Study of gene action and combining ability for seed yield and yield attributing traits in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Eight CMS lines and seven restorers were crossed in a line x tester fashion to elucidate the information on combining ability for achene yield, yield components and oil content and also to know the nature of gene action involved in inheritance of important traits. A total of 56 crosses were evaluated for 9 different quantitative traits. The analysis of variance revealed the existence of a statistically significant difference between the genotypes used in crossing, which confirmed the differences among selected parents. Among the lines, CMS-853A and CMS-852A exhibited significant *gca* effect for most of the characters studied except autogamy (%) and were found to be the best combiners. Likewise, tester EC-601878 was the best combiner for plant height, head diameter, days to 50% flowering, achene yield, autogamy (%), hull content, volume weight and oil content. Twenty-three crosses showed significant positive *sca* effect for yield. Among the crosses, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878 and CMS-853A x EC-623027 exhibited higher positive *sca* effect for yield. Non additive component of the genetic variance was observed for majority of the traits studied.

Keywords: Achene yield, Combining ability, Gene action, Sunflower, Oil content

Sunflower (*Helianthus annuus* L.) is an important oilseed crop in India popularly known as Surajmukhi. The crop is insensitive to day-length and is considered a short duration, requiring about 110 days from planting to harvesting (Putnam *et al.,* 1990; Salunkhe, 1992). Sunflower crop fits well in different types of cropping patterns due to short duration. Sunflower contribution towards attaining self-sufficiency in edible oil as well as to "yellow revolution" has been documented (Mangala Rai, 2002). The main objectives of sunflower breeding programs are the development of productive F1 hybrids with high achene yield and high oil content. The national sunflower hybrid breeding programme was started in early 1980s. Sunflower hybrid breeding was started economically after discovering of CMS by Leclercq in 1969 and restorer line by Kinman in 1970. First sunflower hybrids were produced in US in 1972 and hybrids occupied 80% area in five years (Miller and Fick, 1997). Availability of CMS and fertility restoring sources and highly cross-pollinated nature of sunflower crop has made the exploitation of heterosis possible on commercial scale. In India, the first sunflower hybrid BSH-1 (CMS-234A x RHA-274) was released for commercial cultivation by University of Agricultural Sciences, Bangalore (Seetharam *et al.,* 1980). Since then, 29 hybrids have been released by public sector which are in commercial cultivation (Sujatha *et al.,* 2019). The superiority of hybrids over open pollinated varieties in terms of uniformity, autogamy, productivity, yield stability, oil content and tolerance to pest and diseases shifted the breeding emphasis from population improvement to heterosis breeding. Careful and critical evaluation and selection of parental lines to develop promising hybrids with improved yield potential is of paramount importance in order to improve production and productivity. Combining ability studies elucidates the nature and magnitude of gene action involved in the inheritance of character by providing the information on the two components of variance *viz.,* additive and dominance variances, which are important to decide upon the parents and crosses to be selected for eventual success (Jondhale *et al.,* 2014). The line × tester analysis is one of the efficient methods of evaluating large number of inbred lines as well as providing information on the relative importance of general combining ability and specific combining ability effects for interpreting the genetic basis of important plant traits. Combining ability analysis helps in identification of best parents for further exploitation in breeding programme. The usefulness of a particular cross in exploiting heterosis is judged by the specific combining ability (*SCA*) effect. Based on the combining ability analysis of different characters, higher *SCA* values refer to dominant gene effects and higher *GCA* effects indicate a greater role of additive gene effects controlling these characters. If both the *GCA* and *SCA* values are not significant, epistatic gene effects share an important role in determining these characters (Fehr, 1993). The present investigation was undertaken to select parents with good *gca* effect and crosses with good *sca* effect through line x tester analysis. This study also gives an idea on the nature of gene action involved in inheritance of important quantitative traits. The objective of

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this study was to estimate *GCA* and *SCA* of parents so as to identify superior combiners for high achene yield and yield contributing traits.

