38.593	69.323	44.837	60.293
7	19.967	14.600	36.300	40.000	60.277	81.863	44.243	88.277
Mean	18.258	14.342	31.100	32.175	42.698	76.343	47.064	84.561
Hybrids								
1 × 4	14.267	18.433	26.833	36.100	52.163	84.017	107.473	171.230
1 × 5	21.033	16.633	26.600	36.100	37.283	76.210	91.787	156.430
1 × 6	17.333	17.667	28.167	41.067	55.557	85.443	110.953	182.260
1 × 7	14.433	15.100	30.167	41.900	37.033	63.667	79.283	100.203
2 × 4	14.467	17.500	26.767	34.900	36.387	76.910	41.057	116.127
2 × 5	14.733	16.833	29.500	39.033	30.260	78.440	67.107	144.410
2 × 6	17.933	16.000	34.400	36.067	55.143	77.487	107.193	155.757
2 × 7	14.600	14.600	26.233	43.833	44.073	82.350	67.573	87.013
3 × 4	18.433	17.800	40.267	36.867	57.757	74.183	114.580	156.320
3 × 5	19.033	16.467	40.267	46.867	53.237	72.570	115.513	149.203
3 × 6	14.867	16.233	24.267	35.233	38.227	68.150	52.943	85.917
3 × 7	22.033	17.967	48.467	26.833	68.507	77.717	146.510	135.183
Mean	16.931	16.769	31.828	37.900	47.136	76.429	91.831	136.671
G. M.	17.054	16.193	31.630	36.281	46.400	75.098	76.322	123.869
LSD $_{0.05}$	0.668	0.661	1.248	2.288	2.111	2.186	3.642	6.875

[2] Combining Ability

Estimates of GCA effects for individual parent for each trait at spring and autumn sowing dates are presented in Table (3). Parent [1] showed desirable GCA effects for days to 50% tasseling and silking at spring sowing date and for flag leaf area and grain yield/plant at autumn sowing date. Parent [2] had desirable effects for plant height only at both sowing dates. Parent [3] had a desirable effect for flag leaf area, no. of row/ear, no. of grains/row, 300-grain weight and grain yield only at spring sowing date. Parent [5] showed desirable GCA effects for no. of row/ear at spring sowing date and for grain yield/plant at autumn sowing date. Parent [7] had desirable effects for no. of flag leaf area at both sowing dates for no. of grains/row at spring sowing date. Whereas, parents [4 and 6] didn't showed any desirable GCA effects in any characters.

The data regarding SCA effects presented in Table (4) showed that the hybrid [3×7] had a desirable SCA effects for the maximum number of characters (7 characters), (no. of days to 50% tasseling, no. of days to 50% silking, flag leaf area, no. of rows/ear, no. of grains/row, 300-grain weight and grain yield/plant) followed by [2×6] which showed a desirable SCA effects for six characters (no. of days to 50% tasseling, no. of days to 50% silking, flag leaf area, no. of rows/ear, no. of grains/row and grain yield/plant) and [1×6] for five characters (flag leaf area, plant height, no. of grains/row, 300-grain weight and grain yield/plant). Also hybrids [3×4] and [3×5] showed a desirable SCA effects for three characters (plant height, no. of grains/row and grain yield/plant) and (no. of days to 50% tasseling, flag leaf area and 300-grain weight), respectively at spring sowing date. While at autumn sowing date, the hybrids [1×6], [2×6] and [3×7] showed desirable SCA effects for three characters (plant height, 300-grain weight and grain yield/plant), (no. of days to silking, plant height and grain yield/plant) and (flag leaf area, 300-grain weight and grain yield/plant, respectively.

The comparison of values revealed that those parents which mentioned above can be further used as the source material in the development of segregating generation. While in case of hybrids the results of SCA effects revealed that the hybrids [3×7], [2×6] and [1×6] had a best specific combiner in desirable direction for most characters at both sowing dates. In contrast, the results indicated that most of the superior hybrids were get from two parents had desirable GCA or one of them at least had a desirable GCA effect, suggesting that involvement of one good general combiner appears to be essential to get the better specific combination. Moreover, the comparison between mean performance and GCA effects of the parents showed a close relationship between them and the desirable GCA effects of the parents were reflected in the desirable SCA effects of the hybrids in most of the studied characters. Therefore, hybrids with desirable SCA and per se performance could be selected to recover trans aggressive segregates. Other researchers also obtained parents which showed a desirable GCA and SCA effects of hybrids for different characters using different genotypes (Hefny, 2010, Amiruzzaman *et al.*, 2013, Aminu and Izge, 2013, Kambe *et al.*, 2013 and El-Badawy, 2013).

