Combining ability for seed yield and yield components in sunflower (*Helianthus annuus* L.)

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ABSTRACT

This study was conducted using four cytoplasmic male sterile lines (cms) and ten restorers of sunflower (*Helianthus annuus* L.) in a line x tester fashions in summer and winter season of 2007at Sennar Research Station Farm, Agricultural Research Corporation, Sudan. The objectives were to determine the general combining ability and specific combining ability effects among 14 parents and their 40 crosses for seed yield and other agronomic traits. The experiment was carried out under supplementary irrigation using a randomized complete block design (RCBD) with three replicates. The traits studied were days to 50% flowering, plant height (cm), head diameter(cm), number of seeds per head, percentage of empty seeds, 1000-seed weight (g), and seed yield (kg/ha). Analysis of variance of the combining abilities revealed highly significant differences for general combining ability (GCA) and specific combining ability (SCA). The highest contribution to the total variance was expressed by SCA for most important traits. The non-additive gene effects were found to be important for the inheritance of all traits except for plant height which was controlled by additive gene effect in the base material. The cms lines SA3 and SA4 and restorers SR41, SR45, SR10 and SR13 were better general combiners for most of the traits including seed yield across two seasons. The best combining hybrids for seed yield in the combined analysis were SA4 x SR1, SA3 x SR41, SA4 x SR45, SA3 x SR13 and SA3 x SR10. The greatest average contribution to the expression of most of the traits was found in the line x tester interaction, while the contribution of the female (A-line) and the male (R-line) were less significant. The simple correlation analysis revealed that seed yield was positively and significantly correlated with 1000-seed weight, head diameter and number of seeds per head and negatively correlated with percentage of empty seeds. Thus, the highly significant SCA effects in the superior crosses could be utilized in heterosis breeding to develop of high yielding local single-cross hybrids or produce synthetic composite varieties.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in the Sudan and the world. The development of hybrids with good agronomic performance is an important target in sunflower breeding programs. Therefore, hybrid sunflower became a reality with the discovery of cytoplasmic male sterility and effective male fertility restoration system during 1970. Hybrid vigor has been the main driving force for acceptance of this oilseed crop. In the Sudan, sunflower producers depended almost exclusively on imported seeds and the value of local hybrid and the importance of heterosis breeding were not sufficiently recognized. Nevertheless, one of the long term objectives of sunflower research program at the Agricultural Research Corporation (ARC) is to develop new single-cross sunflower hybrids characterized by uniform plant height, flowering date and seed quality. In addition, the hybrids are more stable, highly responsive to high-input agriculture and highly self-fertile, resulting in higher seedset in areas where pollinators are not abundant. Thus, the development of sunflower hybrids for Sudanese conditions is an important step towards narrowing down the gap between supply and demand in the seed market and boosting sunflower production and productivity in the country. This will also cut down the time and resources being spent on importations from abroad. Sunflower hybrid seed produced locally is likely to be adopted by the majority of sunflower growers, since the seed source is readily available (Mohamed, 2010).

Sunflower, as a cross-pollinated crop, provided an opportunity for developing new and superior hybrids through the use of breeding for heterosis. In heterosis breeding, the selection of parents/inbreds with good combining ability is very important in producing superior hybrids. The estimation of general combining ability (GCA) and specific combining ability (SCA) helps in identifying the potential parents/inbreds in the production of superior hybrids for seed yield, oil content and oil quality. Hence, estimation of combining ability is a pre-requisite in sunflower breeding where it aimed at the development of hybrids or improvement of lines.

The line x tester analysis(Kempthorne, 1957)is one of the simplest and efficient methods of evaluating large number of inbreds for combining ability and *per se* performance. Analysis of GCA and SCA is useful in knowing the type of gene action controlling various characters and development of suitable breeding strategies. Therefore, the objectives of this study were to determine the general combining ability and specific combining ability effects among parents and their crosses for seed yield and other agronomic traits, as well as components of genetic variance and to find out the best testers for testing F_1 hybrid combinations for important yield traitsas an attempt to develop high yielding local single-cross hybrids or produce synthetic composite varieties.