MATERIALS AND METHODS

A set of eight cytoplasmic male sterile lines *viz.,* CMS-850A, CMS-852A, CMS-10A, CMS-853A, P-89-1A, CMS-103A, P-2-7-1A, CMS-207A and seven restorers *viz*., EC-601878, EC-623023, EC-623016, EC-623027, EC-601751, EC-601725, EC-623021 were planted during 2014-15 at Nimpith, West Bengal. The seed material was obtained from ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad and other sunflower AICRP centres. Crossing was performed in line x tester fashion and seeds were harvested separately to study the combining ability analysis. During late *rabi* 2015-16, seven selected exotic collection lines as testers, eight CMS lines, resultant 56 F_1 hybrids along with three checks were sown in a Randomized Block Design (RBD) with two replications. Each entry was raised with two rows in a plot size 3.0 m x 0.6 m by adopting a spacing of 60 cm between rows and 30 cm between plants. Observations were recorded on five randomly selected plants on 9 quantitative characters *viz.,* days to 50 per cent flowering, plant height (cm), head diameter (cm), achene yield (kg/ha), 100 seed weight (g), autogamy (%), hull content (%), volume weight (g/100 ml) and oil content (%). The analysis of variance was computed as per Panse and Sukhatme (1954), for all the characters. Data were further analyzed for general and specific combining abilities, following Line × Tester analysis given by Kempthorne (1957). The significance of *GCA* and *SCA* effects was determined at the 0.05 and 0.01 levels using the t-test.

RESULTS AND DISCUSSION

The analysis of variance for parents and crosses (Table 1) indicated significant differences for all the characters indicating the existence of genetic diversity in the parental material. Mean sum of squares for crosses were also found to be significant for all the traits. The lines, testers and line v/s testers exhibited significant differences among themselves for all characters except 100 seed weight in lines and testers and 100 seed weight and oil content in lines v/s testers. Our results are in conformity with Ortis *et al.* (2005) and Binodh *et al.* (2008). It could be because of the diverse nature of testers and the significant interaction between lines and testers. The parent v/s crosses interactions had non-significant difference for all the characters studied. Similar results have also been reported by Habib *et al.* (2007) and Khan *et al.* (2008). The variance component due to specific combining ability (*sca*) was greater in magnitude than that of general combining ability (*gca*) for all characters indicating predominance of non-additive type of gene action which is in agreement with the findings of Radhika *et al.* (2001), Sakthivel (2001), Varaprasad *et al.* (2006) and Jondhale *et al.* (2014). Additive type of gene action was noticed for plant height only while, additive and non-additive types of gene action was reported for achene yield. Additive gene action was reported for plant height, days to 50% flowering (Bhat *et al.,* 2000) and head diameter (Gvozdenovic *et al.,* 2005).

The general combining ability effects (Table 2) indicated that among the lines, CMS-103A followed by CMS-850A, CMS-852A and CMS-10A possessed genes for earliness as evident from its significant negative highest *gca* effect in desirable direction for days to 50 per cent flowering. Among the testers, EC-623016 followed by EC-601878, EC-601751 and EC-601725 recorded significant negative *gca* effect in desirable direction for days to 50% flowering. Early duration hybrids are required for North India during *rabi* and spring seasons. Hence, above mentioned lines and testers can serve the purpose and can be utilized for development of early hybrids. Dwarf or medium plant height is desirable for sunflower hybrids. Line CMS-103A showed highest significant negative *gca* effect for plant height followed by CMS-850A. These results are in contradiction with the finding of Goksoy *et al.* (2000). These two CMS lines can be exploited for development of medium to dwarf hybrids. Among testers, none of the lines was dwarf. For head diameter, almost all the lines and testers exhibited significant positive *gca* effect except CMS-850A and CMS-103A. Among the female parents, highest positive significant *gca* effect was reported in CMS-853A followed by CMS-852A, P-89-1A and P-2-7-1A for achene yield. Significant positive *gca* effect for achene yield was reported by all the testers while highest was reported by tester EC-601725 followed by EC-623027, EC-623021 and EC-601751.