Table (3): Estimates of general combining ability effects of parents (males and females) for studied characters

	No. of days to 50% tasseling		No. of days to 50% silking		Flag leaf area (cm^2)		Plant height (cm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Females								
1	-2.556*	-0.444	-1.33*	-0.694	-23.29	25.45*	-3.361	-6.389
2	1.495	-0.528	1.333*	0.139	-38.7*	-43.9*	13.22*	18.19*
3	1.061	0.972	0.000	0.556	61.99*	18.456	-9.86*	-11.8*
Males								
4	0.145	0.111	0.000	0.056	17.936	9.856	-5.139	-2.778
5	-3.521*	-0.889	-2.1*	-0.7*	-42.7*	-31.1*	-0.028	-3.333
6	4.196*	1.778*	2.667*	1.833	-16.31	-21.43	3.639	1.111
7	-0.820	-1.00*	-0.556	-1.167	41.10*	42.71*	1.528	5.000
$SE(gi-gj)$	0.576	0.480	0.569	0.614	11.959	12.244	4.863	5.501

	No. of rows/ear		No. of grains/row		300-grain weight (g)		Grain yield/plant (g)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Females								
1	-0.164	0.189	-3.89*	0.892	-1.626	0.906	5.543	15.86*
2	-1.50*	-0.536	-2.60*	0.558	-5.67*	2.368	-21.1*	-10.84
3	1.661*	0.347	6.489*	-1.450	7.296*	-3.27*	15.55*	-5.015
Males								
4	-1.21*	1.142	-0.539	-1.944	1.633	1.941	-4.128	11.221
5	1.336*	-0.125	0.294	2.767	-6.88*	-0.689	-0.362	13.34*
6	-0.219	-0.136	-2.88*	-0.444	2.507	0.598	-1.468	4.640
7	0.092	-0.881	3.128*	-0.378	2.736	-1.851	5.958	-29.2*
$SE(gi-gj)$	0.600	0.598	0.813	1.870	1.798	1.435	3.150	5.889

Table (4): Estimates of specific combining ability effects of hybrids for studied characters

	No. of days to 50% tasseling		No. of days to 50% silking		Flag leaf area (cm^2)		Plant height (cm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1 × 4	-2.08*	0.556	-2.00*	0.361	14.548	90.69*	-23.2*	-9.722
1 × 5	0.028	1.556	-0.222	1.472	-43.0*	-30.26	1.361	-7.500
1 × 6	-0.417	-0.778	-1.000	-0.083	64.56*	-54.2*	16.36*	4.722
1 × 7	2.472*	-1.333	3.222*	-1.750	-36.1*	-6.236	5.472	12.500
2 × 4	-0.083	0.639	0.000	0.528	-12.74	0.969	6.222	-0.972
2 × 5	2.361*	2.306*	1.778*	2.972*	-28.06	35.192	0.111	-7.083

2 × 6	-2.42*	-1.028	-1.67*	-1.92*	99.20*	19.325	-9.222	20.14*
2 × 7	0.139	-1.92*	-0.111	-1.583	-58.4*	-55.5*	2.889	-12.08
3 × 4	2.167*	-1.194	2.000*	-0.889	-1.808	-91.7*	16.97*	10.694
3 × 5	-2.39*	-3.86*	-1.556	-4.4*	71.03*	-4.933	-1.472	14.583
3 × 6	2.833*	1.806*	2.667*	2.000*	-163*	34.867	-7.139	-24.9*
3 × 7	-2.6*	3.250*	-3.1*	3.333*	94.54*	61.72*	-8.361	-0.417
$SE(sij-sij')$	0.814	0.679	0.804	0.868	16.913	17.315	4.863	7.780

