Mohamed Ali Abd El-Satar*

Genetic Analysis of Half Diallel Matting with Different Methods and their Comparisons for Yield and its Associated Traits in Sunflower under Saline Soil Stress Conditions

DOI 10.1515/helia-2017-0001
Published online March 14, 2017

Abstract: A half diallel cross between five divergent sunflower genotypes was evaluated under two contrast locations of Kafr El-Hamam (fovourable soil as a control) and Tag Al-Ezz (as salt affected soil) Agricultural Research Stations using randomized complete block design with three replications. High significance variation among genotypes and their components was detected for all studied traits at both and combined locations. Selection in early generations would be effective at both locations for improving days to 50 % flowering, days to physiological maturity, plant height, head diameter, No. of green leaves plant^{-1} and seed oil content, but the remaining studied traits took an opposite trend. The parent L_{125} behaved as the best combiner at both locations for seed weight plant^{-1} and one or more of its components. The cross $L_{460} \times L_{335}$ was found to be superior and exhibited highest specific combining ability effects and heterosis at both locations for seed weight plant^{-1} and one or more of its attributes. Gardner and Eberhart and Jones's analyses (modified Hayman analysis) gives the same information as Griffing's analysis method 2. Moreover, Hayman's analysis may be given more information over the others about genetic component, so recommended using any one of these three methods along with Hayman's analysis.

Keywords: gene action, half diallel analyses, heterosis, salinity, sunflower

Introduction

Sunflower is considered a medium salt tolerant crop and appears to be well adapted for growth under moderately saline soil conditions (Francois, 1996). To

***Corresponding author: Mohamed Ali Abd El-Satar,** Oil Crops Research Department, Field Crops Research Institute, Agricultural Research Center, 9 El-Gamaa St. Giza, Egypt,
E-mail: mohamedtemraz1@yahoo.com

be able to improve salt tolerance in sunflower, the breeder should first be able to create genetic variability with a high degree of salt tolerance. For this purpose, improving salt tolerance of sunflower depends on precise estimates of genetic control that have been derived from the plant material developed by crossing the selected parents according to any adequate statistical methods, specially diallel crossing system. Little information, however, is available about comparing and relative efficiency of half diallel analyses methods. Thus, several methods have been devised for analyzing half diallel data to estimate the genetic components in plant populations. One of the followed methods, Griffing method used the half diallel analysis for combining ability (Griffing, 1956), while Gardner and Eberhart (1966) using the set-up multiple regression approach, partitioning heterosis in terms of average, general and specific heterosis effects. Jones (1965) extended the analysis of variance of full diallel table to half diallel one. The general-known methods for diallel analysis are those developed by Hayman (1954a, 1954b) which include numerical and graphical analyses provides a picture of genetic behavior of the parents and the extent of the nature of heterosis. The lacking of information with the contradicting results on the use of these genetically statistic methods necessitate to carry out the present study to obtain detailed genetical information about yield and the relevant traits to formulate effective breeding and/or selection program to improve sunflower yield under saline soil stress. The objectives of this study were (1) to estimate the relative importance of general and specific combining abilities and estimate the type of gene action and genetic parameters controlling yield and the relevant traits, (2) to find out good *per se* performances of parent and crosses with high combining ability, (3) to determine the amount of heterosis and (4) to identify relative efficiency of half diallel analysis methods.

Materials and methods

Methodology

Five widely genetic divergent inbred lines of sunflower (*Helianthus annuus* L.) designated as L_{460} (P_1), L_{770} (P_2), L_{125} (P_3), L_{335} (P_4) and $Sakha_{53}$ (P_5) were received from Oil crops Research Department, FCRI, ARC, Egypt for crossing in 2013 summer season at Kafr El Hamam Agricultural Research Station to produce a 5×5 half diallel cross. In 2014 summer season, the derived 10 F_1 crosses and their five parental genotypes were sown in a randomized complete block design with three replicates at two locations, that differed in their soil salinity degrees, *i. e*, Kafr El Hamam Agricultural Research Station, Ash-Sharqiya Governorate (favourable soil as a

Table 1: Main soil properties in 2014 summer season for the two experimental sites.

Site	Soil texture	pH	Organic matter ($g\ kg^{-1}$)	EC ($ds\ m^{-1}$)	Salt concentration in soil ($mg\ kg^{-1}$)
Kafr El Hamam	Sand silty loam	7.9	1.85	1.93	1235.2
Tag Al Ezz	Clay	7.7	1.32	5.3	3392.0

control) and Tag Al Ezz Agricultural Research Station, Ad-Daqahliya Governorate (as a salt affected soil). The experimental plot consisted of two ridges, 5 m long and 60 cm width with 30 cm between plants. The seedlings were thinned to one plant per hill on one side of the ridge. Soil samples of each site were analyzed and the main properties were illustrated in Table 1. The cultural practices were followed as recommended by Oil Crops Research Department, Field Crops Res. Inst., ARC, Egypt. Ten competitive plants were randomly taken from each plot to measure plant height (cm), number of green leaves plant^{-1}, head diameter (cm), 100-seed weight (g) and seed weight plant^{-1} (g) which was adjusted at 15.5 % seed moisture. Seed oil content was determined, after drying at 70 °C for 48 h, by Soxhlet extraction technique, using diethyl ether (AOAC, 1990). Days to 50 % flowering and days to physiological maturity were determined on all plants in plot mean.

Statistical analysis

A separate and combined analysis of variance was performed for each location and combined data as outlined by Steel *et al* (1997), when the homogeneity test was insignificant. The statistical genetic analyses were performed using several genetic methods to compare among half diallel analyses approaches as following: General and specific combining abilities were computed as Griffing's approach (1956), method 2, model 1. The combining ability ratio was calculated according to Baker (1978). Modified Hayman analysis of variance (ANOVA) was computed according to Hayman (1954a) following Jones (1965) modification. Variance/covariance (Vr/Wr) graphs of each trait were prepared according to Jinks (1954) to determine the frequency of dominant and recessive alleles in the parental sunflower genotypes at the two locations whereas, genetic components along with related genetic parameters were estimated according to Hayman (1954b). The covariance matrix of Hayman (1954b) was used to provide estimates of the standard error for the genetic parameters D, H_1, H_2 and F, where the variance ratio F was used to test the statistical equality *i. e* homogeneity of variances for additive, non additive types of gene action and M.S. error. These parameters provided the estimation of the following ratios:

1. $(H_1/D)^{1/2}$ = measure the average degree of dominance over all loci .
2. $(H_2/4H_1)$ = measure the mean value of the product u and v which are the frequencies of positive (u) and negative (v) alleles in the parents. It has a maximum value of 0.25 when p = q = 1/2 .
3. (K_D/K_R): it refers to the ratio of the total number of dominant to recessive genes in all the parents.

Types of heterosis: two types of heterosis [relative heterosis (MP) and heterobeltiosis (BP)] were estimated and expressed as percentages (Mather and Jinkes, 1971). Relative heterosis and heterobeltiosis were estimated as the deviation of F_1 mean over the mid-parents (MP) and better parent (BP) in each cross, respectively for the two locations as follow:

a. Mid-parent heterosis (MP) = $[(F_1\text{-MP})/\text{MP}]$ x100 (relative heterosis)
b. Better parent heterosis (BP) = $[(F_1\text{- BP})/\text{BP}]$ x100 (heterobeltiosis)

Heterosis components *i. e* average heterosis, variety heterosis and specific heterosis were estimated according to Gardner and Eberhart (1966)'s analysis. Relative potence of gene set was used to determine the direction of dominance according to Petr and Frey (1966). All statistical analyses were carried out using MS-EXCEL (2007) with spreadsheet formula commands.

Results and discussion

Analysis of variance

Separate analysis of variance

The separate and combined analyses of variances for all studied traits, as shown in Tables 2 and 3, showed highly significant differences among genotypes, parents, crosses and parents *vs* crosses, indicating existence of adequate magnitude of genetic diversity among aforementioned materials which allows to improve these traits. Similar results were reported by Alza and Fernandez-Martinez (1997), Abd El-Satar *et al.* (2015) and Pourmohammad *et al.* (2016).

Locality effects

Moreover, highly significant location mean squares and their interaction with genotypes, parents, hybrids and parents *vs.* crosses were detected for all studied

Table 2: Analysis of variance for all studied traits of each location separately at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.

S.O.V	d.f.	Days to 50 %flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
		K	T	K	T	K	T	K	T
Genotypes	14	37.28**	40.15**	158.26**	154.91**	481.93**	473.37**	54.10**	53.07**
Parents (P)	4	79.77**	82.23**	290.27**	290.73**	942.69**	844.06**	55.77**	53.67**
Crosses (C)	9	18.09**	18.97**	79.37**	71.76**	274.59**	295.45**	16.67**	19.28**
P x C	1	40.00**	62.50**	340.28**	360.00**	505.05**	591.87**	384.40**	354.82**
Error	28	1.09	0.75	1.09	1.78	10.08	11.70	1.11	1.43
S.O.V	**d.f.**	**Head diameter**		**100-seed weight**		**Seed weight Plant^{-1}**		**Seed oil content**	
		K	T	K	T	K	T	K	T
Genotypes	14	51.50**	35.42**	2.08**	1.09**	66.46**	59.55**	18.84**	22.50**
Parents (P)	4	35.42**	29.49**	1.17**	0.73**	28.76**	24.38**	17.97**	21.85**
Crosses (C)	9	22.21**	25.49**	1.11**	0.63**	18.57**	17.23**	16.73**	18.51**
P x C	1	379.46**	148.48**	14.48**	6.72**	648.24**	581.10**	41.34**	61.01**
Error	28	0.33	0.52	0.03	0.04	1.29	2.37	0.45	0.52

Note: ** significant at 0.01 level of probability.

