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Combining ability analysis in sunflower (*Helianthus annuus* L.)

R. Dhanalakshmi[1,2], N. Manivannan*[2], PL. Viswanathan[1], R. Sasikala[1], L. Rajendran[1]and M. Senthivelu[1]

[1]Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore - 641003.
[2]Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore - 641003.
***E-Mail**: nm68@tnau.ac.in

Abstract
A study was carried out to assess the combining ability of ten CMS lines with four testers using the line x tester method. Biometrical observations were taken for days to 50% flowering, plant height, head diameter, days to maturity, volume weight, hundred seed weight, seed yield /plant, oil content and oil yield/plant. Specific combing ability variance was greater than the general combining ability variance for all the characters which indicated that non-additive gene action played a major role in inheritance. The *gca* of parents were not in agreement with the *per se* performance for various traits. Hence, the selection of parents should be based on *gca* alone for a breeding programme. Three lines *viz*., COSF 12A, COSF 13A and CMS 207A, and tester IR 6 were identified as good general combiners for seed and oil yield. Among the hybrids generated using good general combiners, COSF 13A x IR 6 had the additive type of gene action for seed and oil yield per plant. In general, most of the crosses had non-significant *sca* for oil yield per plant and oil content which indicated the presence of an additive type of gene action. Hence, the selection of good general combiners for oil content, seed and oil yield will help to evolve high oil yielding hybrids in sunflowers.

Keywords: Sunflower, line x tester, combining ability, seed yield, oil yield

INTRODUCTION

Sunflower (*Helianthus annuus* L.; 2n=2x=34) is the most popular global edible oilseed crop due to its high-quality oil and wider adaptability to different agro-climatic regions and soil types. It belongs to North America and was introduced in India for the first time in 1969 (Sharma *et al*., 2022). In India, this crop occupies the fourth position, in the cultivated vegetable oilseed category after groundnut, mustard and soybean. Sunflower cultivation in India is about 2.28 lakh ha area with a production of 2.125 lakh tonnes with a productivity of 931 kg/ha (Ministry of Agriculture, GOI, SOPA-2019-20).

The development of hybrids is the primary objective of most sunflower breeding programs in the world. Sunflower hybrid breeding was started economically after the discovery of CMS by Leclercq in 1960 and restorer genes by Kinman in 1970 (Miller and Fick, 1997). The first sunflower hybrid was produced in the US in 1972 and reached 80% of production in five years (Fick and Miller, 1997). Single-cross hybrids quickly became dominant among sunflower cultivars in the world. Hybrids were preferred by farmers due to their high yield and quality potential, homogeneity, same time maturing and the easy possibility of cultural applications both in India and the world. The use of hybrids has reached over 95% of India's sunflower production in the last 10 years (Lakshman *et al*., 2019). In India, sunflower is mostly grown in the states of Karnataka, Maharastra, Andara Pradesh and Tamil Nadu (Dutta, 2011). Line x Tester analysis has been widely used for evaluating the inbreds and identifying promising hybrid combinations. Hence, the present study was carried out to identify the best general and specific combiners for yield and yield attributing components in sunflowers.

MATERIALS AND METHODS

A field experiment was carried out at the Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore (11° N latitude and 77° E longitude). This research work consisted of ten CMS (cytoplasmic genic male sterile) lines as female parents and four testers (fertility restorers) as male parents. Forty hybrids were produced from these parents using a line x tester mating design. During *kharif* 2021, 40 hybrids and their parents were evaluated in a randomized complete block design with two replications. Each entry was raised in a single 5 m length row adopting a spacing of 60 x 30 cm. Normal agronomic practices were followed during the whole crop period. Morphological observations were taken on nine quantitative traits *viz.,* days to 50% flowering, plant height (cm), head diameter (cm), days to maturity, volume weight (g/100ml), hundred seed weight (g), seed yield /plant (g), oil content (%) and oil yield/plant (g) with randomly selected five plants in each entry in each replication. The oil content of the seeds was estimated at the Centre of Excellence in Molecular Breeding, Tamil Nadu Agricultural University, Coimbatore by using a Near-infrared (NIR) spectroscopy instrument (Make: M/s ZEUTEC, Germany; Model: SPA 1.0). Mean values were calculated for all the observed data and subjected to combing ability analysis as per Kempthorne (1957) using TNAUSTAT software (Manivannan, 2014).

RESULTS AND DISCUSSION

The analysis of variance revealed significant differences among parents and crosses for all the characters indicating the presence of adequate variability in the experimental population (**Table 1**). The variance due to parents vs hybrids showed a significant difference for all characters which confirmed the presence of heterosis in crosses. The combining ability ANOVA is presented in **Table 2**. The variance due to lines, testers and L x T interactions showed significant differences for all traits. Results indicated that specific combining ability variances were higher than general combining ability variances for all the traits indicating a preponderance of non-additive types of gene action for all the traits. Hence, these characters can be subjected to heterosis breeding (Khalid *et al*., 2018; Lakshman *et al*., 2019 and Hilli *et al*., 2020).