MATERIALS AND METHODS

The initial breeding material of cytoplasmic male sterile lines and their counterparts were introduced from France and Russia, respectively. The full-sib progeny method was used in both the female and maintainer lines (B-lines) for monitoring purity from pollen shedders and branching types. Plants selected as pairs of A and B-lines were characterized by uniformity in height, flowering period and emergence date. The four selected female parents (A-lines) and their maintainers (B-lines) were maintained and increased for further crossing and redesigned as SA1, SA2, SA3 and SA4, respectively. Ten R-lines (male or restorer lines) were developed from finished F_1-hybrids introduced by the program. Thus, theten male lines (R-lines SR1, SR2, SR3, SR6, SR7, SR10, SR 13, SR14, SR41 and SR 45) used for this study were characterized by uniformity in flowering, plant height, maturity and high degree of self-fertility and classified as branching types except SR 41, which is non-branching. The experiment was carried out during 2005-2007 at Sennar Research Station Experimental Farm in the clay plains of central Sudan (13° 33′ N, 33° 34′ E and 421masl). The soil is a vertisol with 60% clay content, pH of 7.8-8.5, about 0.4-0.5% organic carbon and 0.05% total nitrogen. The region has semi-arid climate with summer rainfall ranging from 300 to 600 mm. The average rainfall, temperature and relative humidity at Sennar from May 2007 to February 2008 are presented in Table 1.

Table 1. Meteorological data for summer and winter season of 2007-2008 at Sennar Research Farm of ARC, Sudan.

Month	Mean maximum temperature (C°)	Mean minimum temperature (C°)	Mean relative humidity (%)	Total rainfall (mm)
April 2007	41.7	21.7	23	12.8
May 2007	42.0	26.6	35	Nil
June 2007	37.9	24.7	66	115.8
July 2007	32.6	22.6	86	286.6
August 2007	32.1	22.7	85	266.7
September 2007	33.6	21.9	81	87.0
October 2007	37.6	22.3	68	17.9
November 2007	37.7	19.0	46	Nil
December 2007	35.3	16.3	50	Nil
January 2008	32.5	14.5	47	Nil
February 2008	34.6	17.0	49	Nil

Source: Sennar Meteorological Station, Sennar-Sudan.

The four cytoplasmic male sterile lines were crossed with the ten restorer lines (testers) in a field experiment in a line x tester mating design during 2005 and 2006 giving 40 F_1 hybrids. Hand pollination was used to develop the breeding material. Pollen grains from the male parent (R-line) were collected in toclassic Petri dish and then dusted on the stigmas of the florets of female parents (A-line) using cotton buds and covering with respective butter cotton bag. The pollinations were repeated 4-6 times on alternate days, to ensure the pollination of all florets in the three to five heads per each cross. These 40 F_1 hybrids (line x tester) along with 14 parents (including 4 lines and 10 testers) were tested at Sennar for summer and winter of 2007.

The materials were tested in a randomized complete block design with three replicates on the 15thof July for summer season and on the 13thof November for winter season. Three seeds per hill were sown to ensure uniform stand which was later thinned to one plant per hill. The plot size consisted of four rows per plot, each of 5 m in length with row to row and plant to plant distances of 0.80 m and 0.30 m, respectively. Nitrogen was applied at 80 kg urea per hectare. Irrigation was applied at intervals of 12-14 days depending on weather conditions. Hand weeding was carried out to keep the crop weed free. The harvest was done manually during the first and

second week of December and March for summer and winter seasons, respectively. Data were recorded on ten randomly selected plants from the middle inner two rows in each plot from each replication for the following traits; days to 50% flowering, plant height (cm), head diameter (cm), number of seeds per head, percentage of empty seeds, 1000-seed weight (g), and seed yield (kg/ha).

The analysis of variance procedure was carried out separately, for each season and then combined, using the IRRISTAT statistical analysis package for windows (2006). Analysis of variance for combining ability was done according to the line x tester analysis method, in which estimates of GCA variances ($б^2_{GCA}$) and SCA variances ($б^2_{SCA}$) were obtained as suggested by Singh and Chaudhary(1985). The significance of GCA and SCA effects were determined at the 0.05 and 0.01 levels using the t-test.

RESULTS AND DISCUSSION

Combining ability analysis

The combining ability analysis is an indication of the variances due to GCA and SCA, which represent a relative measure of the additive and non-additive gene action, respectively. The variance components due to GCA and SCA are used to derive conclusions regarding the gene action that is prevalent in determining any trait. Hence, the ANOVA for combining ability (combined over two seasons) from a line x tester design involving four females (lines) and ten males (testers), partitioning the variation due to hybrids (crosses) into three components namely females, males and their interactions is given in Table 2. However, the results revealed that the variance due to females (lines) was highly significant for all tested traits except for percentage of empty seeds. The mean squares due to males (testers) were also highly significant only for days to 50% flowering, plant height, head diameter, one thousand seed weight and seed yield. The variation due to female x male (line x tester) interactions was found significant for all the seven traits studied.

Table 2. Analysis of variance for combining ability for seven characters of 4 females, 10 males and 40 F_1- hybrids evaluated over two seasons of 2007at Sennar Research Station Farm.