Table 3: Combined analysis of variance for all studied traits at the two locations in summer season 2014.

S.O.V	d.f	Days to 50 % flowering	Days to physiological maturity	Plant height	No. of green leaves plant^{-1}
Location (L)	1	1166.40**	528.04**	2791.13**	237.49**
Genotypes (G)	14	19.19**	78.21**	237.00**	26.72**
Parents (P)	4	40.20**	145.14**	445.91**	27.30**
Crosses (C)	9	9.18**	37.71**	140.06**	8.90**
G × L	14	58.24**	234.96**	718.30**	80.45**
P × L	4	121.80**	435.86**	1340.83**	82.13**
C × L	9	27.88**	113.42**	429.97**	27.04**
P × C	1	25.31**	175.03**	273.80**	184.73**
P × C × L	1	77.19**	525.24**	823.12**	554.49**
Error	56	0.92	1.44	10.89	1.27
S.O.V.	**d.f**	**Head diameter**	**100-seed weight**	**Seed weight plant^{-1}**	**Seed oil content**
Location (L)	1	853.16**	143.01**	871.298**	61.64**
Genotypes (G)	14	20.93**	0.74**	31.261**	10.27**
Parents (P)	4	16.06**	0.44**	13.067**	9.88**
Crosses (C)	9	11.49**	0.38**	8.698**	8.77**
G × L	14	65.99**	2.44**	94.743**	31.07**
P × L	4	48.85**	1.45**	40.081**	29.94**
C × L	9	36.21**	1.36**	27.094**	26.48**
P × C	1	125.33**	5.12**	307.106**	25.35**
P × C × L	1	402.60**	16.08**	922.235**	77.00**
Error	56	0.42	0.03	1.83	0.48

Note: ** significant at 0.01 level of probability.

traits (Table 3), indicating that location had sufficient environmental variability resulted in fluctuations in all population components ranking, i. e., deferential responses of different genotypes and ranked differently from location to another.

Genetic studies

Analysis of variance for combining ability as Griffing (1956)'s approach was performed for all studied traits in the F_1 separately (Table 4) and combined data (Table 5) for both locations. It is well known that general combining ability (GCA) is a function of additive gene effects and the additive portions of epistatic

Table 4: Half diallel's analyses with Griffing method 2 model 1(1956), Gardner and Eberhart (1966) and Jones (1965) modification for studied traits at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.

S.O.V			d.f.	Days to 50 % flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
				K	T	K	T	K	T	K	T
GCA	V_i	a	4	23.64**	25.33**	130.24**	126.30**	363.63**	308.46**	24.03**	25.96**
SCA	h_{ij}	b	10	7.94**	8.61**	21.76**	21.77**	79.45**	97.52**	15.64**	14.38**
P x C	h\	b_1	1	13.33**	20.83**	113.43**	120.00**	168.35**	197.29**	128.13**	118.27**
	h_j	b_2	4	9.03**	10.33**	9.49**	9.97**	37.97**	40.92**	4.14**	3.98**
	$S_{ij\backslash}$	b_3	5	5.99**	4.78**	13.24**	11.57**	94.86**	122.84**	2.34**	1.92**
Error			28	0.36	0.25	0.36	0.59	3.36	3.90	0.37	0.48
Baker ratio				0.86	0.85	0.92	0.92	0.90	0.86	0.75	0.78
S.O.V			**d.f.**	**Head diameter**		**100- seed weight**		**Seed weightPlant^{-1}**		**Seed oil content**	
				K	T	K	T	K	T	K	T
GCA	V_i	a	4	21.93**	22.45**	0.51**	0.44**	6.46**	7.59**	11.08**	13.19**
SCA	h_{ij}	b	10	15.26**	7.55**	0.77**	0.33**	28.43**	24.75**	4.36**	5.23**
P x C	h\	b1	1	126.49**	49.49**	4.83**	2.24**	216.08**	193.70**	13.78**	20.34**
	h_j	b2	4	1.78**	1.61**	0.19**	0.12**	5.38**	2.07**	3.00**	2.95**
	$S_{ij\backslash}$	b3	5	3.80**	3.91**	0.42**	0.12**	9.34**	9.11**	3.57**	4.03**
Error			28	0.11	0.17	0.01	0.01	0.43	0.79	0.15	0.17
Baker ratio				0.74	0.86	0.57	0.73	0.31	0.38	0.84	0.83

Note: "GCA and SCA of Griffing (1956)"; "h_{ij}, V_i, h\, h_j, and $S_{ij\backslash}$of Gardner and Eberhart (1966)'s analysis" and "a, b, b_1, b_2 and b_3 of Jones (1965) modification", P (parents) and C (Crosses), ** significant at 0.01 level of probability.

Table 5: Half diallel's analyses with Griffing method 2 model 1(1956), Gardner and Eberhart (1966) and Jones (1965) modification for studied traits in the F_1 combined analysis across locations in summer season 2014.

S.O.V.			d.f	Days to 50 % flowering	Days to physiological maturity	Plant height	No. of green leaves plant^{-1}
GCA	Varieties (V_i)	a	4	48.89**	256.43**	670.70**	49.95**
SCA	Heterosis (h_{ij})	b	10	16.27**	43.42**	174.12**	29.90**
Average heterosis ($h^{\backslash}$)		b_1	1	33.75**	233.38**	365.07**	246.31**
Variety heterosis (h_j)		b_2	4	18.87**	19.36**	76.26**	7.99**
Specific heterosis ($S_{ij\backslash}$)		b_3	5	10.69**	24.68**	214.23**	4.14**
GCA × L	$V_i \times L$	a × L	4	0.08	0.11	1.39	0.04
SCA × L	$h_{ij} \times L$	b × L	10	0.28	0.11	2.85	0.12
$h^{\backslash} \times L$		$b_1 \times L$	1	0.42	0.05	0.57	0.10
$h_j \times L$		$b_2 \times L$	4	0.50	0.10	2.63	0.13
$S_{ij\backslash} \times L$		$b_3 \times L$	5	0.07	0.13	3.48	0.11
Error			56	0.31	0.48	3.63	0.42
S.O.V.			**d.f**	**Head diameter**	**100-seed weight**	**Seed weight plant^{-1}**	**Seed oil content**
GCA	Varieties(V_i)	a	4	43.70**	0.94**	14.01**	24.16**
SCA	Heterosis(h_{ij})	b	10	21.58**	1.00**	52.75**	9.51**
Average heterosis ($h^{\backslash}$)		b_1	1	167.11**	6.82**	409.47**	33.80**
Variety heterosis (h_j)		b_2	4	2.73**	0.26**	6.82**	5.91**
Specific heterosis ($S_{ij\backslash}$)		b_3	5	7.55**	0.43**	18.15**	7.53**
GCA × L	$V_i \times L$	a × L	4	0.68**	0.01	0.04	0.10
SCA × L	$h_{ij} \times L$	b × L	10	1.23**	0.10**	0.43	0.08
$h^{\backslash} \times L$		$b_1 \times L$	1	8.87**	0.25**	0.31	0.32
$h_j \times L$		$b_2 \times L$	4	0.65**	0.05**	0.62	0.04
$S_{ij\backslash} \times L$		$b_3 \times L$	5	0.16	0.12**	0.30	0.07
Error			56	0.14	0.01	0.61	0.16

Note: L: Location; "GCA and SCA of Griffing (1956)"; "a, b, b_1, b_2 and b_3 of Jones (1965) modification" and "h_{ij}, V_i, $h^{\backslash}$, h_j, and $S_{ij\backslash}$of Gardner and Eberhart (1966)'s analysis"; ** significant at 0.01 level of probability variance, while specific combining ability (SCA) is a function due to non-additive gene effects and the remainder of epistatic variance (Matzinger *et al.*, 1959). Results as shown in Table 4 showed highly significant mean squares for both GCA and SCA in all studied traits, revealing the important role of both additive and non-additive gene effects in the expression of these traits. However, a greater ratio of GCA/SCA than unity was detected for all studied traits except 100-seed weight and seed weight plant^{-1}, revealing that the inheritance of most studied traits mainly was controlled by additive and additive x additive gene effects. However, although additive gene effects made the greatest contribution to variability of the majority of traits, the role of dominance and overdominance in the genetic system of control of yield components was also considerable. To compare among half diallel analyses methods, the analysis of data were conducted using Gardner and Eberhart (1966) and Jones (1965) (modified Hayman analysis) alongside Griffing (1956) method 2 model 1 as shown in Table 4 as well as genetic components of Hayman (1954b) (Table 6) and graphical analysis of Jinks (1954) (Figures 1(a)–8(b)).