The mean performance of parents (lines and testers) is presented in **Table 3**. A wide range of variation was observed for all the characters for their mean performance among the parents. Among the lines, COSF 6B, COSF 10B, COSF 12B, CMS 104B, CMS112B, CMS 207B and RCR CMS 38B and testers CSFI 99 and LTRR 341 recorded superior oil yield per plant. Lines COSF 10B, COSF 12B and restorer CSFI 99 also recorded superior performance for seed yield per plant and oil content. Parents COSF 10B for plant height, COSF 12B for volume weight and CSFI 99 for head diameter and volume weight recorded superior performance. Hence, considering the mean performance, parents COSF 10B, COSF 12B and CSFI 99 were adjudged as superior parents.

Table 1. Analysis of variance for various traits in sunflower

Source of variation	df	Days to 50% flowering	Plant height	Head diameter	Days to maturity	Volume weight	100 seed weight	Seed yield / plant	Oil content	Oil yield / plant
Rep	1	2.68	3.23	1.50	6.26	0.40	0.07	7.72	5.17	53.92
Parents	13	45.37**	1137.99**	6.83**	48.11**	35.71**	2.34**	264.93**	27.82**	31.66**
Hybrids	39	36.85**	530.30**	10.92**	39.50**	28.38**	1.97**	481.49**	20.25**	76.82**
Parents vs Hybrids	1	114.54**	16480.54**	85.66**	122.15**	1172.06**	12.61**	15414.98**	791.41**	3495.92**
Error	53	3.34	9.33	0.59	3.47	6.01	0.49	48.71	4.48	14.61

**significant effect at 0.01 probability

Table 2. Combining ability ANOVA and gene action for nine traits in sunflower

Source of variation	df	Days to 50% flowering	Plant height	Head diameter	Days to maturity	Volume weight	100 seed weight	Seed yield / plant	Oil content	Oil yield / plant
Lines (L)	9	28.97**	526.35**	14.42**	37.64**	27.43**	2.37**	443.96**	35.85**	79.18**
Testers (T)	3	255.50**	2904.85**	7.48**	257.51**	100.38**	5.74**	561.66**	40.57**	167.36**
L × T	27	15.19**	267.77**	10.14**	15.89*	20.69**	1.41**	485.09**	12.79**	65.97**
Error	39	3.66	10.72	0.59	3.86	4.95	0.51	48.88	4.54	18.52
GCA		0.53	6.46	0.02	0.58	0.19	0.01	-0.09	0.18	0.27
SCA		5.76	128.53	4.78	6.01	7.87	0.45	218.1	4.13	23.72
GCA/SCA		0.09	0.05	0	0.1	0.02	0.03	0	0.04	0.01

* and **: significant effect at 0.05 and 0.01 probability.

Table 3. Mean performance of parents for yield and its component traits in sunflower

Characters	Days to 50% flowering	Plant height (cm)	Head diameter (cm)	Days to maturity	Volume weight (g/100ml)	100 seed weight (g)	Seed yield / plant (g)	Oil content (%)	Oil yield / plant (g)
Lines									
COSF 6B	57.50	146.70	13.04	90.00	38.00[a]	3.95	30.70	40.81[a]	12.50[a]
COSF 10B	52.50	100.90[a]	12.62	83.50	30.20	4.34	45.06[a]	39.76[a]	17.94[a]
COSF 12B	51.50	118.80	12.40	82.50	36.94[a]	4.64	42.96[a]	40.74[a]	17.47[a]
COSF 13B	53.50	112.10	12.37	85.50	30.65	4.77	30.11	39.79[a]	11.94
CMS 104B	61.50[a]	179.40	16.09[a]	91.50	32.15	5.54[a]	40.25	37.93[a]	15.27[a]
CMS 112B	55.00	157.30	15.02	87.50	29.10	4.80	36.32	37.93[a]	13.78[a]
CMS 207B	56.00	126.60	14.37	88.00	25.20	3.16	51.00[a]	32.36	16.45[a]
CMS 519B	61.00[a]	140.13	15.30[a]	92.00[a]	25.55	2.87	20.41	27.78	5.66
BRM 248B	58.00	159.30	12.72	91.00	28.75	3.70	27.49	35.88	9.91
RCR CMS 38B	58.00	167.20	16.66[a]	88.00	33.85[a]	4.99	42.78[a]	33.95	14.56[a]
Testers									
IR 6	63.00[a]	133.30	12.37	95.50[a]	29.35	3.27	17.20	33.73	5.81
CSFI 99	50.50	148.60	16.20[a]	84.00	38.25[a]	4.92	49.68[a]	39.65[a]	19.60[a]
RHA-1-1	45.50	105.08[a]	10.45	76.00	33.70[a]	6.70[a]	32.08	35.69	11.44
LTRR 341	57.00	151.23	14.71	89.50	34.75[a]	5.82[a]	55.77[a]	35.81	19.91[a]
SE	1.29	2.16	0.54	1.32	1.73	0.50	4.93	1.50	2.68
CD (5%)	3.62	6.05	1.52	3.69	4.85	1.39	13.82	4.19	7.49

[a]on par with superior parents.