Source/ trait	DF	PH	HD	NSH	ES	SW	SY
Crosses	36.86**	656.0**	6.53**	9280.58**	13.1**	126.1**	47472.2**
Females (F)	34.76**	721.3**	6.82**	18017.4**	13.1ns	139.4**	52745.8**
Males (M)	99.67**	4586.3**	26.6**	1542.1ns	2.72ns	541.9**	206182**
F x M	30.58**	197.53**	4.20**	7228.1**	14.2**	75.39**	28079.9**
Error	1.40	88.71	0.38	3080.74	0.37	6.65	5796.75

Where, DF = days to 50% flowering, PH = plant height (cm), HD = head diameter (cm), NSH = number of seeds per head, ES = percentage of empty seeds, SW = 1000-seed weight (g), and SY = seed yield (kg/ha).

*,** Significant at 0.05 and 0.01 levels of probability, respectively, and ns = non-significant.

Table 3. Estimates of variance due to GCA, variance due to SCA, additive variance (V_A), dominance variance (V_D), ratio of GCA to SCA and degree of dominance (V_A/V_D) of seven sunflower traits combined over two seasons of 2007at Sennar Research Station Farm.

Genetic component	DF	PH	HD	NSH	ES	SW	SY
GCA	1.74	116.97	0.60	121.51	-0.02	12.63	4827.81
F=0,V_A	3.49	467.8	2.39	486.03	-0.07	50.53	19311.2
F=1,V_A	6.98	635.7	4.78	972.06	-0.14	101.0	38622.3
SCA	9.73	36.27	1.28	1382.46	4.64	22.92	7427.73
F=0,V_D	9.73	145.0	5.10	5529.8	18.5	91.66	2971.9
F=1,V_D	38.92	580.36	20.40	22119.3	74.28	366.64	11887.6
V_D/ V_A $_{F=0}$	1.67	0.56	1.46	4.77	0.00	1.90	0.55
V_D/ V_A $_{F=1}$	2.36	0.79	2.07	3.37	0.00	1.35	0.39
GCA/SCA	0.18	3.22	0.47	0.09	0.00	0.55	0.65

Where: DF= Days to 50% flowering, PH = Plant height (cm), HD = Head diameter (cm), NSH = No. of seeds per head, ES = Percentage of empty seeds, SW = 1000- seed weight (g), & SY = Seed yield (kg/ha).

On the other hand, the mean square for GCA ($б^2$gca) was highly significant for plant height, indicating the importance of additive gene effect for this trait. The components of variance showed that SCA variance ($б^2$sca) was higher than GCA variance ($б^2$gca) for all traits studied except plant height, indicating the importance of non-additive gene effect for these traits. Also, as the variances due to SCA were highly significant for number of seeds per head and seed yield, these characteristics were influenced by dominant gene actions. Furthermore, the ratio of GCA to SCA variance ($б^2$gca/$б^2$sca) for all traits, except plant height, were less than one, indicating that the inheritance of these traits was due to the non-additive gene action. It revealed that dominance and epistasis played major roles in the inheritance of these traits. It also revealed the possibility of hybrid breeding for these traits. The estimates of non-additive gene actions for all the characters(except plant height) in this study were generally in agreement with the results reported by Gangappa *et al.*(1997), Shekar *et al.*(1998), Ashok *et al.*(2000), and Goksoy *et al.*(2004).

General and specific combining ability effects

The GCA and SCA effects of the parents and hybrids derived for assaying test genotypes in an L x T analysis for seven sunflower traits combined over two seasons is given in Tables 4 and 5, respectively. For days to 50% flowering, favorable GCA effects were shown by parents that manifested earliness by having negative GCA estimates for flowering time. In combined analysis, the favorable GCA effects in the negative direction were obtained by SR41 followed by SA4 and SR10 (good combiners for earliness), while the unfavorable GCA effect was obtained by SR7 (good combiner for late flowering) in a positive direction (Table 4). There is a variation among the crosses for earliness due to variation in SCA. Favorable negative and significant SCA effect was obtained by SA1 x SR1 followed by SA2 xSR10, SA2 x SR14 and SA3 x SR13. The latest flowering cross was SA2 x SR1 (Table 4). These results confirmed the findings of Shekar *et al.*(1998), Naik *et al.*(1999), Ashok *et al.* (2000) and Goksoy *et al.* (2004) who reported significant and negative SCA effects for early flowering. Also, as mentioned earlier, the greatest average contribution for this trait was 57% due to SCA in crosses, compared to 22% for lines and 21% for testers (Table 6).

The ratio of GCA/SCA effects was less than unity, which confirmed that this trait was controlled by non-additive gene action (Table 2).

Table 4. Estimates of GCA effects of 14 sunflower parents (4 lines and 10 testers) for seven traits evaluated across two seasons of 2007at Sennar Research Station Farm.