Both general and specific combining abilities as well as error variance of Griffing (1956)'s analysis were identical with those of varieties, heterosis and error variance in Gardner and Eberhart (1966)'s analysis and additive effect (a), dominance effect (b) and error variance in Jones (1965)'s analysis (modified Hayman analysis) (Table 4). While, the Hayman (1954b) genetic components analysis slightly differed from the previous analyses for additive (D), dominance (H_1) and environmental error (E) in the most traits at both locations (Table 6). Furthermore, as shown in Tables 4 and 5, three heterosis components *i. e.* average, variety and specific heterosis as Gardner and Eberhart (1966)'s analysis were numerically identical with those of b_1, b_2 and b_3 in Jones (1965)'s analysis (modified Hayman analysis) for all studied traits at both and combined locations. Again, the interactions of locations with both types of combining abilities for Griffing method-2 were numerically identical and highly significant with those of (a and b) of (Jones, 1965) and (varieties and heterosis) of (Gardner and Eberhart, 1966) for all tested traits (Table 5), reflecting the highly significant environment effect on both types of gene action either additive or non additive ones. Highly significant mean square due to interaction of b_l (Jones, 1965) and average heterosis components (Gardner and Eberhart, 1966) with location were only detected for head diameter and 100-seed weight, indicating that mean deviation of the F_1's from their mid parental values for two traits was probably affected by variations between soil types and climate conditions at each location. However, the other traits showed insignificant interaction mean squares of location with b_l (Jones, 1965) and average heterosis (Gardner and Eberhart, 1966), indicating that these components were stable across two

Table 6: Components of the genetic variance (Hayman, 1954b**) for all studied traits at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.**

Parameter	Days to 50 % flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
	K	T	K	T	K	T	K	T
E	0.37	0.25	0.38	0.60	3.20	3.74	0.35	0.48
D	26.22**	27.16**	96.38**	96.31**	311.03**	277.61**	18.24**	17.41**
F	23.29**	24.01**	36.50	39.90*	167.95	167.19	8.87	6.09
H_1	31.91**	34.16**	71.32**	69.93**	296.21**	363.52**	42.63**	38.79**
H_2	24.55**	25.63**	63.57**	61.91**	266.24**	331.39**	39.37**	35.73**
h^2	10.00*	15.84**	86.87**	91.78**	127.24*	149.13*	98.18**	90.53**
$(H1/D)^{0.5}$	1.10	1.12	0.86	0.85	0.98	1.14	1.53	1.49
$H_2/4H_1$	0.19	0.19	0.22	0.22	0.22	0.23	0.23	0.23
K_D/K_R	2.35	2.30	1.56	1.64	1.77	1.71	1.38	1.27
h^2/H_2	0.41	0.62	1.37	1.48	0.48	0.45	2.49	2.53
h^2 (n.s)	0.44	0.47	0.68	0.67	0.55	0.45	0.38	0.43
t^2	0.91	0.36	0.06	0.002	2.57	0.23	1.19	1.34
Parameter	**Head diameter**		**100-seed weight**		**Seed weight Plant^{-1}**		**Seed oil content**	
	K	T	K	T	K	T	K	T
E	0.11	0.22	0.01	0.01	0.44	0.81	0.15	0.17
D	11.70**	9.61**	0.38*	0.23*	9.15*	7.32	5.84*	7.11**
F	−0.08	−3.49	0.24	0.04	10.95	5.58	1.15	1.21
H_1	41.16**	22.29**	2.35**	0.98	79.94**	66.67**	15.95*	18.27**
H_2	39.73**	21.07**	2.19**	0.89**	75.68**	65.42**	13.51*	15.90*
h^2	97.07**	37.87**	3.70**	1.71**	165.67**	148.25**	10.49*	15.51**
$(H1/D)^{0.5}$	1.88	1.52	2.49	2.06	2.96	3.02	1.65	1.60
$H_2/4H_1$	0.24	0.24	0.23	0.23	0.24	0.25	0.21	0.22
K_D/K_R	1.00	0.79	1.30	1.08	1.51	1.29	1.13	1.11
h^2/H_2	2.44	1.80	1.69	1.93	2.19	2.27	0.78	0.98
h^2 (n.s)	0.40	0.57	0.21	0.37	0.06	0.08	0.50	0.50
t^2	0.57	0.03	0.75	0.81	0.23	1.13	0.77	1.02

Note: *and ** significant at 0.05 and 0.01 levels of probability, respectively.

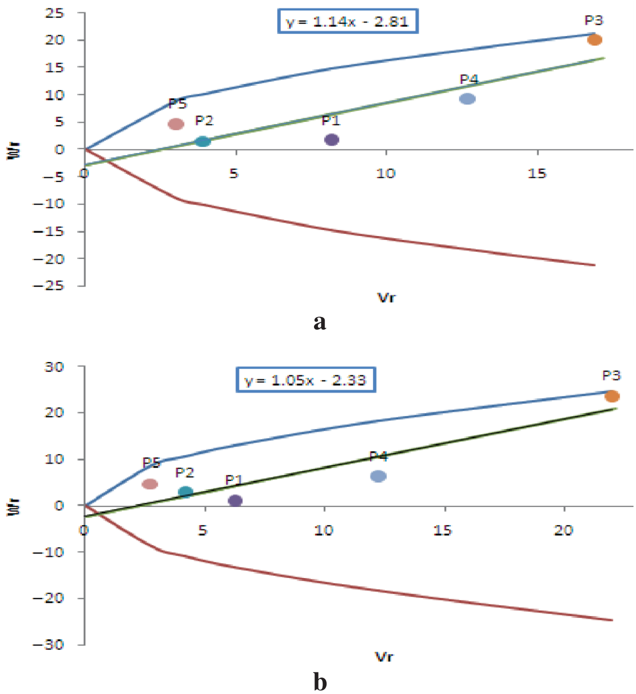
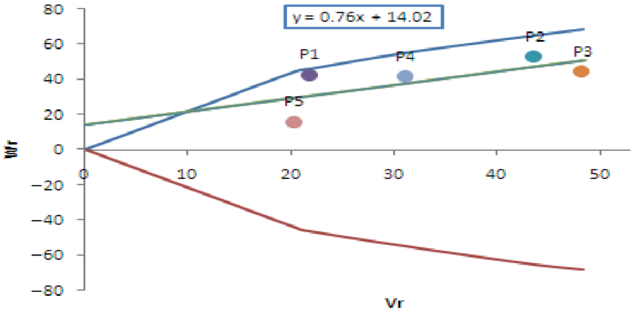


Figure 1: Wr/Vr graphs for days to 50 %flowering (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

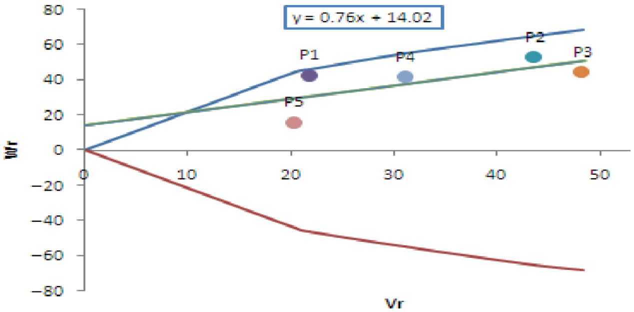
locations. Also, insignificant mean squares of interaction of b_2 (Jones, 1965) and variety heterosis (Gardner and Eberhart, 1966) with location were detected for all traits except, head diameter and 100-seed weight, revealing that b_2 and variety heterosis components were stable across two locations. Insignificant mean squares of interaction of b_3 (Jones, 1965) and specific heterosis (Gardner and Eberhart, 1966) with location were detected for all traits except 100-seed weight, indicating that b_3 and specific heterosis components were stable across two locations.

Genetic components and derived parameters

The data were further subjected to the diallel analysis proposed by Hayman (1954b) to separate out the components of genetic variance and their ratios for all studied traits. Data of Table 6 indicated that the additive genetic component



a



b

Figure 2: Wr/Vr graphs for days to physiological maturity (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

(D) at both locations were positive and significant or highly significant for all studied traits except seed weight plant^{-1} at Tag Al-Ezz. Meantime, significant or highly significant values of dominance (H_1 and H_2) were detected at both locations for all studied traits, indicating importance of both additive and non-additive components in the inheritance of these traits. The magnitude of dominance (H_1& H_2) was significant or highly significant higher than additive components (D) for most traits indicating the presence of over-dominance for these traits. Value of H_1 was greater than H_2 for all traits indicating that frequency of gene distribution in the parents was unequal, and that was also supported by the ratio of $H_2/4H_1$ (<0.25) which showing asymmetrical gene distribution at the loci in the parents showing dominance for all the traits. The F value was positive for all traits except head diameter at both locations, indicating that the presence of higher number of dominant than recessives genes and it was confirmed by the high value of K_D/K_R for all traits except the above trait, which had negative

