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Combining Ability Analysis for Achene Yield and Related Components in Sunflower (*Helianthus annuus* L.)

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Abstract: For determination of best general and specific combiners for achene yield and related components, a study on a 7 × 7 diallel fashion in sunflower was conducted at experimental field of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan. The data were recorded on quantitative traits; days to maturity, plant height, stem diameter, head diameter, number of leaves, Achene per head, achene yield per plant, 100-achene weight, filled achene percentage and oil contents and subjected to Analysis of variance and combining abilities. The accessions were significant for studied traits except oil contents. The accessions A-544, A-554 and A-552 showed significant general combining ability effects days to maturity, plant height, stem diameter, head diameter, number of leaves and filled achene, achene per head and achene yield per plant. The best cross combination A-546 × A-560 showed significant specific combining ability effects for number of leaves and filled achene percentage. Among reciprocal crosses, the cross A-560 × A-534 proved best for plant height and stem diameter while A-548 × A-546 for number of leaves and achene per head.

Keywords: sunflower, hybrids, combining ability, diallel

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Introduction

Sunflower (*Helianthus annuus* L.) is an important edible oilseed crop in the world (Mijić *et al*., 2009) also in Pakistan due to increase in demand for edible oil. It is 2nd major hybrid crop after maize and ranked 5th among oilseed crops. Sunflower seeds contain a high amount of oil i. e. 40–50% (Lopez *et al*., 2000; Leon *et al*., 2003; Monotti, 2004), 23% protein (Tahir *et al*., 2002), 30% carbohydrates, and about 4% ash (Khalil and Jan, 2002). Moreover, sunflower is an economically important raw material for making lubricants, detergents, chemical synthesis or surfactants, pharmaceuticals and metal working fluids (Dorrell and Vick, 1997; Fick and Miller, 1997; Aslam *et al*., 2010).

The major objective of any sunflower breeding program mainly emphasizes on high yield and oil contents (Nehru and Manjunath, 2003). Achene yield of sunflower is a complex quantitative trait influenced by environmental, morphological and physiological parameters ((Nadarajan and Gunasekaran, 2005). Achene yield is mainly dependent on other yield related attributes which are interrelated to each other. Therefore, it is of prime importance to understand the genetic mechanism controlling yield and related components, help to select parents possessing required genetic potential (Yasin and Singh, 2010).

To understand the nature of gene action involved in complex genetic characteristics many biometrical approaches are utilized by researcher. The diallel analysis developed by Hayman in 1954 and Jinks in 1956, have been widely utilized to get accurate information regarding gene expression for complex characters like yield and related attributes and to predict the performance of progenies in the latter segregating generations based on their additive and non-additive effects (Jinks, 1956).

Breeding for seed yield primarily based on selection of best germplasm which later leads toward development of inbred lines. The ability of inbred to transfer desirable performance in its next generations is referred as combing ability. It is further divided into general and specific combing ability. The general combining ability (GCA) of a line means the average value of its performance in a series of crosses with other lines. The performance of a specific cross and those of inbred lines which are used for this superior cross is used to obtain specific combining ability (SCA) (Fick and Miller, 1997). Based on the combining ability analysis of different characters, higher SCA values refer to dominance gene effects and higher GCA shows additive gene effects controlling these characters. When both the SCA and GCA values are insignificant then epistatic gene effects play an imperative role in shaping these traits (Fehr, 1993).

Keeping in view the situation, the proposed study was planned with the following objectives

(1) Estimation of combining ability in diallel cross experiment for selected inbreds
(2) To develop selection criteria for yield and its related attributes

Material and methods

Present research was conducted at the research area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan. The experimental material was comprised of seven accessions of sunflower i. e. A-534, A-544, A-546, A-548, A-552, A-554, A-560. Crosses were attempted in a 7×7 complete diallel pattern through controlled pollinations. The seed of 42 crosses along with their parents were harvested, cleaned and stored for the next crop season. The seed of 42 crosses and 7 parents were planted following RCBD with three replications. The sowing was done keeping plant-to-plant and row-to-row distance of 25 and 75 cm, respectively. One row of 3 m length of each entry was planted. Sowing was done with the help of a dibbler. All of the recommended cultural and agronomic practices were uniformly performed for all experimental units from the time of sowing to the time of harvesting. Ten guarded plants of each entry in each replication were taken at random and data were recorded on the following pre-harvest and post-harvest plant traits. The quantitative traits are, Days to maturity (from emergence to maturity), Plant height (cm), Stem diameter (cm) (measured at cotyledon scar), Head diameter (cm), Number of leaves per plant, Number of achenes per head, Achene yield per plant (g),100-achene weight (g), Filled achene and Oil contents (%).