Parent	DF	PH	HD	NSH	ES	SW	SY
SA1	0.97**	-9.87**	-1.29**	-8.95	0.45**	-5.52**	-94.75**
SA2	2.07**	15.51**	0.013	-2.49	-0.12	-0.55	-34.22*
SA3	-1.23**	4.41*	0.32**	6.69	-0.22*	4.63**	97.29**
SA4	-1.80**	-10.05**	0.95**	4.76	-0.12	1.44**	31.68
SR1	1.98**	16.10**	-0.35*	-17.04	0.24	-3.62**	-0.01
SR2	-1.35**	-7.02**	-0.05	11.63	1.06**	-2.43**	-37.51*
SR3	-0.85*	-10.10**	-0.98*	-31.57*	0.21	-2.39**	-79.98**
SR6	0.57*	3.65**	-0.31*	-44.47*	-0.47*	-3.19**	-78.11**
SR7	3.15**	-1.85	-0.24	-27.84	2.35**	-3.01**	-55.21*
SR10	-1.43**	7.73**	0.46*	57.73**	-0.40*	3.20**	65.06**
SR13	0.82*	-4.94**	-0.64*	44.28*	-1.20**	1.74**	36.09*
SR14	-0.52*	-3.52	-0.30	-10.75	-0.37*	0.55	-27.96
SR41	-2.52**	-2.94	0.85*	52.40**	-0.99*	6.18**	104.85**
SR45	0.15	2.90	1.57**	-34.38	-0.45*	2.97**	72.77**
SE± line	0.48	3.85	0.25	22.66	0.25	1.05	31.08
SE±tester	0.31	2.43	0.16	14.33	0.16	0.67	19.66

Where, DF= days to 50% flowering, PH = plant height (cm), HD = head diameter (cm), NSH = number of seeds per head, ES = percentage of empty seeds, SW = 1000- seed weight (g), and SY = seed yield (kg/ha)

*,** Significant at 0.05 and 0.01 levels of probability, respectively, and ns = non-significant

Table 5. Estimates of SCA effects of 40 sunflower hybrids (crosses) for seven traits evaluated across summer and winter seasons of 2007 at Sennar Research Station Farm.

Hybrids	DF	PH	HD	NSH	ES	SW	SY
SA1 x SR1	-5.38**	-2.75	-0.54*	27.71	2.74**	0.07	-18.88
SA1 x SR2	0.28	-3.46	-1.44**	-26.64	1.32**	-1.60	5.39
SA1 x SR3	0.12	-2.38	0.39	-18.97	-1.79**	1.57	30.32
SA1 x SR6	2.03**	2.54	0.02	-8.84	0.39	1.93	33.88
SA1 x SR7	-2.88**	-4.30	1.51**	82.81*	-0.47	-1.45	18.62
SA1 x SR10	0.70	-2.21	0.02	58.20*	-0.90*	0.32	59.12
SA1 x SR13	0.78	11.12*	2.12**	-33.65	0.06	5.52**	-5.78
SA1 x SR14	-0.22	-1.63	-0.76*	16.45	-1.28**	-5.28**	-32.13
SA1 x SR41	2.45**	3.79	-0.57*	42.46	-2.82**	3.08*	-19.88
SA1 x SR45	2.12**	-0.71	-0.76*	-23.18	2.75**	-4.16*	-70.66*
SA2 x SR1	9.85**	4.36	0.33	21.55	0.24	-9.87**	-107.3*
SA2 x SR2	-0.15	-4.18	-0.54*	19.64	2.44**	3.69*	64.06*
SA2 x SR3	-0.65	-0.43	0.12	43.14	-0.80*	-0.54	17.86
SA2 x SR6	-0.73	14.49*	0.69*	-37.69	-0.73*	0.62	-50.81
SA2 x SR7	3.68**	-2.35	-1.62**	-51.18*	1.44**	4.32**	42.59

SA2 x SR10	-3.73**	-6.60	-0.31	-1.52	-1.90**	-6.04**	-78.74*
SA2 x SR13	-0.98*	3.07	-1.05**	45.96*	-0.89*	0.14	4.69
SA2 x SR14	-3.65**	5.32	1.88**	31.33	1.02**	7.14**	193.5**
SA2 x SR41	-2.32**	-3.60	0.56*	-21.62	-1.31**	0.80	-57.04
SA2 x SR45	-1.32*	-10.10*	-0.06	-49.61*	0.49	-0.26	-28.85

Table 5. Continued.