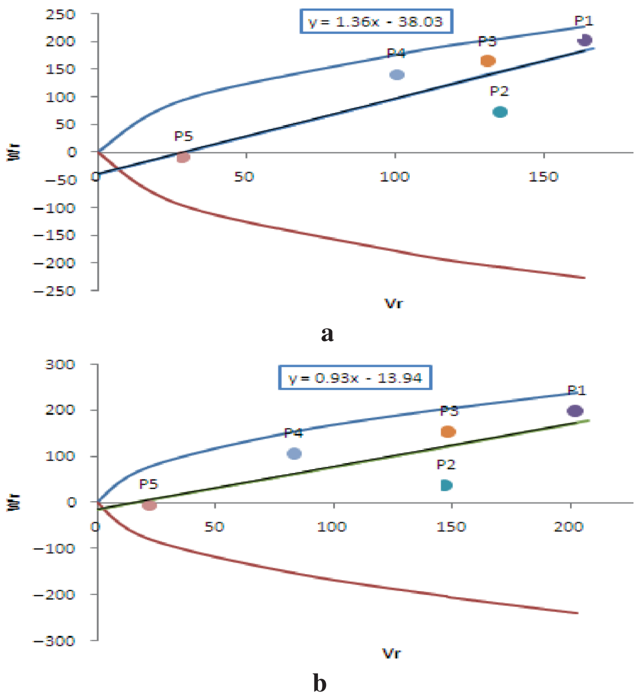


Figure 3: Wr/Vr graphs for plant height (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

value indicated presence of higher number of recessive than dominants genes. The overall dominance effects of heterozygous loci (h^2) were found to be positive and significant or highly significant for all studied traits at both locations, indicating that most of the dominant genes had positive effects. The h^2/H_2 values were less than unity for all studied traits except days to physiological maturity, No. of green leaves plant^{-1}, head diameter, 100-seed weight and seed weight plant^{-1} at both locations implied to be governed by one gene. The non-significance of t^2 test validated the use of simple additive dominance model for genetic analysis of all studied traits at both locations. Significant additive and non-additive components of genetic variance illustrated the involvement of both additive and non-additive genetic effects for all studied traits. However, backer ratio of Griffing analysis (1956), varieties/heterosis ratio of Gardner and Eberhart (1966) and a/b of Jones (1965) revealed that the inheritance of all studied traits except 100-seed weight and seed weight plant^{-1} at Kafr El-Hamam and both locations, respectively were largely controlled by additive gene effects (fixable),

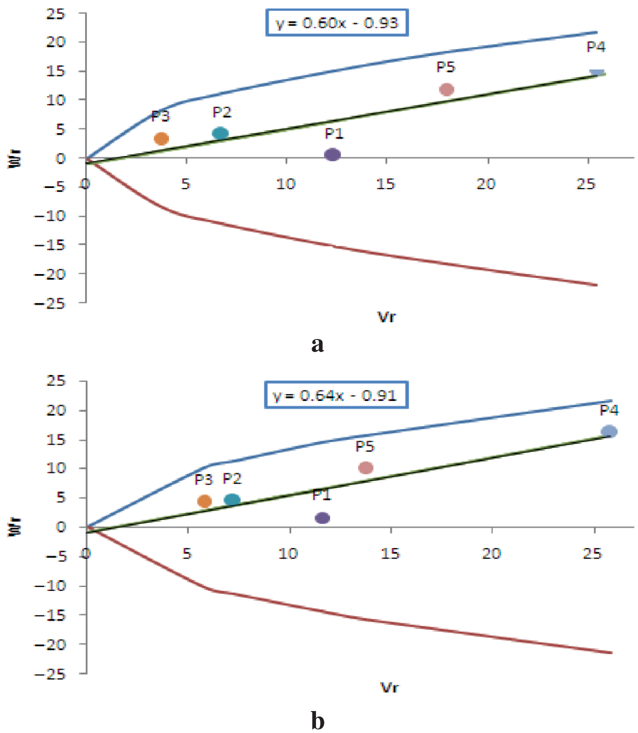
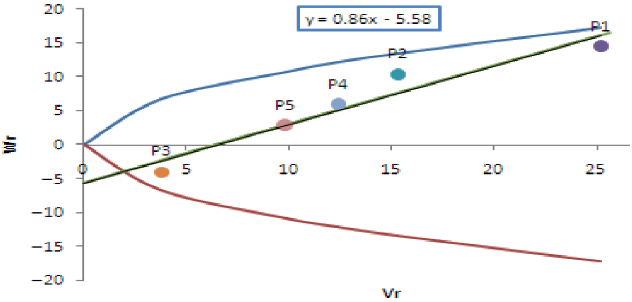


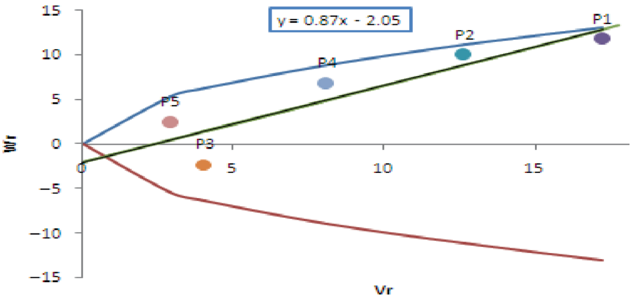
Figure 4: Wr/Vr graphs for No. of green leaves plant$_{-1}$ (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

although dominance gene effects (non-fixable) was also involved, so the genetic gain is achievable through selection in early segregating generations for these traits (Tables 4 and 5).

The average degree of dominance overall loci, as estimated by $(H_1/D)^{1/2}$ ratio was found to be more than unity for all traits except days to physiological maturity at both locations and plant height at Kafr El-Hamam, indicating the role of over dominance gene effects in the inheritance of most studied traits. On the opposite, days to physiological maturity at both locations and plant height at Kafr El-Hamam which have $(H_1/D)^{1/2}$ ratio less than unity indicate the presence of partial dominance in the control of the traits. Also, this confirmed by estimating of narrow sense heritability, which recorded high values at both locations for days to physiological maturity (0.68 at Kafr El-Hamam and 0.67 at Tag Al-Ezz), plant height (0.55 at Kafr El-Hamam), head diameter (0.57 at Tag Al-Ezz), and medium for days to 50 %



a



b

Figure 5: Wr/Vr graphs for head diameter (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

flowering (0.44 at Kafr El-Hamam and 0.47 at Tag Al-Ezz), plant height (0.45 at Tag Al-Ezz), No. of green leaves plant^{-1} (0.38 at Kafr El-Hamam and 0.43 at Tag Al-Ezz), head diameter (0.40 at Kafr El-Hamam) and seed oil content (0.50 at Kafr El-Hamam and 0.50 at Tag Al-Ezz). On the other hand, each of 100-seed weight (0.21 at Kafr El-Hamam and 0.37 at Tag Al-Ezz) and seed weight plant^{-1} (0.06 at Kafr El-Hamam and 0.08 at Tag Al-Ezz) showed low narrow sense heritability, indicating predominance of non-addetive gen effects in the inheritance of both traits.

Graphical analysis

A great deal about the genetical situation and adequacy of the additive/dominance model of gene action can be obtained from the graphically variance/covariance analysis as drawn in (Figures 1(a)–8(b)). The array points of parental genotypes were widely scattered for all traits, indicating presence of genetic diversity among the tested parents.

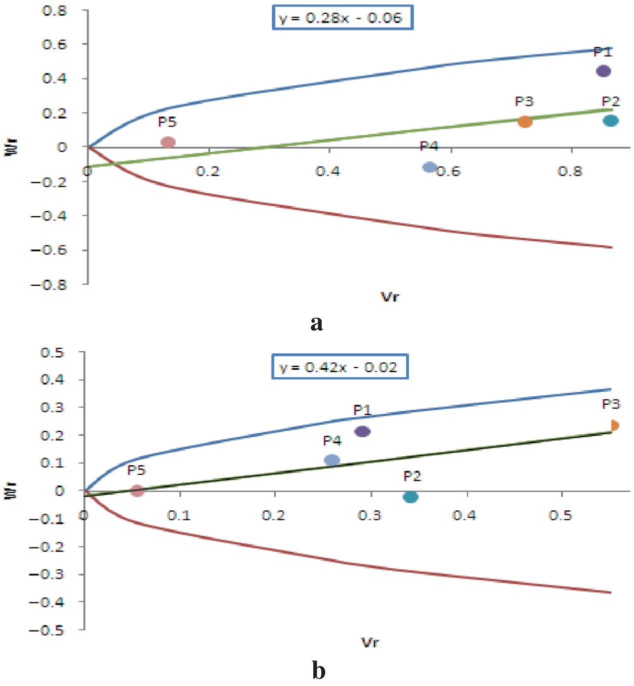
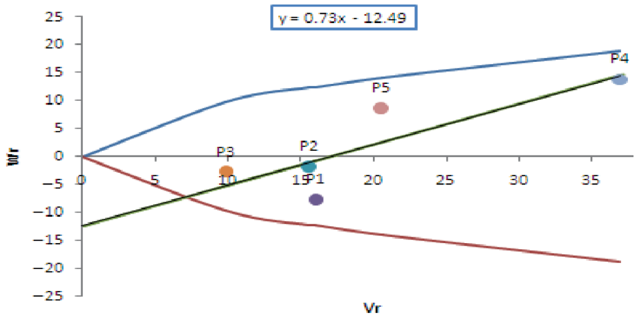


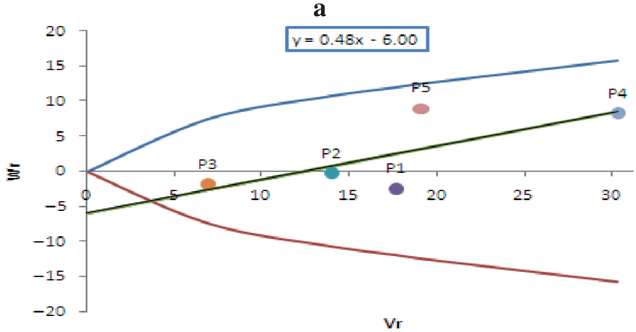
Figure 6: Wr/Vr graphs for 100- seed weight (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