Higher 100-seed weight contributes to higher seed yield. Among lines, CMS-853A and among testers, EC-623027 and EC-601751 exhibited high *gca* effect in desirable direction for 100 seed weight. For autogamy (%), among lines, only two P-89-1A and CMS-103A showed significant positive *gca* effect while among testers, EC-601878 and EC-623016 exhibited *gca* effect in desirable direction. *GCA* effect in the desirable direction for hull content was reported in CMS-850A and CMS-103A among the lines and among the testers in EC-601878 and EC-623016. Among lines, highest significant negative *gca* effect was reported in CMS-850A followed by CMS-10A, CMS-103A and CMS-207A while among testers, EC-623016 followed by EC-623021, EC-601751 and EC-601878 in desirable direction. For oil content, only EC-601878 exhibited significant positive *gca* effect in desirable direction. These results were in agreement with Ashok *et al.* (2000). In the present study, significant *gca* effect for achene yield was also observed as reported earlier by Radhika *et al.* (2001). Many workers, have reported good general combiners for most of the characters in sunflower (Halaswamy *et al.,* 2004; Manivannan *et al.,* 2005; Tavade *et al.,* 2009). The parents, which are good general combiners for economic traits, may be extensively used in hybridization programmes.

Table 1 Analysis of variance for yield and yield components

Source of variation	d. f.	Days. to 50% flowering	Plant height (cm)	Head diameter (cm)	Autogamy %	100 seed weight (g)	Hull content (%)	Volume weight (g/100 ml)	Achene yield (kg/ha)	Oil content (%)
Location	1	212.46	2978.5**	28.01	176.9	1.182	26.22	39.01	441289.2**	10.58
Repl./Loc	2	27.14	540.8	9.03	26.21	2.887	5.93	19.17	143396.6*	18.21
Line	7	194.04**	9449.0**	25.2**	36.11**	3.522	57.04**	35.63**	1965372.0**	9.49**
Tester	6	74.85**	4816.9**	20.23**	17.35**	0.640	55.80**	14.16**	958346.7**	6.49*
L x T	42	31.86**	510.12**	21.50**	10.51**	0.654	16.30**	13.60**	176794.2**	2.38
L x Loc.	7	0.382	6.92	0.031	0.216	0.004	0.034	0.028	1501.09	0.007
T x Loc.	6	0.360	4.27	0.036	0.199	0.003	0.009	0.033	1278.4	0.004
L x T x LC	42	0.290	2.37	0.026	0.015	0.002	0.054	0.010	752.3	0.005
Error	110	0.002	0.261	0.002	0.029	0.003	0.008	0.006	98.22	0.002
VGCA		3.41	220.6	0.678	0.548	0.047	1.34	0.375	42814.23	0.187
VSCA		15.93	253.76	11.25	5.24	0.83	8.15	6.802	88348.02	1.19
Gene action		Non additive	Additive	Non additive	Non additive	Non additive	Non additive	Non additive	Additive & Non-additive	Non additive

*Significant at 5% level; **Significant at 1%

Table 2 Estimation of general combining ability effects of male and female parents for yield and yield contributing traits