SA3 x SR1	-1.18*	-5.54	-0.95*	-75.43*	-2.00**	1.70	-71.06*
SA3 x SR2	0.15	8.25	2.39**	45.43*	-0.03	2.40*	50.25
SA3 x SR3	-0.68	3.34	0.01	-7.97	2.47**	-1.03	-75.72*
SA3 x SR6	0.57	-12.08*	-1.19**	-2.30	-1.59**	-4.71**	-20.39
SA3 x SR7	-1.68*	10.42*	0.74*	16.74	1.05**	2.79*	67.14*
SA3 x SR10	1.23*	2.84	-0.82*	1.76	2.82**	1.40	50.37
SA3 x SR13	-3.35**	-13.83*	0.74*	70.35*	-1.93**	3.70*	68.81*
SA3 x SR14	2.98**	-11.58*	-0.93*	-44.19	-1.34**	-4.83**	-172.8
SA3 x SR41	-0.35	2.50	0.12	-33.34	3.43**	-0.14	133.91**
SA3 x SR45	2.32**	15.67**	-0.10	28.94	-2.90**	-1.27	-30.47
SA4 x SR1	-3.28**	3.93	1.16**	26.17	-0.99*	8.10**	197.2**
SA4 x SR2	-0.28	-0.61	-0.41	-38.44	-3.73**	-4.49**	-119.7*
SA4 x SR3	1.22*	-0.53	-0.52*	-16.21	0.12	0.001	27.53
SA4 x SR6	-1.87*	-4.95	0.48	48.83*	1.93**	2.17*	37.32
SA4 x SR7	0.88	-3.78	-0.63*	-48.36*	-2.02**	-5.66**	-128.3**

SA4 x SR10	1.80*	5.97	1.12**	57.96*	-0.03	4.32**	-30.74
SA4 x SR13	3.55**	-0.36	-1.82*	-82.66*	2.75**	-9.36**	-67.71*
SA4 x SR14	0.88	7.89*	-0.19	-3.59	1.61**	2.97*	11.45
SA4 x SR41	0.22	-2.70	-0.11	12.49	0.70*	-3.74**	-57.00
SA4 x SR45	-3.12**	-4.86	0.91*	43.80	-0.34	5.69**	129.98**
SE ± SCA	0.97	7.69	0.50	45.32	0.50	2.11	62.17

Where, DF= days to 50% flowering, PH = plant height (cm), HD = head diameter (cm), NSH = number of seeds per head, ES = percentage of empty seeds, SW = 1000- seed weight (g), and SY = seed yield (kg/ha)
*,** Significant at 0.05 and 0.01 level of probability, respectively, and ^{ns} = non-significant

Development of dwarf or medium plant height is the recent trend in breeding work to avoid lodging of sunflower hybrids. In combining analysis, the favorable negatively significant GCA effects of plant height for parents wereSR3 followed by SA4, SA1, SR2 and SR13 (Table 4). The variation among crosses for plant height and favorable negatively significant SCA effects obtained by SA3 x SR13 (-13.83) followed by SA3x SR6 (-12.08), SA3 x SR14 (-11.58), SA2 x SR45 (-10.10) and SA2 x SR10 (-6.60) as a best cross-combinations for the development of dwarf to moderate height sunflower hybrids. While, the unfavorable SCA effect (in positive direction) was observed by SA3 x SR45 as the tallest cross (Table 5). These results agreed with the results of Kumar *et al.*(1998), Gokosy *et al.*(1999),Naik *et al.*(1999) and Ashok *et al.*(2000)who reported negative SCA effects for plant height in sunflower.

Head size is influenced greatly by environmental effects especially by plant population, soil moisture and soil fertility. Thus, the portion of total variation in head size attributable to genetic effects was often less than it was for certain other agronomic traits. Hence, for head diameter, positive values of GCA and SCA are desirable. Over two seasons, the favorable large head diameter having positive and significant GCA effects for parents were obtained by SR45, SA4, SR41, SR10 and SA3 (Table 4). The crosses that revealed positive and significant SCA effects were SA3x SR2 (2.39) followed by SA1xSR13 (2.12) and SA2xSR14 (1.88), whereas, the unfavorable negatively SCA effects hybrids were SA4 x SR13, SA2 x SR7 and SA1 x SR2 (Table 5). Also, from Table 2,SCA variances were higher than GCA variances for head diameter. This result provided an information that greater amount of genetic variability was due to SCA effects, indicating non-additive type of gene action being involved in this trait. Also, the greatest average contribution was obtained by SCA (45%) for crosses compared with GCA (24%) for lines and (32%) for testers (Table 6). This is desirable for heterosis breeding and can be exploited in hybrid seed production. These results are in accordance with the findings of Gangappa *et al.*(1997), and Kumar *et al.*(1998), who reported positive and significant SCA effects for head diameter in sunflower hybrids.