	No. of rows/ear		No. of grains/row		300-grain weight (g)		Grain yield/plant (g)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1 × 4	-1.292	0.333	-0.569	-0.747	5.021	4.741*	14.23*	7.478
1 × 5	2.931*	-0.200	-1.636	-5.458	-1.350	-0.436	-5.225	-9.444
1 × 6	0.786	0.844	3.108*	2.719	7.541*	7.511*	15.05*	25.09*
1 × 7	-2.43*	-0.978	-0.903	3.486	-11.2*	-11.8*	-24.1*	-23.1*
2 × 4	0.242	0.125	-1.919	-1.614	-6.71*	-3.828	-25.6*	-20.9*
2 × 5	-2.04*	0.725	-0.019	-2.192	-4.330	0.332	-3.264	5.240
2 × 6	2.719*	-0.097	8.058*	-1.947	11.17*	-1.908	37.93*	25.29*
2 × 7	-0.925	-0.753	-6.12*	5.753*	-0.128	5.404*	-9.117	-9.609
3 × 4	1.050	-0.458	2.489*	2.361	1.692	-0.913	11.32*	13.443
3 × 5	-0.894	-0.53	1.656	7.650*	5.681*	0.104	8.489	4.204
3 × 6	-3.51*	-0.747	-11.2*	-0.772	-18.7*	-5.6*	-53.0*	-50.4*
3 × 7	3.350*	1.731	7.022*	-9.24*	11.34*	6.413*	33.17*	32.7*
$SE(sij-sij')$	0.848	0.846	1.150	2.645	2.543	2.030	4.454	8.328

[3] Gene Action and Other Genetic Parameters

Estimates of additive (σ^2A), dominance (σ^2D), and environmental (σ^2E) variances for studied characters are illustrated in in Table (5). The results revealed that values of environment variance were significant for all characters, while values of additive and dominance genetic variance were not significant for all the studied characters at both sowing dates. The values of dominance genetic variance were greater than additive genetic variance for all studied characters at both sowing dates, which depicts the importance of dominant gene effect for controlling these characters. Such results were also reported by Kage *et al.* (2013) which supports our investigation.

Average degree of dominance (ā), heritability in broad sense ($h^2_{B.S.}$), narrow sense ($h^2_{N.S.}$) and expected genetic advance (GA %) from selection for studied characters were presented in Table (6). Average degree of dominance, was greater than unity for all of the characters at both sowing dates. These results indicated that these characters were affected by over-dominance effects of some genes controlling the characters under study which is reflected in the low narrow-sense heritability. Similar results were recorded by Shahrokhi *et al.,* (2013) whom also showed the importance of dominance relative to additive genetic effects in maize using generation mean analysis method. While, the values of heritability in broad sense ($h^2_{B.S.}$) were high for all characters at both sowing dates. The expected genetic advance as a percent of mean (EGA %) was high for grain yield/plant at both sowing dates and for no. of grains/row at spring sowing date only, while it is varied between low to moderate for other characters and between two sowing dates. In general, the values of genetic advance at spring sowing date are greater than the values at autumn sowing date for all studied characters.

Table (5): Estimates of additive (σ^2A), dominance (σ^2D), and environmental (σ^2E) variances for studied characters

	σ^2A		σ^2D		σ^2E	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
DT	4.939 ±4.881	2.298 ±2.322	7.720 ±7.886	7.505 ±7.621	0.497* ±0.144	0.346* ±0.100
DS	5.642 ±5.603	2.044 ±2.286	7.270 ±7.433	9.197 ±9.386	0.485* ±0.140	0.566* ±0.163
FLA (cm^2)	4266.958 ±4504.690	2530.768 ±2499.183	10351.389 ±10422.98	4967.896 ±5043.038	214.535* ±61.931	224.869* ±64.914
PH (cm)	152.228 ±201.155	261.808 ±362.009	224.201 ±230.140	297.755 ±313.008	17.740* ±5.121	45.391* ±13.103
NR/E	3.510 ±3.818	0.822 ±0.945	8.924 ±9.105	0.984 ±1.167	0.539* ±0.156	0.537* ±0.155
NG/R	37.956 ±45.908	4.510 ±7.416	50.084 ±50.415	38.959 ±42.970	0.991* ±0.286	5.247* ±8.258
300-GW (g)	64.305 ±67.792	10.647 ±12.589	150.391 ±152.010	55.585 ±56.618	4.850* ±1.400	3.090* ±0.892
GY/P (g)	374.306 ±508.126	579.824 ±569.745	1216.057 ±1221.010	1035.020 ±1052.406	14.879* ±4.295	52.016* ±15.016