Name of the parent	Plant height (cm)	Head diameter (cm)	Days to 50% flowering	Achene yield/plant (g)	100 seed weight (g)	Autogamy (%)	Hull content (%)	Volume weight (g/100 ml)	Oil content (%)
Lines									
CMS-850A	-6.25**	-0.22*	-1.82**	- 6.08*	-1.28*	0.35	-0.56*	-0.55*	-0.55*
CMS-852A	8.65**	0.66**	-0.61*	13.27**	1.22*	0.32	0.45*	0.57*	-0.58*
CMS-10A	11.45**	0.45**	-0.55*	5.42	-1.08*	0.41	0.45*	-0.48*	-0.65*
CMS-853A	14.45**	0.81**	0.41**	14.42**	1.62*	0.32	0.41*	0.71*	-0.71*
P-89-1A	9.56**	0.52**	-0.35	10.55**	-1.16*	0.71*	0.49*	0.35*	-0.55*
CMS-103A	-9.87**	-0.26*	-2.31**	-7.42*	-1.56*	0.83*	-0.78*	-0.38*	-0.48*
P-2-7-1A	9.02**	0.46**	-0.29	10.51**	-1.02*	0.65	0.41*	0.47	-0.56*
CMS-207A	7.12*	0.36**	-0.31	8.28*	-1.16*	0.37	0.41*	-0.41*	-0.55*
SEm(±)	2.62	0.14	0.12	3.48	0.05	0.25	0.27	0.31	0.31
Testers									
EC-601878	3.41*	0.81 **	-0.72*	5.08*	-1.18*	0.73*	-0.25*	-0.47*	0.39*
EC-623023	8.85**	0.89**	1.17**	10.08**	-1.18*	-0.25	0.32*	0.55*	-0.37*
EC-623016	8.25**	0.49**	-1.14*	6.27**	-1.42**	0.65*	-0.35*	-1.06**	-1.25**
EC-623027	11.25**	1.58**	1.54**	14.27**	1.22**	0.35	0.25*	1.21**	-0.38**
EC-601751	8.21**	1.17**	-0.72*	10.08**	0.75*	-0.38	0.36*	-0.55*	-0.55*
EC-601725	6.28**	1.09**	-0.55*	14.55**	-1.28*	-0.27	0.25*	0.57*	-1.26**
EC-623021	12.25**	1.60**	0.64*	11.23**	-1.02*	-0.45	-0.40	-1.05**	-1.05**
SEm(±)	4.28	0.21	0.38	1.28	0.07	0.36	0.56	0.41	0.36

*Significant at 5% level; ** Significant at 1% level

Table 3 *Per se* performance and corresponding *sca* effect for yield and yield attributing characters