Number of seeds per head has a direct relationship with seed yield and consequently positive values of GCA and SCA effects are desirable. In this study, the parents having positive and significant GCA effects for this trait in the two seasons and across them were SR10, SR41 and SR13 (Table 4). The maximum number of seeds per head and favorable positively significant SCA effects were obtained by SA1 x SR7 (82.81) followed by SA3 x SR13 (70.5)and SA1 x SR10 (58.20), and the minimum number of seeds per head of hybrids were SA4 x SR13(-82.66),SA3 x SR1(-75.43)and SA2 x SR7 (-51.18) (Table 5). Thus, in the two seasons and across them and generally, the crosses have SCA variances higher than GCA variances for number of seeds per head, and also the ratio of GCA/SCA effects was less than unity, indicating that this trait is controlled by non-additive gene action. Also, the proportional contribution of SCA for crosses have reached 54% compared with GCA 45% for lines and 1% for tester (Table 6). This is desirable for heterosis breeding needed in hybrid production. These findings are in line with those reported by Gangappa *et al.* (1997) and Kumar *et al.*(1998).

In sunflower, disk flowers in the center of the head fail to produce seeds, a phenomena occurring in both open pollinated varieties as well as hybrids. It varies in extent and severity depending on genotypes and environment. In this case, negative GCA and SCA effects are desirable for achieving low percent empty seed in genotypes. Based on estimates of GCA effects for parents in the combining analysis (Table 4), the best combiner parents for lower empty seeds per head was SR13 followed by SR41 and SR6 and the poor combiner for this trait was SR7 followed by SR2 and SA1. With reference to crosses the best cross-combinations that had negative and significant SCA effects were SA4 x SR2 (-3.73), SA3 x SR45 (-2.90), SA1 x SR41 (-2.82), SA4 x SR7 (-2.02) and SA3 x SR1 (-2.00). The crosses that had positive and significant SCA effects were SA3 x SR41 (3.43) and SA3 x SR10 (2.82) (Table 5). Furthermore, the greatest average contribution for this trait in combined analysis was obtained by SCA (75%) compared with GCA (23% for lines and 2% for testers). Also, the contributions of hybrids (SCA variances for crosses) were greater than their parents (GCA for lines and testers) and the ratio of GCA/SCA was zero which was less than unity. This indicates that this trait is predominantly controlled by non-additive gene action (Table 2).

For one thousand seed weight, positive values of GCA and SCA are desirable. In this study the best combining parents having significant positive GCA were SR41, SA3, SR10 and SR45 in the combined analysis. Also, in both seasons and their combined, the unfavorable GCA effects parent was shown by parent SA1 followed by SR1 (Table 4). Among the crosses, the best cross-combinations with positive and significant SCA effects were SA4 x SR1 (8.10) followed by SA2 x SR14 (7.14), SA4 x SR45(5.69) and SA1 xSR13 (5.52), so the negative cross was SA2 x SR1 (-9.87) followed by SA4 x SR13(-9.36) and SA2 x SR10 (-6.04) (Table 5). On the other hand, the SCA variances were higher than GCA variances for 1000-seed weight. Also, the ratio of GCA/SCA was less than unity, which provide information that greater amount of genetic variability, was due to SCA effects. These results indicate non-additive type of gene action being involved for controlling this character. Also, the average contribution in their combined analysis showed higher SCA (41%) than GCA (26% for lines

and 33% for testers) (Table 6). However, these results confirmed those of Ashok *et al*., (2000)and Goksoy *et al.* (2004).

Proportional contribution

The proportional contribution of lines, testers, and their interaction to the total variance are presented in Table 6. There were different contribution of lines, testers, and their interaction in expression of the studied traits. The contribution of maternal and paternal interaction (line x tester) was very high for all traits except for plant height. It revealed preponderance of paternal and maternal interaction (line x tester) influence for all these traits, while it revealed preponderance of paternal (testers) influence for plant height. These results confirmed those reported by Goksoy *et al.* (2004).

Table 6. Proportional contribution of lines, testers and their interaction in seven sunflower traits evaluated over two seasons of 2007 at Sennar Research Station Farm.

Character	DF	PH	HD	NSH	ES	SW	SY
Lines	21.76	25.37	24.10	44.80	23.10	25.53	25.64
Testers	20.80	53.78	31.37	1.28	1.60	33.07	33.41
L x T	57.44	20.85	44.54	53.92	75.30	41.42	40.95

Where; DF= Days to 50% flowering, PH = Plant height (cm), HD = Head diameter (cm), NSH = No. of seeds per head, ES = Percentage of empty seeds, SW = 1000- seed weight (g) and SY = Seed yield (kg/ha).