DT= no. of days to 50% tasseling, DS= no. of days to 50% silking, FLA= flag leaf area, PH= plant height, NR/E= no. of rows/ear, NG/R= No. of grains/row, 300-GW= 300-grain weight and GY/P= grain yield/plant.

**= The σ^2A and σ^2D values were set to zero when estimated variance turned out to be a negative.

Table (6): Average degree of dominance ($\bar{a}$), heritability in broad sense ($h^2_{B.S.}$), narrow sense ($h^2_{N.S.}$) and expected genetic advance (GA %) from selection for studied characters

	$\bar{a}$		$h^2_{B.S.}$		$h^2_{N.S.}$		GA		GA %	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
DT	1.768	2.556	0.962	0.966	0.375	0.226	2.805	1.486	3.870	2.392
DS	1.605	3.000	0.964	0.952	0.421	0.173	3.176	1.225	4.234	1.887
FLA (cm^2)	2.203	1.981	0.986	0.971	0.288	0.952	72.173	59.321	18.412	7.581
PH (cm)	1.716	1.508	0.955	0.925	0.386	0.433	15.795	21.927	7.805	9.053
NR/E	2.255	1.547	0.958	0.771	0.271	0.351	2.007	1.106	11.856	6.595
NG/R	1.625	4.157	0.989	0.892	0.426	0.093	8.287	1.331	26.036	3.512
300-W(g)	2.163	3.231	0.978	0.955	0.293	0.154	8.940	2.634	18.967	3.447
GY/P (g)	2.549	1.889	0.991	0.969	0.233	0.348	19.245	29.256	20.957	21.406

DT= no. of days to 50% tasseling, DS= no. of days to 50% silking, FLA= flag leaf area, PH= plant height, NR/E= no. of rows/ear, NG/R= No. of grains/row, 300-GW= 300-grain weight and GY/P= grain yield/plant.

[4] Heterosis

The mid-parent heterosis values at spring and autumn sowing dates are presented in Table (7). The hybrids of negative significant heterosis values were no. of days to 50% tasseling and silking. Also, there were significant positive heterosis values for the other characters. The best hybrids at spring sowing date for days to 50% tasseling were [1×4] (-7.667); for no. of days to silking were also [1×4] (-8.333); for flag leaf area were [3×7] (235.417); for plant height were [4×2] (45.167); for no. of rows/ear were [1×5] (4.917); for no. of grains/row were [3×7] (11.900); for 300-grain weight [1×6] (15.578); for grain yield/plant were [3×7] (99.460). While the best hybrids at autumn sowing date were for no. days to 50% tasseling (-8.167) and no. of days to silking (-8.667); [3×7] (224.067) for flag leaf area; [2×6] (57.500) for plant height; [3×4] (4.017) for no. of rows/ear; [3×5] (15.667) for no. of grains/row were; [1×6] for 300-grain weight (15.292) and grain yield/plant (79.373). The results of heterosis revealed that maximum number of hybrids showed heterosis for grain yield/plant (11) and (9) hybrids at spring and autumn sowing dates, respectively (Table, 8). The high heterosis were exhibited by the following hybrid combinations [1×6, 2×6, 3×4, 3×5 and 3×7] for most studied characters at both sowing dates. Therefore, it can be concluded that the parents with desirable GCA may be extensively used in the hybridization program which had a good performance and produced hybrid combinations showing high desirable SCA effects and heterosis for most characters including grain yield/plant suggest the usefulness for developing maize by utilizing the potential of these hybrids and also need to be evaluated through different environments. Some researchers obtained high heterosis of yield and its components in maize (Uddin *et al.*, 2006, Abdel-Moneam *et al.*, 2009 and Amiruzzaman *et al.*, 2013)