Statistical analyses

The data collected for all the traits were subjected to analysis of variance (ANOVA) following Steel *et al.* (1997). General combining ability, specific combining ability and reciprocal effects were determined using Griffing's approach model 1, method 1 (Griffing, 1956). "R" software was used to calculate the combining abilities.

Results

The data of different plant traits of 49 genotypes, including parents seven parental lines, 21 direct cross combinations and 21 indirect crosses, were subjected to analysis of variance. The mean squares from the analysis of variance

Table 1: Analysis of variance for combining ability of achene yield and its components in sunflower.

Parameter	Entries	GCA	SCA	RE
Days to maturity	44.87*	39.81*	48.47*	42.71**
Plant height	1151.05**	3218.74*	603.13**	1108.20**
Stem diameter	9.145**	11.93*	9.80**	7.68**
Head diameter	7.02*	9.16 *	8.43**	5.0**
Number of leaves	20.673**	28.81 *	24.60**	14.41**
Achenes per head	18,880.75**	46,655.16 *	23,595.26**	6,230.21**
Achene yield/plant	127.52**	187.44**	125.89**	112.03**
100-achene weight	6.74**	3.41 *	8.27**	6.17**
Filled achene (%)	602.32**	1,219.78*	464.66**	563.56**
Oil contents	3.79	5.09	5.02	2.20
Degrees of freedom	48	6	20	20

*Significant at 0.05 probability level. **Highly significant at 0.01 probability level.
GCA = general combining ability; SCA = specific combining ability; RE = reciprocal effects.

for all the traits are presented in Table 1. The results showed significant ($P < 0.05$) differences among all genotypes for all traits except oil contents Table 1. Combining ability analysis revealed about the potential of several parents or accessions. Suitable parents were selected on the basis of significant positive and negative GCA, SCA and reciprocal effects depending upon the requirement of traits (Gopikana and Ganesh, 2013). Combining ability analysis of variance has been shown in Table 1. ANOVA for combining abilities showed significant results for GCA, SCA and Reciprocal effects. Achene yield per plant was found to be highly significant for GCA, all other traits except oil contents showed significant GCA. Similarl results were found for SCA and RE, significant for all the traits except for oil contents. GCA effects were measured as statistical scale given to parents in relation to their mean performance in cross-combinations. General combining ability effects were computed for all the traits under study and given in Table 2. GCA was found significant or all the traits except days to maturity (DM) and oil contents (OC). Highest GCA value for 100 Achene weight (100 AW) was observed in line 2 (A-544) followed by lines 4 (A-548), 3 (A-546), 1 (A-534), 5 (A-552) and 6 (A-554). Only two parents 2 and 4 showed positive significant GCA for 100 achene weight. Parents A-534, A-544, A-546 and A-552 showed negative GCA values and are responsible for less days to maturity. The parent A-544 showed significant GCA for all traits except days to maturity and oil contents and A-548 had non-significant GCA for most of the traits except plant height (PH), stem diameter (SD), 100 achene weight (100AW) and filled achene percentage (FA). Parent 5 best general combiner for Plant

Table 2: Estimates of GCA, SCA and R effects of 7 parents and their direct and indirect cross combinations sunflower.