Hybrid combination	Days to 50% flowering		Plant height (cm)		Head diameter (cm)		Achene yield (kg/ha)		Autogamy (%)	
	Per se	*sca*	*Per se*	*sca*	*Per se*	*sca*	*Per se*	*sca*	*Per se*	*sca*
CMS-853A x EC-623027	73	-1.25*	194.5	7.10**	16.4	-0.03	2462	218.0**	87	-0.82*
CMS-853A x EC-623023	75	2.13*	186.5	10.33**	16.0	0.03	2428	212.5**	87	-0.09
CMS-853A x EC-623021	74	0.47	174.0	-4.23*	15.7	-0.09	2292	157.3**	87	-0.67*
CMS-853A x EC-601751	69	-4.95**	158.0	-14.52**	15.4	-0.94*	1861	-411.5**	91	4.06**
CMS-853A x EC-601778	68	0.57	145.0	-11.20**	15.5	1.38*	1575	-202.1**	86	-2.56**
CMS-853A x EC-601725	75	2.13*	192.5	20.03**	16.4	0.147	2278	3.1	87	0.42
CMS-853A x EC-623016	72	-0.09	160.5	-7.50**	15.0	-0.50	2072	22.5	87	-0.34
CMS-852A x EC-623027	76	1.62*	185.0	2.37	15.1	1.02*	2270	-14.1	92	2.02**
CMS-852A x EC-623023	76	2.55*	180.0	3.79	15.4	0.29	2328	69.8**	88	-1.23**
CMS-852A x EC-623021	77	3.34**	184.0	5.30*	15.4	0.10	2272	92.6**	91	1.17**
CMS-852A x EC-601751	72	-1.58*	170.1	-3.00	15.4	0.65*	2284	-44.0*	90	0.45
CMS-852A x EC601878	66	-3.90**	153.0	6.11*	15.0	1.09*	1761	-66.6*	91	0.28
CMS-852A x EC-601725	70	-2.87*	155.0	-16.14**	16.7	0.77*	2072	-243.1**	87	-1.22**
CMS-852A x EC-623016	73	0.84	175.5	6.91*	15.3	1.09*	2306	205.5**	88	-1.48**
CMS-850A x EC-623027	69	0.99	133.0	-0.81	15.2	1.05*	1861	137.3**	91	-0.12
CMS-850A x EC-623023	64	-3.01**	122.5	-0.03	13.8	0.12	1472	-214.4**	91	-0.36
CMS-850A x EC-623021	63	-4.67**	112.0	-12.67**	13.2	-1.26**	1340	-265.8**	90	-1.46**
CMS-850A x EC-601751	69	1.24*	133.0	13.18**	15.4	-1.31**	1861	93.6**	91	0.32
CMS-850A x EC-601878	65	1.92*	92.5	0.66	9.6	2.12**	1500	229.4**	94	1.10**
CMS-850A x EC-601725	69	1.36*	112.0	6.44*	13.7	-0.22	1836	77.0**	91.	1.13**
CMS-850A x EC-623016	68	2.15*	122.5	7.47*	13.3	0.11	1472	-57.1**	91	-0.61*
CMS-103A x EC-623027	67	0.50	138.5	-6.19*	13.5	-0.05	1350	-127.6**	89	-1.41**
CMS-103A x EC-623023	67	0.92*	135.0	1.45	12.7	-0.35	1340	-100.12**	90	-0.15
CMS-103A x EC-623021	66	-0.73	132.0	-3.99	12.7	-0.12	1348	-22.7	90	-0.25
CMS-103A x EC-601751	67	0.25	130.1	-0.50	13.4	-0.06	1472	-42.5*	91	1.53**
CMS-103A x EC-601978	66	3.35**	124.5	19.83**	12.8	1.59**	1533	504.4**	90	-1.15**
CMS-103A x EC-601725	62	-3.50**	120.5	-8.87**	12.2	-1.09*	1232	-268.6**	91	1.85**