Yield is a polygenic character, influenced by the fluctuating environments. Also, it is a complex trait depending on many components. Therefore, one of the main directions of sunflower breeding in the Sudan and elsewhere is the development of hybrids with high genetic potential for seed yield and with plant architecture adaptable to varying environmental conditions. In the combined analysis, GCA effects for seed yield ranged from – 95 for SA1 to 105 for SR41. The best general combining parents for seed yield were SR41, SA3, SR45, SR10 and SR13(Table 4). With regards to specific combining ability, twenty crosses showed significant SCA effects for higher seed yield. However, the variation among the crosses revealed positive and significant SCA in SA4 x SR1 (197.2), SA3 x SR41 (133.91), SA4 x SR45 (129.98), SA3 x SR13 (68.81)and SA3 x SR10 (50.37). While, the unfavorable negatively SCA effects were in SA3 x SR14(-172.8), SA4 x SR7 (-128.3) and SA4 x SR2 (-119.7) (Table5).

Specific combining ability variances were higher than general combining ability variance for seed yield, an indication of non-additive type of gene action being involved for this trait. Also, the non-additive component of genetic variance was more influential in the inheritance of seed yield, as confirmed by the GCA/SCA ratio being below one in the F_1 generation (0.65) (Table 3). Hence, the greatest average contribution to the expression of seed yield (41%) was found in the lines x testers. The contribution of 26% by lines and 33% by testers were insignificant (Table 6). These results were in agreement with the findings of Gangappa *et al.*(1997), Kumar *et al.*(1998), Goksoy *et al.* (1999), Naik *et al.*(1999),Ashok *et al.*(2000)and Goksoy and Turan (2004).

Therefore, across two seasons, parents including SR10, SR13, SR41, SR45, SA3 and SA4 all have positive GCA effects for seed yield. Out of these parents SR41, SA3 and SR10 had positive effects for 1000-seed weight and head diameter, in addition to positive GCA effects for number of seeds per head except SA3 (male sterile line) which has negative GCA effect for number of seeds per head. Those parents have high potential for seed yield and other desirable traits. Also, those parents are more suitable for recombination for developing parents of hybrids for both rainfed and irrigated systems of Sudan.

Information on the relative amount of GCA and SCA variances is of great value in the development of efficient breeding programs. In the present study, the ratio of GCA and SCA variance was less than one for seed yield, 1000-seed weight, number of seeds per head, head diameter, and days to50% flowering. This implies that gene action for these traits was non-additive in nature. Also, the relative contribution of line x tester interactions was found more important for the above mentioned traits.

With regards to SCA across two seasons, the best crosses with positive SCA effects for seed yield were SA3 x SR41, SA3 x SR10, SA3 x SR13, SA4 x SR45 and SA4 x SR1. In this study, the estimates of SCA effects revealed that the best crosses were SA1 x SR1 for days to flowering, SA3 x SR13 for plant height, SA3 x SR2 for head diameter, SA1 x SR7 for number of seeds per head, SA4 x SR2 for percentage of empty seeds, SA4 x SR1 for 1000-seed weight and SA4 x SR1 followed by SA3 x SR41 and SA4 x SR45for seed yield.

Therefore, high SCA effects resulting from crosses between higher general combiners can be improved through early selection. High SCA effects resulting from low GCA combiners suggest that such crosses may be utilized for further improvement through single plant selection in the later generations.

Trait association

The rank correlation coefficients of general combining ability (GCA) between agronomic traits of sunflower parents across the two seasons were presented in Table (7). Seed yield was positively and significantly correlated with 1000-seed weight(r =0.88**), and head diameter (r =0.71**) and significantly correlated with days to 50% flowering(r =0.50*).The highest correlation coefficients with seed yield were recorded with seed weight and head diameter, indicating the importance of these components in sunflower seed yield. This result agreed with the results obtained by Nehru and Manjunath(2003) and Wani(2004) who independently reported positive association between seed yield with head diameter and number of seeds per head. Also, seed yield per head (data not shown) and seed yield were highly significant and positively correlated with days to 50% flowering, head diameter, number of seeds per head and 1000-seed weight. This indicates the importance of these characters as yield components. This strong association could be due to the fact that head size is determined by its diameter and the yield per plant is determined by seed number per head and weight per 1000 seeds. Generally, the large –sized heads give more seeds; hence the plant will yield more if the weight of1000 seeds is also high. Thus, number of filled seeds and 1000-seed weight exert the highest direct effects on seed yield.

Table 7. Coefficient of rank correlation for various traits based on ranking GCA effects for sunflower parental populations and lines across two seasons.

	DF	PH	HD	NSH	ES	SW
PH	0.32					
HD	0.53*	0.25				
NSH	0.52*	0.11	0.29			
ES	0.35	0.11	0.29	0.22		
SW	0.64**	-0.10	0.70**	0.57*	0.65**	
SY	0.50*	-0.35	0.71**	0.53*	-0.60 *	0.88**

DF = days to 50% flowering, PH = Plant height (cm), HD = Head diameter (cm), NSH = number of seeds per head, ES = Percentage of empty seeds, SW = 1000- seed weight (g), and SY = Seed yield (kg/ha).