Average degree of dominance

One of the information point may be obtained from the graph, is a measure of the average level of dominance by the departure from the origin of the point where the regression line cuts the Wr axis. In view of this point, the intercept of regression line on the covariance axis (Figures 1, 3, 4, 5, 6 and 7 in both locations) being below the origin in days to 50 % flowering, plant height, No. of green leaves plant^{-1}, head diameter, 100-seed weight and seed weight plant^{-1} at both locations, as well as seed oil content at Tag Al- Ezz (Figure 8 (b)), indicating some expression of over- dominance of factors for these traits. However, the regression line cut the Wr axis above the point of origin in days to physiological maturity (Figure 2 (a) and (b)) and seed oil content at only Kafr El-Hamam location (Figure 8 (a)) shows a clear cut case of partial dominance.



a



b

Figure 7: Wr/Vr graphs for seed weight plant$_{-1}$ (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

Distribution of dominant and recessive genes among the parents

The order of the array points along the regression line throws light upon the distribution of dominant and recessive genes among the parents. The parents with most dominant genes have their points nearest to the origin, while the parents with most recessive genes fall furtherest from origin. It is clearly noticed that, in Figures 1, 2, 3, 5 and 6, the parent 5 (Sakha$_{53}$) falls near the point of origin, in dyas to 50 % flowering, days to physiological maturity, plant height, head diameter and 100-seed weight, as well as in Figures 1 (a) and (b), 4 (a) and 7 (a), the parent 2 (L_{770}) also falls near the point of origin, in dyas to 50 % flowering, No. of green leaves plant^{-1} and seed weight plant^{-1}, revealing concentration of dominant genes in both parents 2 & 5 for the above corresponding traits in both locations. On the contrary, the same parent (P_2) falls furtherest from origin in head diameter (Figure 5 (a) and (b)), 100-seed weight (Figure 6 (a)) and days to

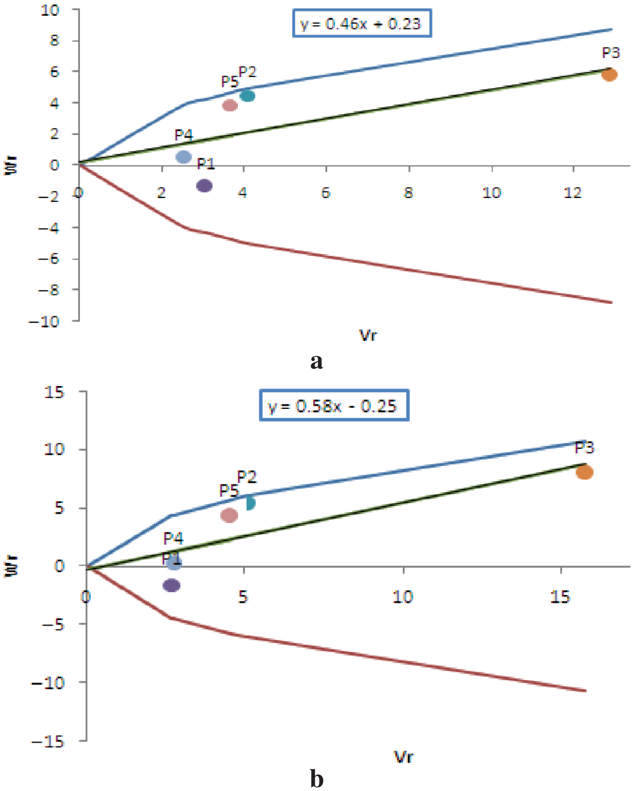


Figure 8: Wr/Vr graphs for seed oil content (a) at Kafr El-Hamam (2014) and (b) at Tag Al-Ezz (2014).

physiological maturity (Figure 2 (a)), and thus apparently had maximum number of recessive genes for these latter traits in corresponding location.

Superior parents with good performance and general combining ability (GCA)

Estimates of GCA effects of individual parental genotypes in the F_1 generation were found to be significant or highly significant for most studied traits. High positive values of GCA effects would be of interest for all investigated traits with exception of days to 50 % flowering, days to physiological maturity and plant height where the reverse situation is desirable i. e., high negative values would be useful from the breeder's point of view. In this regard, P_4 behaved as the best general combiner for early flowering, physiological maturity and plant height as indicated by its highest negative GCA effect and shortest flowering and physiological maturity time as well as dwarf parent (Table 7 and 8), revealing that this parent possessed more decreasing alleles towards earliness and dwarfness. The superior parents with valuable positive GCA effects and hence good performance were P_3 for No. of green leaves plant^{-1}, head diameter and seed weight plant^{-1} at both locations, P_3 and P_2 for 100-seed weight, P_5 and P_4 for seed oil content at Kafr El-Hamam and Tag Al-Ezz, respectively. In this regard, Khan *et al.* (2008) reported that genotypes with high positive GCA estimates for seed weight plant^{-1} are good candidates to be used as parents in a population improvement program.

Superior hybrids with good performance and specific combing ability (SCA)

It is worthy to appear as shown in Tables 7 and 9 that some correspondence between performance and SCA effects for the most traits at both locations. Concerning the performance of all genotypes (Table 7), the data show that the earliest cross combinations were $P_1 \times P_5$ for days to 50 % flowering at both locations and $P_4 \times P_5$ and $P_2 \times P_4$ for days to physiological maturity at Kafr El-Hamam and Tag Al-Ezz research stations, respectively. The shortest hybrid was $P_1 \times P_4$ at both contrasting locations. The best cross combinations at both locations were $P_1 \times P_3$ for No. of green leaves plant^{-1}, $P_2 \times P_3$ for head diameter, 100-seed weight and seed weight plant^{-1}, $P_1 \times P_4$ for seed oil content. The specific combining ability effects of hybrids are presented in Table 9. The earliest crosses due to SCA effects at both locations were $P_3 \times P_4$ for days to 50 % flowering and $P_2 \times P_4$ for days to physiological maturity. These results are in line with the finding of Ashok *et al.* (2000), Abd El-Satar *et al.* (2015) and Pourmohammad *et al.* (2016), who found significant and negative SCA effects for physiological maturity in sunflower hybrids. However, the shortest crosses were $P_2 \times P_5$ for plant height. The valuable positive SCA effects were detected at both locations in $P_1 \times P_4$ for No. of green leaves plant^{-1} and seed weight plant^{-1}, $P_1 \times P_3$ for head diameter and seed oil content. These results are in line with the findings of Bajaj *et al.* (1997), Naik *et al.* (1999), Abd El-Satar *et al.* (2015) and Pourmohammad *et al.* (2016).

Table 7: Mean performance for all studied traits of five parental sunflower genotypes and their F_1 hybrids at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.

Genotype	Days to 50 % flowering (day)		Days to physiological maturity (day)		Plant height (cm)		No. of green leaves plant^{-1}	
	K	T	K	T	K	T	K	T
P_1	55.33	47.00	89.67	85.00	166.70	155.87	25.67	23.00
P_2	57.00	50.00	103.33	98.67	185.53	173.5	27.67	24.33
P_3	60.33	54.33	110.67	106.33	194.50	183.7	31.33	28.00
P_4	47.33	40.67	86.67	82.33	148.93	140.57	20.67	17.23
P_5	50.67	44.33	98.67	93.00	168.67	156.97	22.00	19.33
P_1xP_2	52.00	45.67	92.67	88.00	181.17	174.37	32.33	29.13
P_1xP_3	53.67	46.33	96.33	91.33	173.23	161.37	34.33	32.00
P_1xP_4	55.00	47.67	84.00	80.00	147.73	136.13	33.67	30.33
P_1xP_5	48.33	41.33	93.33	88.00	159.90	148.8	33.00	29.00
P_2xP_3	54.33	47.00	99.00	94.00	173.33	156.6	34.33	31.23
P_2xP_4	55.00	47.67	86.33	81.00	168.73	155.93	31.33	28.00
P_2xP_5	52.67	44.67	92.00	87.00	155.73	146.5	29.33	26.00
P_3xP_4	49.33	42.00	98.00	92.67	166.07	153.97	30.33	27.00
P_3xP_5	51.67	44.00	92.00	87.00	167.33	156.47	31.00	27.00
P_4xP_5	49.33	41.33	86.00	81.67	164.37	154.13	27.00	23.67
LSD $_{5\%}$	0.78	0.65	0.78	1.00	2.37	2.56	0.79	0.89
LSD $_{1\%}$	1.05	0.87	1.05	1.35	3.20	3.45	1.06	1.21

Genotype	Head diameter plant^{-1}(cm)		Hundred seed weight (g)		Seed weight plant^{-1}(g)		Seed oil content (%)	
	K	T	K	T	K	T	K	T
P_1	14.00	10.47	5.70	3.73	31.00	24.00	40.52	42.55
P_2	18.93	14.03	6.91	4.95	32.57	26.33	38.64	39.54
P_3	23.23	18.33	6.97	4.44	34.57	28.90	35.48	36.58
P_4	16.27	10.97	6.61	4.25	26.69	21.78	41.13	42.72
P_5	18.20	13.73	7.36	4.85	28.77	22.90	41.34	42.54
P_1xP_2	19.33	14.03	7.28	4.98	35.33	29.40	41.91	43.87
P_1xP_3	27.33	21.90	7.58	4.74	35.84	31.30	44.14	46.09
P_1xP_4	22.33	14.93	8.15	5.01	41.87	35.57	44.75	46.49
P_1xP_5	23.77	15.87	7.55	4.92	38.27	31.47	41.91	44.11
P_2xP_3	28.07	22.17	9.18	6.34	42.03	35.27	37.58	39.42
P_2xP_4	21.20	14.03	8.56	5.48	41.10	34.70	40.64	42.50
P_2xP_5	24.90	17.13	7.75	5.06	38.03	32.10	42.17	43.98
P_3xP_4	24.87	18.47	7.49	5.51	38.02	30.80	42.06	44.25
P_3xP_5	26.27	18.30	8.23	5.44	40.64	34.33	37.58	38.89
P_4xP_5	24.8	16.77	7.37	5.14	36.59	29.13	41.82	42.99
LSD $_{5\%}$	0.43	0.54	0.13	0.15	0.85	1.15	0.50	0.54
LSD $_{1\%}$	0.58	0.73	0.17	0.20	1.14	1.55	0.68	0.73

Table 8: General combining ability effects of five parental sunflower genotypes at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.