CMS-103A x EC-623016	64	0.79	124.0	-1.81	12.7	1.11*	1340	57.1**	90	-0.43
P-2-7-1A x EC-623027	73	1.50*	184.0	8.22**	16.4	0.65*	2094	-6.0	89	-0.24
P-2-7-1A x EC-623023	68	-2.53*	145.5	-18.30**	15.7	0.40*	2192	117.2**	88	-0.48
P-2-7-1A x EC-623021	70	0.78	168.5	7.22*	14.9	0.40*	1872	-26.6	90	1.19**
CP-2-7-1A x EC-601751	76	4.69**	177.5	15.84**	15.8	0.14	2340	90.3**	87	-1.28**
P-2-7-1A x EC-601978	64	-2.59*	137.5	2.54	11.5	-1.84**	1340	-297.1**	90	0.47
P-2-7-1A x EC-601725	68	-2.53*	145.5	-14.66**	15.7	0.16	2192	54.0*	88	0.50
P-2-7-1A x EC-623016	70	0.70	155.5	-1.05	14.9	0.09	1878	-31.7	90	0.77*
CMS-207A x EC-623027	63	-6.54**	142.5	20.87**	14.0	-1.09*	1567	-325.1**	92	2.30**
CMS-207A x EC-623023	73	3.74**	142.5	-9.84**	14.7	0.06	2194	313.8**	88	-1.42**
CMS-207A x EC-623021	70	0.6	167.0	11.65**	14.4	-0.05	1886	90.9**	90	1.45**
CMS-207A x EC-601751	68	-1.87*	145.5	-4.35*	15.7	0.65	1962	16.4	88	-0.77*
CMS-207A x EC-601978	67	1.23*	115.0	8.05**	13.5	0.72	1431	-13.8	90	-0.44
CMS-207A x EC-601725	71	2.27*	172.5	23.23**	14.8	-0.11	2017	77.8**	86	-2.41**
CMS-207A x EC-623016	68	0.55	153.0	7.88*	14.0	-0.18	1547	-159.9**	92	2.30**
P-89-1A x EC-623027	73	1.21*	180.0	12.75**	15.6	0.50*	2218	225.4**	88	-0.97*
P-89-1A x EC-623023	73	1.64*	168.5	12.58**	15.0	0.37	1974	14.9	89	0.27
P-89-1A x EC-623021	71	-1.02*	148.5	-9.31*	14.2	-0.20	1856	-22.6	89	0.17
P-89-1A x EC-601751	71	-1.01*	154.0	1.35	15.1	0.12	2144	109.8**	85	-3.01**
P-89-1A x EC-601978	68	0.58	123.0	-3.35	12.0	-0.69*	1445	-84.8**	91	1.27**
P-89-1A x EC-601725	73	1.64*	148.5	-3.08	15.0	0.13	1960	-61.7**	89	1.25**
P-89-1A x EC-623016	67	-3.05**	136.5	-11.12*	13.9	-0.24	1611	-181.5**	90	1.02**
CMS-10A x EC-623027	72	1.98*	167.5	2.18	15.4	-0.02	1722	-107.8**	88	-0.77
CMS-10A x EC-623023	64	-5.47**	154.0	0.03	14.6	-0.32	1380	-413.8**	92	3.41**
CMS-10AA x EC-623021	71	1.22*	162.5	5.94*	15.2	0.45*	1722	-2.9	8	-0.67
CMS-10A x EC-601751	73	3.23*	142.5	-8.26**	14.7	-0.58*	1967	87.5**	87	-1.31**
CMS-10A x EC-601978	64	-1.60*	119.0	-5.45*	12.8	-0.23	1306	-69.7**	92	1.97**
CMS-10A x EC-601725	70	0.94	156.5	6.33*	15.4	0.18	2240	361.4**	86	-1.50**
CMS-10A x EC-623016	68	0.31	145.5	-0.77	15.0	0.52*	1792	145.2**	87	-1.26**
S.Em(±)	0.11	0.09	0.05	0.04	0.263	0.227	0.162	0.140	6.35	5.50