Genotype coding	Parents and crosses	DM	PH	SD	HD	NOL	APH	AYP	100-AW	FA	OC
Parental lines											
1	A-534	−0.33	7.05*	0.62*	0.15	−0.38	25.42*	1.97*	0.11	−10.2*	−0.02
2	A-544	−1.22	−14*	−0.8*	−0.57*	−0.97*	−63.2*	−1.30*	0.33*	−2.93*	0.30
3	A-546	−0.95	−1.62	−0.11	0.05	−0.41	3.51	−1.17*	0.27	1.63*	−0.09
4	A-548	0.11	5.37*	−0.40*	−0.14	−0.19	10.52	0.68	0.29*	2.49*	0.36
5	A-552	−0.08	4.06*	−0.11	−0.10	0.69*	37.36*	2.5*	−0.27	4.03*	−0.44
6	A-554	1.35	8.3*	0.20	0.91*	1.51*	7.47	0.70	−0.29*	5.85*	−0.43
7	A-560	1.13	−8.2*	0.63*	−0.30	−0.24	−21.0*	−3.4*	−0.32*	−0.82	0.32
Direct crosses	S.E	1.84	3.79	0.30	0.44	0.59	18.28	0.95	0.28	1.57	0.739
1	A-534 × A-544	2.63*	4.50	−1.06*	−1.27*	−0.54	−5.80	−4.81*	−0.27	0.32	−0.93
2	A-534 × A-546	1.35	−1.78	−0.27	−0.01	−1.7*	−0.88	0.21	−1.00*	−10.22*	−0.55
3	A-534 × A-548	0.51	2.40	−0.44*	0.02	−2.1*	−6.29	9.90*	1.07*	0.78	0.83
4	A-534 × A-552	0.63	9.90*	−0.57*	−0.23	3.8*	−2.79	−2.43*	0.15	−9.49*	0.76
5	A-534 × A-554	−1.38	6.62*	0.03	0.24	1.54*	34.95*	2.41*	1.38*	11.13*	0.25
6	A-534 × A-560	1.28	2.77	4.49*	2.04*	0.57	48.76*	3.53*	0.74*	−1.30	−0.52
7	A-544 × A-546	−2.21	5.00	0.03	0.60	2.41*	38.04*	−0.35	0.59*	−5.18*	−0.04
8	A-544 × A-548	2.20	8.25*	0.48*	1.40*	0.04	40.30*	5.43*	0.96*	−6.20*	0.44
9	A-544 × A-552	2.18	−2.62	0.17	0.03	−1.8*	66.1*	−0.14	0.94*	−0.33	1.0
10	A-544 × A-554	−0.92	−5.21	0.006	0.38	−0.25	11.14	3.55*	1.00*	8.14*	−1.0
11	A-544 × A-560	−0.10	−17.8*	0.19	0.82*	−1.7*	−4.04	0.18	1.15*	−0.22	−0.48
12	A-546 × A-548	−2.06	−8.47*	0.63*	0.15	0.12	−11.13	−2.81*	−0.14	3.77*	0.27
13	A-546 × A-552	2.34	2.07	0.38	0.92*	0.42	102.1*	4.48*	0.55*	2.40*	0.17
14	A-546 × A-554	0.90	−11.9*	−0.16	−1.06	−1.0*	40.05*	5.46*	0.13	−4.94*	1.3*
15	A-546 × A-560	0.27	3.38	−0.35	−0.82*	2.4*	−16.94	−2.46*	−0.62*	13.59*	0.51
16	A-548 × A-552	−5.3*	5.23	0.44*	0.17	1.76*	−0.38	−1.14	0.33	4.97*	−0.48

(*continued*)

Table 2: (*continued*)

Genotype coding	Parents and crosses	DM	PH	SD	HD	NOL	APH	AYP	100-AW	FA	OC
17	A-548 × A-554	1.89	−12.3*	−0.49*	−2.6*	1.11*	−12.56	−6.86*	−0.41*	7.22*	−1.6*
18	A-548 × A-560	1.51	12.9*	−0.23	0.55	2.6*	19.94	−0.92	−0.43*	3.59*	1.2*
19	A-552 × A-554	−0.19	−7.44*	0.36	−0.12	−0.15	−46.1*	−4.09*	−1.09*	−3.85*	−0.07
20	A-552 × A-560	−6.2*	−2.69	0.18	−0.95*	0.33	10.53	4.55*	0.64*	7.02*	−1.5*
21	A-554 × A-560	−1.47	13.7*	−0.50*	−0.10	−0.8*	75.0*	2.48*	0.37	4.65*	0.03
Direct crosses	S.E.	2.61	5.36	0.43	0.62	0.84	25.85	1.34	0.39	2.23	1.04
1	A-544 × A-534	−2.4*	−21.4*	−0.27	0.65	0.70	−22.2	0.26	1.57*	−11.5*	0.5
2	A-546 × A-534	−3.7*	3.93	−0.05	−1.12	−0.01	7.91	−0.86	0.08	−10.4*	−0.6
3	A-548 × A-534	−2.8*	−0.18	0.09	1.03	1.26	20.15	4.85*	1.87*	20.5*	−1.0
4	A-552 × A-534	−2.4*	−11.9*	−1.4*	−2.2*	−0.80	−34.5	−5.2*	−0.47	14.1*	0.2
5	A-554 × A-534	−2.5*	16.11*	0.26	0.86	1.43*	−35.7	0.25	0.80*	12.6*	−0.1
6	A-560 × A-534	1.7	−31.0*	4.5*	0.02	−3.5*	−69.*	−1.1	−0.9*	12.2*	1.1
7	A-546 × A-544	−0.04	10.85*	0.25	−0.77	−1.33	−32.9	2.21	1.17*	−7.8*	−0.75
8	A-548 × A-544	3.53*	16.73*	0.27	−0.33	0.41	−12.2	9.83*	2.31*	4.8*	−0.7
9	A-552 × A-544	1.46	19.85*	−0.10	−0.96	−0.45	−32.4	3.11*	0.11	−15.3*	−0.4
10	A-554 × A-544	3.15*	2.61	−0.40	−0.62	1.68*	−6.58	6.10*	1.25*	−0.8	0.2
11	A-560 × A-544	−6.1*	13.76*	0.27	0.04	0.88	−16.7	0.31	0.34	−4.7*	−0.8