*,** Significant at, 0.05 and 0.01 levels of probability, respectively

Seed yield was negatively and significantly correlated (r = -0.60*) with percentage of empty seeds; negative but not-significantly correlated with plant height. This indicates that percentage of empty seeds depends mainly on some of sunflower morphological character like plant height. Because the increase in stem diameter leads to increase in plant height and total vegetative surface, hence reducing the seed set and seed yield. On the other hand, days to 50% flowering showed a significant and positive correlation with head diameter with r value of 0.53* (Table 7). This indicates that early flowering provides sufficient time for seed formation process and good seed filling period with respect to head diameter. Also, this result suggested that seed yield is positively correlated with good vegetative growth and the earliness can be reliable selection criteria for seed yield in sunflower for genetic materials under study. Thus, sunflower seed yield per unit area can be enhanced by improving days to flowering, head diameter, number of seeds per head and 1000-seed weight.

CONCLUSION

Based on the study results, significant differences were found among the genotypes studied (parents and hybrids) in the general and specific combining ability effects. The sunflower female lines SA3 and SA4 and the restorers SR 41, SR 45, SR 10 and SR 13 were better general combiners for most of the traits including seed yield across two seasons. However, the hybrid demonstrated best specific combining ability effects for seed yield was SA4 x SR1 followed by SA3 x SR41, SA4 x SR45, SA3 x SR13and SA3 x SR10.The non-additive component of genetic variance played the main role in the inheritance of all traits except plant height, as shown by the analysis of variance of combining abilities and genetic variance components. This was supported by the GCA/SCA ratio in the F_1 generation, which was below the value of one of all traits (except plant height) across two seasons of study. Also, the relative contribution of line x tester was very high, which revealed predominance of parental and maternal interaction influence for all traits except plant height. Hence, testers played an important role towards plant height, which revealed predominance of parental influence for this trait. Furthermore, simple correlation analysis revealed that seed yield was positively and significantly correlated with 1000-seed weight, head diameter and number of seeds per head, and negatively correlated with percentage of empty seeds.

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المقدرة علي التآلف لإنتاجية البذور ومكوناتها
في محصول زهرة الشمس (*Helianthus annuus* L.)

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الخلاصة

أجريت هذه التجربة بتهجين أربعة خطوط ذات عقم سايتوبلازمى ذكرى مع عشرة خطوط معيدة لخصوبة من محصول زهرة الشمس باستخدام تحليل Line x Tester في موسمي صيف وشتاء 2007 بمحطة بحوث سنار – السودان لتقدير المقدرة العامة والخاصة على التآلف لإنتاجية البذور ومكونتها لأربعة عشر من الآباء وأربعين من هجن الزهرة. أجريت التجربة بالقطاع المروى باستخدام تصميم القطاعات العشوائية الكاملة بثلاثة مكررات. كانت الصفات المدروسة هي عدد الأيام حتى 50% إزهار ، طول النبات، قطر القرص ، عدد البذور بالقرص، نسبة البذور الفارغة، وزن الآلف حبة، وإنتاج البذور (كيلوجرام/هكتار). أظهر تحليل التباين للقدرة على التالف قدرة الارتباط بين الآباء وأهمية كل من الفعل الجيني الإضافي وغير الإضافي في توريث الصفات المدروسة. بيد أن تأثيرات الفعل الجيني الإضافي كانت مهمة في توريث صفة طول النبات وأن الفعل الجيني غير الإضافي كانت مهمة في توريث معظم الصفات المدروسة. تأثيرات القدرة العامة للاتحاد أظهرت أن الأبوين العقيمين SA3 وSA4 والآباء الخصبة SR45, SR41, SR10,SR13 هم الأفضل في القدرة على الاتحاد العام لمعظم الصفات بما فيها صفة أنتاج البذور خلال الموسمين والتحليل المشترك. وأفضل قدرة للاتحاد الخاص لصفة أنتاج البذور في التحليل المشترك ، أظهرت بواسطة الهجن SA4 x SR1, ، SA3 x SR41، SA4 x SR45، SA3 x SR 13 وSA3 x SR10.أظهرت الدراسة أن مساهمة تفاعل الآباء المذكرة مع الآباء المؤنثة في توريث معظم الصفات اكبر من مساهمة أي من الأبوين منفرداً. ارتبطت إنتاجية البذور ارتباطاً موجباً مع وزن الألف بذرة، وقطر القرص، وعدد البذور بالقرص وسلبياً مع نسبة البذور الفارغة. وعليه الفروقات المعنوية الكبيرة لتأثير القدرة الخاصة على التآلف في التهجينات المتفوقة يمكن الاستفادة منها في برنامج التربية لتطوير هجن مفردة محلية من الزهرة ذات إنتاجية عالية من البذور أو في تطوير أصناف تركيبيه.