*Significant at 5% level; ** Significant at 1% level

Table 3 *Per se* performance and corresponding *sca* effect for yield and yield attributing characters (contd...)

Hybrid combination	100 seed weight (g)		Hull content (%)		Volume weight (g/100 ml)		Oil content (%)	
	Per se	*sca*	*Per se*	*sca*	*Per se*	*Sca*	*Per se*	*sca*
CMS-853A x EC-623027	6.1	0.52**	32.1	1.60**	42.8	-0.17	35.7	-0.57
CMS-853 A x EC-623023	5.9	0.56**	29.8	0.03	43.0	0.05	35.6	-0.62
CMS-853A x EC-623021	5.6	-0.17	27.8	-1.93**	43.7	1.86*	36.4	0.39
CMS-853A x EC-601751	5.3	-0.23*	27.3	-1.98**	42.6	-0.78*	36.8	1.00*
CMS-853A x EC-601778	5.4	-0.31*	24.8	-1.93**	45.3	1.21*	37.4	0.30
CMS-853A x EC-601725	5.5	-0.10	33.1	2.62**	40.0	-3.03**	35.2	-1.00*
CMS-853A x EC-623016	5.5	0.27*	31.9	1.60**	43.8	0.85*	37.2	0.50
CMS-852A x EC-623027	4.9	0.18	29.8	-1.10**	40.0	-1.93*	35.8	-0.41
CMS-852A x EC-623023	4.6	-0.24*	34.6	4.45**	43.2	1.31*	36.1	-0.06
CMS-852A x EC-623021	5.0	-0.24*	29.8	-0.31	40.0	-0.83*	35.8	0.15
CMS-852A x EC-601751	4.8	-0.25*	31.1	1.37**	41.6	-0.75*	36.4	0.66
CMS-852A x EC601878	5.1	-0.08	27.3	0.19	42.6	-0.46	36.8	-0.27
CMS-852A x EC-601725	5.5	0.46**	31.9	1.02*	43.8	1.88*	37.2	1.09*
CMS-852A x EC-623016	5.8	0.53**	25.2	-5.53**	42.7	0.78*	35.8	-0.86*
CMS-850A x EC-623027	5.1	0.23*	27.3	-2.30**	42.6	0.26	36.8	0.56
CMS-850A x EC-623023	4.5	-0.10	30.9	6.17**	43.6	1.27*	38.4	1.14*
CMS-850A x EC-623021	4.8	-0.18	29.0	0.15	42.2	0.96*	37.2	0.13
CMS-850A x EC-601751	5.1	0.26*	27.3	-1.08**	42.6	-0.16	36.8	-0.08
CMS-850A x EC-601878	5.0	0.05	27.8	1.97**	39.7	-3.82**	37.0	-1.21*
CMS-850A x EC-601725	5.1	0.27	27.3	-2.23**	42.6	0.21	37.2	-0.06
CMS-850 x EC-623016	4.5	-0.53**	30.9	1.50**	43.6	1.28*	38.4	0.64
CMS-103A x EC-623027	5.1	0.10	34.4	3.88**	43.2	-0.19	38.7	1.13*
CMS-103A x EC-623023	4.8	0.02	29.0	-0.87*	42.2	-1.22*	37.2	-0.34
CMS-103A x EC-623021	4.8	-0.36*	29.0	-0.78*	42.2	-0.11	37.2	-0.14
CMS-103A x EC-601751	5.1	0.08	30.3	0.92*	42.6	-1.23*	36.8	-0.35
CMS-103A x EC-601978	5.7	0.59**	23.6	-3.18**	48.5	4.03**	38.4	-0.03
CMS-103A x EC-601725	4.7	-0.29*	29.8	-0.65*	43.4	-0.03	38.1	0.60
CMS-103A x EC-623016	5.1	-0.14	31.0	0.68	42.2	-1.23*	37.2	-0.85*
P-2-7-1A x EC-623027	5.1	-0.61**	34.4	0.59*	43.2	0.03	37.0	-0.32
P-2-7-1A x EC-623023	5.4	-0.09	32.5	-0.68*	43.5	0.33	37.6	0.35
P-2-7-1A x EC-623021	6.6	0.85**	33.6	1.34**	42.4	-0.14	37.8	0.60
CP-2-7-1A x EC-601751	5.5	-0.21*	31.9	-0.74**	42.6	-0.01	35.2	-1.65*
P-2-7-1A x EC-601978	5.3	-0.52**	30.8	0.84**	45.6	1.29*	38.7	0.58
P-2-7-1A x EC-601725	5.4	-0.30*	32.5	-1.32**	43.5	0.29	37.6	0.38
P-2-7-1A x EC-623016	6.8	0.87**	33.6	-0.03	42.4	0.80*	37.8	0.05
CMS-207A x EC-623027	4.7	-0.11	32.6	-0.59*	39.6	-0.39	39.0	1.33*
CMS-207A x EC-623023	4.4	-0.17	29.3	-3.16**	39.9	-0.10	36.4	-1.27*
CMS-207A x EC-623021	5.0	0.02	33.8	1.38**	38.0	0.89*	37.5	0.07
CMS-207A x EC-601751	5.4	0.61**	32.5	0.48*	43.5	3.15**	37.6	0.38
CMS-207A x EC-601978	5.2	0.33*	31.9	2.48**	39.2	1.94*	38.5	-0.03
CMS-207A x EC-601725	4.8	0.02	33.1	-0.02	40.0	0.03	36.8	-0.85*
CMS-207A x EC-623016	4.3	-0.70**	32.4	-0.59*	40.2	0.20	38.5	0..38
P-89-1A x EC-623027	4.5	-0.30*	30.9	0.80**	45.1	2.93**	37.6	0.29
P-89-1A x EC-623023	4.6	0.05	31.6	0.58*	39.7	-2.53**	36.8	-0.49
P-89-1A A x EC-623021	4.8	-0.10	31.6	0.62*	39.7	-1.42*	36.8	-0.28
P-89-1A x EC-601751	5.1	0.36*	30.6	0.12	45.5	2.92**	37.4	0.56
P-89-1A x EC-601978	5.0	0.10	25.8	-2.08**	45.2	1.88*	38.8	0.66
P-89-1A x EC-601725	4.6	-0.16	31.6	-0.06	39.7	-2.56**	36.8	-0.47
P-89-1A x EC-623016	5.1	0.09	33.1	1.62**	41.0	-1.23*	37.5	-0.27
CMS-10A x EC-623027	5.4	0.34*	30.6	-1.27**	40.8	-0.54	36.5	-0.89*
CMS-10A x EC-623023	4.8	-0.02	29.0	-2.34**	42.2	0.88*	38.6	1.31*
CMS-10A x EC-623021	5.4	0.21*	30.7	-0.48*	40.8	0.57	36.5	-0.63
CMS-10A x EC-601751	4.4	-0.64**	31.6	0.90**	39.6	-2.15*	36.4	-0.52
CMS-10A x EC-601978	5.0	-0.16	29.8	1.70**	40.3	-2.18*	38.2	0.01
CMS-10A x EC-601725	5.1	0.10	32.5	0.65*	44.6	3.27*	37.6	0.31
CMS-10A x EC-623016	5.4	0.15	32.5	0.75*	41.5	0.15	38.2	0.41