(*continued*)

Table 2: (*continued*)

Genotype coding	Parents and crosses	DM	PH	SD	HD	NOL	APH	AYP	100-AW	FA	OC
12	A-548 × A-546	1.64	12.23*	-0.3	0.32	2.51*	−13.7	−2.41	−0.61	12.4*	0.4
13	A-552 × A-546	3.29*	9.16	0.25	−0.11	0.83	−54*	−2.08	−0.09	−2.0	0.8
14	A-554 × A-546	1.03	−15.2*	−1.3*	−0.93	−3.9*	−26.1	4.08*	−0.06	−8.8*	−0.7
15	A-560 × A-546	2.74*	−10.1*	−0.57	0.36	−0.41	−4.88	−5.20*	0.64	3.9	−0.2
16	A-552 × A-548	−1.00	−0.86	0.31	−0.86	−0.10	30.70	5.55*	1.34*	−9.2*	−0.6
17	A-554 × A-548	−0.74	18.55*	0.59	1.53*	−0.96	−31.0	0.41	−0.73	1.3	−0.3
18	A-560 × A-548	0.82	2.21	−0.25	−1.03	−1.00	−0.58	3.86*	0.28	−5.8*	−0.1
19	A-554 × A-552	−3.2*	3.43	0.32	0.24	−0.51	−56*	−6.18*	−0.15	2.8	−0.8
20	A-560 × A-552	0.32	9.56	−0.70	1.12	−1.5*	−12.6	2.25	−1.44	−9.6*	−0.7
21	A-560 × A-554	−2.7*	5.38	0.18	0.69	0.01	42.80	6.86*	0.28	1.2	−0.01
	S.E.	2.38	10.03	0.81	1.17	1.57	48.36	2.52	0.74	4.17	1.9

*Significant at 0.05 probability level. **Significant at 0.01 probability level. SE = Standard Error; DM = Days to maturity; PH = Plant height; SD = Stem diameter; HD = Head diameter; NOL = Number of leaves; APH = Achene per head; AYP = Achene yield/plant; 100-AW = 100 achene weight; FA = Filled achene; OC = Oil contents.

height, Number of leaves, Achene per head, Achene yield per head and Filled achene percentage as it has shown positive significant results for mentioned traits. Parent 1 (A-534) has shown positive significant GCA effects for Plant height, Stem diameter, Achene per head and Achene yield per head. Plant height, Head diameter, Number of leaves and filled achene were significant for parent 6 (A-554). Filled achene per head was found significant for all parents except 7 (A-560).

The crosses 5, 6 and 13 showed significant positive results for achene per head (APH), achene yield per plant (AYP) and 100 achene weight (100AW) which are directly contributing toward high yield. Cross combination 13 showed highest positive specific combining ability effects for achene per head. All the traits were showed significant effects for the cross 17 except days to maturity and achene per head, though positive significance was observed only for number of leaves and filled achene percentage. Filled achene showed highest positive significant SCA effects for cross combinations 15, 5, 10, 17, 20, 16 and 21 respectively. Cross combination 5 showed highest positive SCA effects for 100 Achene weight followed by 11, 3, 10, 8, 7 and 20.

Parental combinations 19, 12, 14 and 17 showed negatively significant CA effects for plant height, hence are best combinations for selection and breeding for short stature hybrids. Plant height is a complex genetic control trait. Reciprocal effects for general combining ability have been presented in Table 2. The crosses 5, 8 and 12 showed significant positive reciprocal effects for plant height and filled achene percentage. Cross combination 8 showed highest positive reciprocal effects for 100 Achene weight followed by 3, 1, 16, 10 and 7. Filled achene showed highest positive significant reciprocal effects of combining ability for cross combinations 3, 4, 5, 12 and 6 respectively. Reciprocal effects were non-significant for oil contents in all the indirect combinations while was found positively significant for direct cross combinations 14 and 18.