Parent	Days to 50 % flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
	K	T	K	T	K	T	K	T
P_1	0.41	0.20	−2.54**	−2.44**	−1.91**	−1.36	1.01**	1.19**
P_2	1.60**	1.63**	1.89**	1.85**	5.89**	5.49**	0.72**	0.70**
P_3	1.84**	2.06**	6.17**	6.18**	8.60**	7.69**	2.15**	2.16**
P_4	−1.92**	−1.94**	−5.11**	−4.91**	−9.14**	−8.66**	−1.99**	−2.09**
P_5	−1.92**	−1.94**	−0.40	−0.68*	−3.44**	−3.16**	−1.90**	−1.97**
LSD $_{gi\text{-}gj\ 5\%}$	1.08	0.89	1.08	1.38	3.28	3.53	1.09	1.23
LSD $_{gi\text{-}gj\ 1\%}$	1.45	1.20	1.46	1.86	4.42	4.76	1.47	1.66
Parent	**Head diameter plant^{-1}**		**100- seed weight**		**Seed weight plant^{-1}**		**Seed oil content**	
	K	T	K	T	K	T	K	T
P_1	−1.80**	−1.26**	−0.44**	−0.40**	−0.46*	−0.49	1.30**	1.58**
P_2	−0.29*	−0.15	0.22**	0.26**	0.73**	0.71*	−0.73**	−0.82**
P_3	2.80**	3.01**	0.19**	0.14**	1.31**	1.47**	−1.76**	−1.83**
P_4	−1.10**	−1.47**	−0.04	−0.04	−0.80**	−0.78*	0.98**	1.01**
P_5	0.39**	−0.13	0.08*	0.05	−0.78**	−0.91**	0.21	0.06
LSD $_{gi\text{-}gj\ 5\%}$	0.59	0.74	0.17	0.21	1.17	1.59	0.69	0.74
LSD $_{gi\text{-}gj\ 1\%}$	0.80	1.00	0.23	0.28	1.58	2.15	0.93	1.00

Note: *and ** significant at 0.05 and 0.01 levels of probability, respectively

Heterosis components

Three heterosis components *i. e.* average, variety and specific heterosis were conducted as Gardner and Eberhart (1966) in separate and combined analysis of variance as shown in Tables 4 and 5. Average heterosis variance or parents *vs.* crosses was highly significant for all studied traits at both and combined locations, indicating presence of adequate genetic diversity among the parental array which resulted in valuable heterosis in the first generation hybrids. To judge overall contribution of a variety or a parent to its array heterosis, the variety heterosis was estimated. Highly significant of variety heterosis variance was detected for all studied traits at both and combined locations, exhibiting the diversities among the parental arrays for the heterosis. With respect to portion of specific heterosis variance, as an indicator to importance of total heterosis of the

Table 9: Specific combining ability effects of ten sunflower F_1 hybrids at Kafr El-Hamam (K) and Tag Al-Ezz (T) in summer season 2014.

Hybrid	Days to 50 % flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
	K	T	K	T	K	T	K	T
P_1xP_2	−2.81**	−1.76**	−0.59	−0.48	9.05**	13.25**	1.00*	0.88
P_1xP_3	−1.38**	−1.52**	−1.21**	−1.48**	−1.59	−1.95	1.57**	2.29**
P_1xP_4	3.71**	3.81**	−2.25**	−1.71**	−9.35**	−10.83**	5.05**	4.88**
P_1xP_5	−2.95**	−2.52**	2.37**	2.05**	−2.88*	−3.67*	4.29**	3.42**
P_2xP_3	−1.90**	−2.29**	−2.97**	−3.10**	−9.29**	−13.58**	1.86**	2.02**
P_2xP_4	2.52**	2.38**	−4.35**	−5.00**	3.85**	2.11	3.00**	3.04**
P_2xP_5	0.19	−0.62	−3.40**	−3.24**	−14.85**	−12.83**	0.90*	0.91
P_3xP_4	−3.38**	−3.71**	3.03**	2.33**	−1.52	−2.05	0.57	0.58
P_3xP_5	−1.05*	−1.71**	−7.68**	−7.57**	−5.95**	−5.06**	1.14*	0.46
P_4xP_5	0.38	−0.38	−2.40**	−1.81**	8.83**	8.97**	1.29**	1.37**
LSD $_{sij-sik\ 5\%}$	1.62	1.34	1.62	2.07	4.92	5.30	1.63	1.85
LSD $_{sij-sik\ 1\%}$	2.18	1.81	2.18	2.79	6.63	7.15	2.20	2.49
LSD $_{sij-skl\ 5\%}$	1.48	1.22	1.48	1.89	4.49	4.84	1.49	1.69
LSD $_{sij-skl\ 1\%}$	1.99	1.65	1.99	2.54	6.06	6.52	2.01	2.28
Hybrid	**Head diameter**		**100–seed weight**		**Seed weight plant^{-1}**		**Seed oil content**	
	K	T	K	T	K	T	K	T
P_1xP_2	−0.80**	−0.64*	−0.01	0.13	−1.02*	−0.68	0.56*	0.68*
P_1xP_3	4.10**	4.07**	0.32**	0.02	−1.10*	0.46	3.83**	3.90**
P_1xP_4	3.00**	1.59**	1.12**	0.47**	7.03**	6.97**	1.69**	1.46**
P_1xP_5	2.95**	1.18**	0.41**	0.29**	3.42**	3.00**	−0.38	0.04
P_2xP_3	3.32**	3.23**	1.26**	0.95**	3.91**	3.22**	−0.71*	−0.37
P_2xP_4	0.35	−0.42	0.87**	0.27**	5.08**	4.90**	−0.39	−0.12
P_2xP_5	2.57**	1.33**	−0.06	−0.23**	2.00**	2.43**	1.91**	2.30**
P_3xP_4	0.93**	0.86**	−0.18*	0.42**	1.42**	0.24	2.06**	2.63**
P_3xP_5	0.84**	−0.65*	0.45**	0.27**	4.02**	3.90**	−1.65**	−1.78**
P_4xP_5	3.27**	2.30**	−0.18**	0.15	2.07**	0.95	−0.16	−0.52
LSD $_{sij-sik\ 5\%}$	0.89	1.11	0.25	0.31	1.76	2.39	1.04	1.12
LSD $_{sij-sik\ 1\%}$	1.20	1.50	0.34	0.42	2.37	3.22	1.40	1.51
LSD $_{sij-skl\ 5\%}$	0.81	1.02	0.23	0.28	1.60	2.18	0.95	1.02
LSD $_{sij-skl\ 1\%}$	1.09	1.37	0.31	0.38	2.16	2.94	1.28	1.37

Note: *and ** significant at 0.05 and 0.01 levels of probability, respectively.

crosses, was highly significant for all traits at both and combined locations, explained that contribution of average, variety and specific heterosis in heterosis of a cross. This result corroborates with the findings of Kaya and Atakisi (2004), Mijic *et al.* (2008), Machikowa (2011) and Abd El-Satar *et al.* (2015).

Heterotic effect and potence of gene set

Highly significant mean squares for parents *vs*. crosses were detected for all the studied traits at both locations as an indication of average heterosis as seen in Table 2. The largest heterotic magnitude expressed by the all traits as the deviation of particular $F_{1\text{'s}}$ mean values were significantly higher than parental means for all traits except days to flowering, days to physiological maturity and plant height where the parental means were significantly higher than $F_{1\text{'s}}$ mean values (Table 2). Significant interaction between mean squares due to parents *vs*. crosses and location were obtained for all traits (Table 3). These results indicated that the heterotic effects were affected the location changes.

Relative heterosis

For days to 50 % flowering and days to physiological maturity, the crosses tended to deviate towards earliness especially at Tag Al-Ezz. Earliness is favorable trait in sunflower. Concerning heterosis relative to mid parent as shown in Table 10, over dominance was observed at both locations in earliness crosses $P_1 \times P_5$ (−8.81 %) and $P_3 \times P_4$ (−11.58 %) for days to 50 % flowering at Kafr El-Hamam and Tag El-Ezz, respectively as well as $P_3 \times P_5$ for days to physiological maturity at both locations. These crosses have highly significant negative heterosis relative to mid parents with high a potence ratio exceeding unity. The shortest crosses were detected in $P_2 \times P_5$ (−12.06 %) at Kafr El-Hamam and $P_2 \times P_3$ (−12.32 %) at Tag Al-Ezz, due to presence of over dominance where their potence ratio exceeding unity. Over dominance as potence ratio pointed out, was detected in crosses $P_1 \times P_4$ for No. of green leaves plant^{-1} and seed weight plant^{-1}, $P_2 \times P_3$ for 100-seed weight, $P_1 \times P_3$ for seed oil content at both locations as well as $P_1 \times P_5$ and $P_1 \times P_3$ at Kafr El-Hamam and Tag Al-Ezz for head diameter.