*Significant at 5% level; ** Significant at 1% level

The *sca* effect showed that none of the single crosses showed maximum *sca* effect in desirable direction for all the characters (Table 3). Hybrid combination CMS-207A x EC-623027 followed by P-2-7-1A x EC-623023 exhibited highest *sca* effect for days to 50% flowering and plant height, while CMS-850A x EC-601878 for head diameter. These results are in accordance with the findings of Sharma *et al.* (2003); Gvozdenovic *et al.* (2005); Hladni *et al.* (2006). Significant *sca* effect in desirable direction for hull content was reported in CMS-852A x EC-623016 and for volume weight in CMS-103A x EC-601978. Twenty-three crosses were noticed significant positive *sca* effect for achene yield. Among these crosses, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878, CMS-853A x EC-623027 and CMS-853A x EC-623023 showed highest positive *sca* effect for seed yield . Four crosses exhibited significant positive *sca* effect for oil percent and highest was reported in the cross CMS-10A x EC-623023. These characters might be due to non-additive gene action indicating that heterosis breeding may be rewarding in sunflower. These results are in conformity with the earlier findings of Patil *et al.* (2007), Binodh *et al.* (2008), Asif *et al.* (2013), Archana *et al.* (2018), Tyagi *et al.* (2020) and Haddadan *et al.* (2020). In the majority of the crosses, high *sca* effect was due to low x low, high x low and low x high combining parents which further substantiated the operation of non-additive gene action for the characters studied.

From the present investigation it could be concluded that almost all the characters studied were governed by non-additive gene action except a few. Six parents, CMS-853A, CMS-852A, EC-623027, EC-601751, EC-623023 and EC-601725 had significant positive *gca* effect for seed yield and other yield contributing traits. The new combinations, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878, CMS-853A x EC-623027 and CMS-853A x EC-623023 may be used in the production of more heterotic hybrids as well as for enhancing seed yield/hectare.

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