Table (7): Mid – parent heterosis for studied characters

	No. of days to 50% tasseling		No. of days to 50% silking		Flag leaf area (cm^2)		Plant height (cm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1 × 4	-7.667*	-1.500*	-8.333*	-3.167*	31.442*	183.80*	5.333	-16.667*
1 × 5	-2.667*	-3.000*	-3.667*	-3.667*	-65.025*	-113.60*	35.500*	-25.833*
1 × 6	0.333	-1.167*	-0.167	-1.333*	102.27*	44.467*	40.833*	2.500
1 × 7	1.167*	-4.000*	1.500*	-5.333*	-2.450	128.82*	33.667*	10.000*
2 × 4	-3.500*	-2.333*	-3.667*	-2.833*	9.350	94.883*	45.167*	31.667*
2 × 5	1.833*	-3.167*	1.000	-2.000*	-44.917*	-47.350*	44.667*	14.167*
2 × 6	0.500	-2.333*	1.833*	-3.000*	142.11*	118.78*	25.667*	57.500*
2 × 7	1.000	-5.500*	0.833	-5.000*	-19.525	80.367*	41.500*	25.000*
3 × 4	-1.500*	-3.000*	-2.667*	-3.500*	122.28*	28.750*	17.000*	21.667*
3 × 5	-3.167*	-8.167*	-3.333*	-8.667*	156.16*	-60.983*	4.167	14.167*
3 × 6	5.500*	1.667*	5.167*	1.667*	-18.863	160.82*	-11.167*	-9.167
3 × 7	-2.000*	0.833	-3.167*	0.667	235.42*	224.07*	-8.667*	15.000*

(Cont.)

	No. of rows/ear		No. of grains/row		300-grain weight (g)		Grain yield/plant (g)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1 × 4	-3.600*	2.767*	1.233	1.917	11.997*	10.132*	57.620*	55.660*

1 × 5	4.917*	-0.617	-1.733*	2.100	0.125	2.023	55.028*	31.683*
1 × 6	1.933*	1.950*	-1.700*	10.400*	15.578*	15.292*	70.023*	79.373*
1 × 7	-3.167*	-1.283*	-1.233	3.733*	-13.787*	-12.755*	38.650*	-16.675*
2 × 4	-2.517*	2.667*	-1.233	-0.500	-5.818*	4.530*	-26.785*	1.797
2 × 5	-0.500	0.417	-1.233	3.817*	-8.937*	5.758*	12.360*	20.903*
2 × 6	3.417*	1.117*	2.133*	4.183*	13.127*	8.840*	48.275*	54.110*
2 × 7	-2.117*	-0.950	-7.567*	4.450*	-8.785*	7.433*	8.952*	-28.625*
3 × 4	-1.383*	4.017*	9.500*	5.483*	9.083*	3.093*	58.310*	70.120*
3 × 5	0.967	1.100*	6.767*	15.667*	7.572*	1.178	72.338*	53.827*
3 × 6	-2.483*	2.400*	-10.767*	7.367*	-10.258*	0.793	5.597*	12.400*
3 × 7	2.483*	3.467*	11.900*	-8.533*	9.180*	4.090*	99.460*	47.675*

Table (8): Number of hybrids showing significant heterosis levels with respective directions and ranges

Characters	Relative heterosis					
	Spring		Autumn		Range	
	Positive	Negative	Positive	Negative	Spring	Autumn
DT	3	6	1	10	[-7.667 – 5.5]	[-8.167 – 1.667]
DS	3	6	1	10	[-8.333 – 5.167]	[-8.667 – 1.667]
FLA	6	2	9	3	[-65.025 – 235.417]	[-113.60 224.07]
PH	8	2	8	2	[-11.167 –45.167]	-25.833 –57.500]
NR/E	4	6	8	1	[-3.600 – 4.917]	[-1.283 – 4.017]
NG/R	4	4	3	1	[-10.767– 11.900]	[-8.533– 15.667]
300-GW	6	5	8	1	[-13.787 – 15.578]	[-26.785 –99.46]
GY/P	11	1	9	2	[-26.785 – 99.460]	[-28.625 –79.37]

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