Table 10: Relative heterosis (M.P.) and heterbeltiosis (B.P.) as well as potence ratio (P) of studied traits in ten sunflower F_1 hybrids at Kafr El-Hamam (K) and Tag El-Ezz (T) in summer season 2014.

Hybrid	Days to 50 % flowering						Days to physiological maturity					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_1xP_2	−7.42**	5.00	−6.02**	−5.84**	1.89	−2.84**	−3.97**	0.56	3.35**	−4.17**	0.56	3.53**
P_1xP_3	−7.20**	1.67	−3.01**	−8.55**	1.18	−1.42	−3.83**	0.37	7.43**	−4.53**	0.41	7.45**
P_1xP_4	7.14**	−0.92	16.20**	8.75**	−1.21	17.21**	−4.73**	2.78	−3.08**	−4.38**	2.75	−2.83*
P_1xP_5	−8.81**	2.00	−4.61**	−9.49**	3.25	−6.77**	−0.88	0.19	4.09**	−1.12	0.25	3.53**
P_2xP_3	−7.39**	2.60	−4.68**	−9.90**	2.38	−6.00**	−7.48**	2.18	−4.19**	−8.29**	2.22	−4.73**
P_2xP_4	5.43**	−0.59	16.20**	5.15**	−0.50	17.21**	−9.12**	1.04	−0.38	−10.50**	1.16	−1.62
P_2xP_5	−2.17**	0.37	3.95**	−5.30**	0.88	0.75	−8.91**	3.86	−6.76**	−9.22**	3.12	−6.45**
P_3xP_4	−8.36**	0.69	4.23**	−11.58**	0.80	3.28**	−0.68	0.06	13.08**	−1.77	0.14	12.55**
P_3xP_5	−6.91**	0.79	1.97*	−10.81**	1.07	−0.75	−12.10**	2.11	−6.76**	−12.71**	1.90	−6.45**
P_4xP_5	0.68	−0.20	4.23**	−2.75**	0.64	1.64*	−7.19**	1.11	−0.77	−6.84**	1.13	−0.81
LSD 5 %	1.51		1.75	1.25		1.45	1.51		1.75	1.93		2.23
LSD 1 %	2.04		2.36	1.69		1.95	2.04		2.36	2.61		3.01
Hybrid	**Plant height**						**No. of green leaves plant^{-1}**					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_1xP_2	2.87	−0.54	8.68**	5.88*	−1.10	11.87**	21.25**	5.67	16.87**	23.10**	8.20	19.73**
P_1xP_3	−4.08	0.53	3.92	−4.96*	0.60	3.53	20.47**	2.06	9.57**	25.49**	2.60	14.29**
P_1xP_4	−6.39**	1.14	−0.81	−8.15**	1.58	−3.15	45.32**	4.20	31.17**	50.79**	3.54	31.88**

(*continued*)

Table 10: (*continued*)

Hybrid	Plant height						No. of green leaves plant^{-1}					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_1xP_5	−4.64*	7.92	−4.08	−4.87	13.85	−4.53	38.46**	5.00	28.57**	37.01**	4.27	26.09**
P_2xP_3	−8.78**	3.72	−6.58*	−12.32**	4.31	−9.74**	16.38**	2.64	9.57**	19.36**	2.76	11.55**
P_2xP_4	0.90	−0.08	13.29**	−0.70	0.07	10.93**	29.66**	2.05	13.25**	34.72**	2.03	15.07**
P_2xP_5	−12.06**	2.53	−7.67**	−11.34**	2.27	−6.67*	18.12**	1.59	6.02**	19.08**	1.67	6.85**
P_3xP_4	−3.29	0.25	11.50**	−5.04*	0.38	9.53**	16.67**	0.81	−3.19**	19.38**	0.81	−3.57**
P_3xP_5	−7.85**	1.10	−0.79	−8.14**	1.04	−0.32	16.25**	0.93	−1.06	14.08**	0.77	−3.57**
P_4xP_5	3.51	−0.56	10.36**	3.61	−0.65	9.65**	26.56**	8.50	22.73**	29.44**	5.13	22.41**
LSD $_{5\%}$	4.60		5.31	4.95		5.72	1.53		1.77	1.73		2.00
LSD $_{1\%}$	6.20		7.16	6.68		7.72	2.06		2.38	2.33		2.69

Hybrid	Head diameter						100– seed weight					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_1xP_2	17.41**	1.16	2.11**	14.56**	1.00	0.00	15.44**	1.61	5.36**	14.78**	1.05	0.61**
P_1xP_3	46.82**	1.89	17.65**	52.08**	1.91	19.45**	19.65**	1.96	8.75**	16.08**	1.86	6.84**
P_1xP_4	47.58**	6.35	37.30**	39.35**	16.87	36.17**	32.36**	4.38	23.25**	25.65**	3.94	17.96**
P_1xP_5	47.62**	3.65	30.59**	31.13**	2.31	15.53**	15.65**	1.23	2.63**	14.73**	1.13	1.51**
P_2xP_3	33.12**	3.25	20.80**	36.97**	2.78	20.91**	32.31**	70.79	31.71**	35.04**	6.37	27.99**
P_2xP_4	20.45**	2.70	11.97**	12.27**	1.00	0.00	26.61**	12.12	23.89**	19.09**	2.50	10.63**
P_2xP_5	34.11**	17.27	31.51**	23.41**	21.67	22.09**	8.62**	2.73	5.30**	3.33**	3.06	2.22**
P_3xP_4	25.91**	1.47	7.03**	26.05**	1.04	0.73	10.26**	3.87	7.41**	26.78**	12.46	24.12**
P_3xP_5	26.79**	2.21	13.06**	14.14**	0.99	−0.18	14.89**	5.52	11.87**	17.27**	3.91	12.31**

(*continued*)

Table 10: (*continued*)

Hybrid	Head diameter						100– seed weight					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_4xP_5	43.91**	7.83	36.26**	35.76**	3.19	22.09**	5.49**	1.03	0.14	13.01**	1.98	6.05**
LSD 5%	0.83		0.96	1.04		1.20	0.24		0.27	0.29		0.34
LSD 1%	1.12		1.29	1.40		1.62	0.32		0.37	0.39		0.45

Hybrid	Seed weight plant^{-1}						Seed oil content					
	K			T			K			T		
	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P	M.P	P	B.P
P_1xP_2	11.17**	4.53	8.50**	16.82**	3.63	11.65**	5.90**	2.48	3.44**	6.89**	1.88	3.11**
P_1xP_3	9.30**	1.71	3.65**	18.34**	1.98	8.30**	16.16**	2.44	8.94**	16.48**	2.19	8.31**
P_1xP_4	45.14**	6.05	35.05**	55.37**	11.44	48.19**	9.60**	12.78	8.78**	9.03**	44.42	8.81**
P_1xP_5	28.05**	7.52	23.44**	34.19**	14.58	31.11**	2.40**	2.38	1.38*	3.69**	235.50	3.67**
P_2xP_3	25.21**	8.44	21.58**	27.70**	5.96	22.03**	1.39**	0.33	−2.74**	3.56**	0.91	−0.32
P_2xP_4	38.71**	3.91	26.20**	44.23**	4.68	31.77**	1.89**	0.60	−1.20*	3.32**	0.86	−0.52
P_2xP_5	24.01**	3.88	16.79**	30.39**	4.36	21.89**	5.46**	1.61	2.01**	7.16**	1.96	3.39**
P_3xP_4	24.12**	1.88	9.98**	21.54**	1.53	6.57**	9.79**	1.33	2.25**	11.58**	1.50	3.57**
P_3xP_5	28.32**	3.09	17.55**	32.56**	2.81	18.80**	−2.16**	−0.28	−9.09**	−1.70**	−0.23	−8.58**
P_4xP_5	31.93**	8.53	27.17**	30.40**	12.16	27.22**	1.40**	5.51	1.14*	0.84	3.82	0.62
LSD 5%	1.64		1.90	2.23		2.58	0.97		1.12	1.04		1.21
LSD 1%	2.22		2.56	3.01		3.48	1.31		1.51	1.41		1.63

Note: *and ** significant at 0.05 and 0.01 levels of probability, respectively.

Heterobeltiosis

Over dominance for heterobeltiosis as shown in Table 10 was observed in the earliest crosses $P_1 \times P_2$ (−6.02 %) and $P_1 \times P_5$ (−6.77 %) for days to 50 % flowering at Kafr El-Hamam and Tag Al-Ezz, respectively and $P_2 \times P_5$ and $P_3 \times P_5$ for days to physiological maturity at both locations, since their heterobeltiosis values were highly significant negative with high potence ratio exceeding unity. The shortest crosses were detected in $P_2 \times P_5$ and $P_2 \times P_3$ at Kafr El-Hamam and Tag Al-Ezz, respectively suggesting presence of over dominance as potence ratio pointed out. Over dominance for heterobeltiosis as potence ratio pointed out, was detected in the promising crosses $P_1 \times P_4$ for No. of green leaves plant^{-1}, head diameter and seed weight plant^{-1}, $P_2 \times P_3$ for 100-seed weight at both locations as well as $P_1 \times P_3$ and $P_1 \times P_4$ for seed oil content at Kafr El-Hamam and Tag Al-Ezz, respectively.