Discussion

Parents with higher GCA would be responsible for production of transgressive segregants in F2 population or further generations (Singh and Singh, 1985). Development of short duration crop with high yield is main objective in breeding sunflower. Hence, earliness together with low percentage of unfilled seed per plant and short plant height are consider as the most desired characters and negative SCA values would be preferred for these trait. Negatively significant SCA was observed in parental combinations 16 and 20. These two crosses also show positive significant SCA effects for filled achene. Development of semi dwarf sunflower hybrids and their applications in agricultural fields have been practiced since last many years and significant achievements have been observed in plant height (Khan *et al.*, 2008). Significant negative GCA, SCA and reciprocal effects are preferable for producing short stature sunflower (Khan *et al.*, 2008; Gvozdenovic *et al.*, 2005). Table 3 describe the ranking of good and superior cross combinations on the basis of specific and reciprocal effects.

Table 3: Ranking of good cross combinations on the basis of SCA and reciprocal effects in a 7 × 7 diallel cross of sunflower.

Traits	Parents with performance for SCA	Good Crosses	Superior common crosses
DM	A-544 × A-534		
	A-552 × A-534	A-544 × A-534	
	A-554 × A-534	A-552 × A-534	A-544 × A-534
	A-548 × A-544	A-554 × A-534	A-552 × A-534
	A-560 × A-546		
PH	A-552 × A-554		
	A-546 × A-548	A-552 × A-554	
	A-560 × A-546	A-546 × A-548	A-552 × A-554
	A-552 × A-534	A-560 × A-546	A-546 × A-548
	A-544 × A-560		
SD	A-560 × A-534		
	A-546 × A-548	A-560 × A-534	
	A-544 × A-546	A-546 × A-548	A-560 × A-534
	A-548 × A-552	A-544 × A-546	A-546 × A-548
	A-554 × A-560		
HD	A-534 × A-560		
	A-554 × A-548	A-534 × A-560	
	A-544 × A-548	A-554 × A-548	A-534 × A-560
	A-546 × A-552	A-544 × A-548	A-554 × A-548
	A-544 × A-560		
NOL	A-534 × A-552		
	A-548 × A-546	A-534 × A-552	
	A-548 × A-560	A-548 × A-546	A-534 × A-552
	A-544 × A-546	A-548 × A-560	A-548 × A-546
	A-546 × A-560		
APH	A-546 × A-552		
	A-544 × A-552	A-546 × A-552	
	A-534 × A-560	A-544 × A-552	A-546 × A-552
	A-544 × A-546	A-534 × A-560	A-544 × A-552

(*continued*)

Table 3: (*continued*)

Traits	Parents with performance for SCA	Good Crosses	Superior common crosses
	A-534 × A-554		
AYP	A-534 × A-548		
	A-548 × A-544	A-534 × A-548	
	A-554 × A-544	A-548 × A-544	A-534 × A-548
	A-544 × A-548	A-554 × A-544	A-548 × A-544
	A-546 × A-554		
100AW	A-548 × A-544		
	A-548 × A-534	A-548 × A-544	
	A-544 × A-534	A-548 × A-534	A-548 × A-544
	A-534 × A-554	A-544 × A-534	A-548 × A-534
	A-554 × A-544		
FA	A-548 × A-534		
	A-552 × A-534	A-548 × A-534	
	A-546 × A560	A-552 × A-534	A-548 × A-534
	A-554 × A-534	A-546 × A560	A-552 × A-534
	A-560 × A-534		

DM = Days to maturity; PH = Plant height; SD = Stem diameter; HD = Head diameter; NOL = Number of leaves; APH = Achene/head; AYP = Achene yield/plant; 100AW = 100 achene weight.

Conclusion

The present study was conducted to determine the extent of genetic variability among the sunflower accessions and crosses. Entries had significant differences (P = 0.05–0.01) for all the traits except oil contents. This suggested that variation exist in the studied material that may be used for further improvement in these characters. The accessions A-544, A-554 and A-552 showed significant general combining ability effects for DM, PH, SD, HD, NOL and FA %age, APH and AYP. The best cross combination A-546 × A-560 showed significant specific combining ability effects for number of leaves and filled achene percentage. Among reciprocal crosses, the cross A-560 × A-534 proved best for plant height and stem diameter while A-548 × A-546 for number of leaves and achene per head. It is concluded from the research that the breeding material used in this research may be used for the improvement of achene yield and its related traits.

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