The relative efficiency of half diallel's analyses

The relative efficiency based on F test of half diallel's analyses for all studied traits at Kafr El-Hamam and Tag Al-Ezz is presented in Table 11. For additive and dominance gene effects and error variances, insignificant F-test was detected between Griffing (1956) and Jones (1965), Griffing (1956) and Gardner and Eberhart (1966) and Jones (1965) and Gardner and Eberhart (1966)'s analyses used for all traits at both locations. This confirmed that these methods are statistically identical. On the other hand, for comparison between Hayman (1954b) and each of Griffing (1956), Gardner and Eberhart (1966) and Jones (1965), the results of dominance gene effects indicated that significant F. test was detected for days to 50 % flowering, days to physiological maturity, plant height and seed oil content at both locations and 100-seed weight at Kafr El-Hamam, indicating that the method of Hayman (1954b) was slightly differed from the other ones used in this respect.

Also, insignificant F test in this concern was obtained between Hayman (1954b) and each of Griffing (1956), Gardner and Eberhart (1966) and Jones (1965) for the other traits. Moreover, additive gene effect and error variance was insignificant and statistically identical or similar.

From above comparison, plant breeder decides based on the desired purpose of analysis to succeed in reaching desirable breeding goals. Since, Griffing method 2 (1956) will be relatively easy to estimate of general combining ability effects for each parent and specific combining ability effects for each cross. However, Gardner and Eberhart (1966) method appears to have some advantages

Table 11: Relative efficiency of half diallel's analyses based on F-test for all studied traits at Kafr El-Hamam (K) and Tag Al-Ezz (T).

Half diallel's analyses	Vari.	Days to 50 % flowering		Days to physiological maturity		Plant height		No. of green leaves plant^{-1}	
		K	T	K	T	K	T	K	T
Gr. x J.	Additive	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H.		1.11	1.07	1.35	1.31	1.17	1.11	1.32	1.49
J. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		1.11	1.07	1.35	1.31	1.17	1.11	1.32	1.49
Ga. x H.		1.11	1.07	1.35	1.31	1.17	1.11	1.32	1.49
Gr. x J.	Dominance	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H.		4.02*	3.97*	3.28*	3.21*	3.73*	3.73*	2.73	2.70
J. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		4.02*	3.97*	3.28*	3.21*	3.73*	3.73*	2.73	2.70
Ga. x H.		4.02*	3.97*	3.28*	3.21*	3.73*	3.73*	2.73	2.70
Gr. x J.	Error	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H.		1.03	1.00	1.06	1.02	1.05	1.04	1.06	1.00
J. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		1.03	1.00	1.06	1.02	1.05	1.04	1.06	1.00
Ga. x H.		1.03	1.00	1.06	1.02	1.05	1.04	1.06	1.00

Half diallel's analyses	Vari.	Head diameter		100- seed weight		Seed weight plant^{-1}		Seed oil content	
		K	T	K	T	K	T	K	T
Gr. x J.	Additive	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H.		1.87	2.34	1.34	1.91	1.42	1.04	1.90	1.86
J. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		1.87	2.34	1.34	1.91	1.42	1.04	1.90	1.86
Ga. x H.		1.87	2.34	1.34	1.91	1.42	1.04	1.90	1.86
Gr. x J.	Dominance	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H		2.70	2.95	3.05*	2.97	2.81	2.69	3.66*	3.49*
J. x Ga		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		2.70	2.95	3.05*	2.97	2.81	2.69	3.66*	3.49*
Ga. x H.		2.70	2.95	3.05*	2.97	2.81	2.69	3.66*	3.49*
Gr. x J.	Error	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gr. x H.		1.00	1.29	1.00	1.00	1.02	1.03	1.00	1.00
J. x Ga.		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
J. x H.		1.00	1.29	1.00	1.00	1.02	1.03	1.00	1.00
Ga. x H.		1.00	1.29	1.00	1.00	1.02	1.03	1.00	1.00

Note: *and ** significant at 0.05 and 0.01 levels of probability, respectively.Gr. (Griffing, 1956), Ga (Gardner and Eberhart, 1966), H. (Hayman, 1954b) and J. (Jones, 1965) modification.

over the others, as partitioned the total sum of squares of heterosis into average, general and specific heterosis effect as well as gave information about combining ability of the parents, and also it cleared a simple relationship between heterosis (h_{ij}) and specific combining ability (s_{ij}). Moreover, Hayman (1954b) analysis may be given more information over the others about genetic component with it is computationally complicated. Similar results were reported by Nawar (1985).

Conclusions

For bove mentioned results, it can be concluded that variance of additive, non-additive and experimental error for all studied traits computed by Griffing (1956), Gardner and Eberhart (1966) and (Jones, 1965) was numerically identical; and it was confirmed by F. test. Moreover, Hayman (1954b)'s analysis may be gave more information over the others about genetic component with it is computationally complicated. A great deal about the genetical situation and adequacy of the additive/dominance model of gene action can be obtained from the graphically variance/covariance analysis. Partial dominance with additive type of gene action with high to medium heritability for days to 50 % flowering, days to physiological maturity, plant height, head diameter, No. of green leaves plant^{-1} and seed oil content suggested effective selection for these traits in early generation while over dominance for 100-seed weight and seed weight plant^{-1} suggested that heterosis breeding may be effective for improvement in these traits. Comparing of cross combinations on the basis of mean performance and desirable heterotic response as well as SCA effects of hybrids, revealed that $P_1 \times P_4$ for seed weight plant^{-1} and the most of the yield associated traits at both locations and $P_3 \times P_4$ for earliness in flowering and $P_2 \times P_4$ for earliness in physiological maturity at both locations were identified as the best crosses.

References

Abd El-Satar, M.A., Fahmy, R.M., Hassan, T.H.A., 2015. Genetic control of sunflower seed yield and its components under different edaphic and climate conditions. The 9th Plant Breeding International Conference September 2015, Egyptian Journal of Plant Breeding 19(5): 103–123 (Special Issue).

Alza, J.O., Fernandez Martinez, J.M., 1997. Genetic analysis of yield and related traits in sunflower (Helianthus annuusL.) in dry land and irrigated environment. Euphytica 95(2): 243–251.

AOAC, 1990. Official Methods of Analysis., 15th ed. Association of Official Analytical Chemists, Virginia.
Ashok, S., Muhammad, S.N., Narayanan, S.L., 2000. Combining ability studies in sunflower (*Helianthus annuus*L.). Crop Research (Hisar) 20(3): 457–462.
Bajaj, R.K., Aujla, K.K., Chalal, G.S., 1997. Combining ability studies in sunflower (*Helianthus annuus* L.). Crop Improvement 24(1): 50–54.
Baker, R.J., 1978. Issues in diallel analysis. Crop Science 18: 533–536.
Francois, L.E., 1996. Salinity effects on four sunflower hybrids. Agronomy Journal 88: 215–219.
Gardner, C.O., Eberhart, S.A., 1966. Analysis and interpretation of the variety cross diallel and related population. Biometrics 22: 439–452.
Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel cross system. Australian Journal of Biological Sciences 9: 462–493.
Hayman, B.I., 1954a. The analysis of variance of diallel tables. Biometrics 10: 235–244.
Hayman, B.I., 1954b. The theory and analysis of diallel crosses. Genetics 39: 789–809.
Jinks, J.L., 1954. The analysis of continuous variation in a diallel cross of nicotianarustica varieties. Genetics 39: 767–788.
Jones, R.M., 1965. Analysis of variance of the half diallel table. Heredity 20: 117–121.
Kaya, Y., Atakisi, I.K., 2004. Combining ability analysis of some yield characters of sunflower (*Helianthus annuus* L.). Helia 27(41): 75–84.
Khan, H., Ur Rahaman, H., Ahmad, H., Alliand, H., Alam, M., 2008. Magnitude of combining ability of sunflower genotypes in different environments. Pakistan Journal of Botany 40(1): 151–160.
Machikowa, T., 2011. General and specific combining ability for quantitative characters in sunflower. The Journal of Agricultural Science 3(1): 91–95.
Mather, K., Jinks, J.L., 1971. Biometrical Genetics, 2nd ed. Chapman and Hall, London.
Matzinger, D.F., Sprague, G.F., Cockerham, C.C., 1959. Diallel crosses of maize in experiments repeated over locations and years. Agronomy Journal 51: 346–350.
Mijic, A., Kozumplik, V., Kovacevic, J., Liovic, I., Krizmanic, M., Duvnjak, T., Maric, S., Horvat, D., Simic, G., Gunjaca, J., 2008. Combining abilities and gene effects on sunflower grain yield, oil content and oil yield. Periodicum Biologorum Journal 110: 277–284.
MS-EXCEL, 2007. Microsoft software excel.
Naik, V.R., Hiremath, S.R., Giriraj, K., 1999. Gene action in sunflower. Karnataka Journal of Agricultural Sciences 12(1/4): 43–47.
Nawar, A.A., 1985. A comparison between seven analysis methods of diallel crosses in maize (Zea mays L.). Minufiya Journal Agricultural Research 10(2): 739–758.
Petr, F.C., Frey, J., 1966. Genotypic correlation, dominance, and heritability of quantitative characters in oats. Crop Science 6: 259–262.
Pourmohammad, A., Toorchi, M., Alavikia, S.S., Shakiba, M.R., 2016. Estimation of genetic parameters for yield and yield components in sunflower under normal and stress water deficit. Bulgarian Journal of Agricultural Science 22(3): 426–430.
Steel, R.G.D., Torrie, J.H., Dickey, D.A., 1997. Principles and Procedures of Statistics: A Biometrical Approach, 3rd ed. McGraw-Hill, New York, 666p.