Several researchers studied the mean performance of parents in sunflowers (Gejli *et al*., 2011; Nasreen *et al*., 2014; Goksoy *et al*., 2020; Abdul-Hamed *et al.,* 2021).

The general combing ability of parents is presented in **Table 4**. Line COSF 12A and tester IR 6 recorded good general combining abilities for oil yield per plant and oil content. In addition to these traits, IR 6 had a good combining ability for days to 50% flowering, head diameter, days to maturity, volume weight and seed yield per plant. Parents COSF 13A and CMS 207A recorded good combining ability for seed yield per plant. Lines COSF 10A and COSF 13A recorded good combining abilities for oil content. Line COSF 207A had good combing ability for plant height and head diameter. Hence, considering the general combining ability effects lines COSF 12A, COSF 13A and COSF 207A and tester IR 6 were considered superior for seed yield and component traits. The *gca* of parents are not in agreement with the *per se* performance for various traits. Hence, the selection of parents should be based on *gca* alone for the breeding programme.

The specific combing ability (*sca*) of hybrids is presented in **Table 5**. Among the hybrids, nine hybrids recorded significant and negative *sca* values for plant height. A similar finding was reported by Karande *et al*. (2020). Out of 40 hybrids, four hybrids (COSF 10A x CSFI 99, CMS 112A x CSFI 99, CMS207A x LTRR341 and ARM248A x RHA1-1) for days to 50% flowering and maturity, 11 hybrids for head diameter, six hybrids for volume weight, two hybrids for hundred seed weight (CMS 112A x LTRR 341, ARM 248A x RHA-1-1), eleven hybrids for seed yield/ plant, two hybrids for oil content (COSF 104A x LTRR341, ARM 248A x CSFI 99) and three hybrids for oil yield/plant (CMS 207A x RHA-1-1, ARM 248A x IR6, ARM248A x CSFI 99) showed significant positive *sca* effects. Among the hybrids generated using good general combiners for seed and oil yield, COSF 13A x IR 6 recorded non-significant *sca* for seed and oil yield per plant. It indicates that the gene action involved in this cross might be due to an additive type of gene action. In the case of COSF 12A x IR 6, non-significant *sca* for oil yield per plant and significant *sca* for seed yield per plant were recorded. Hence, the gene action for oil yield per plant and seed yield may be of additive and additive x additive type of gene action, respectively in this cross. The hybrid CMS 207A x IR 6 recorded significant positive *sca* for both seed and oil yield per plant and hence the gene action may be of additive x additive type. In general, most of the crosses had non-significant *sca* for oil yield per plant and oil content which indicates the presence of an additive type of gene action. About 25% of crosses recorded significant *sca* effects for plant height, head diameter and seed yield per plant which indicate the presence of epistasis. This result conforms with the earlier reports of Chandirakala *et al.* (2016), Nichal *et al.* (2017),

Table 4. General combining ability (*gca*) effects of parents in sunflower

Characters	Days to 50% flowering	Plant height	Head diameter	Days to maturity	Volume weight	100 seed weight	Seed yield / plant	Oil content	Oil yield / plant
Lines									
COSF 6A	0.73	-11.80**	-2.72**	-0.04	-0.62	-0.59*	-6.76**	0.99	-0.78
COSF 10A	-1.40*	7.02**	-0.46	-2.16**	3.24**	0.45	-3.03	2.72**	2.04
COSF 12A	-2.65**	4.53**	-1.05**	-2.04**	1.42	-0.33	3.57	2.51**	3.28*
COSF 13A	-2.15**	0.03	0.18	-2.41**	1.04	-0.05	5.3*	1.71*	2.33
CMS 104A	0.22	-4.62**	-0.99**	0.46	1.66*	-0.52*	-11.19**	0.00	-4.59**
CMS 112A	-0.90	0.83	0.40	-1.16	-1.41	-0.01	5.78*	0.09	1.92
CMS 207A	-0.40	-10.11**	0.59*	-0.66	-2.46**	-0.19	6.21*	-1.37	0.87
CMS 519A	3.47**	15.67**	0.79**	4.34**	-0.11	-0.22	-1.82	-4.15**	-3.66*
ARM 248A	2.10**	-3.25**	1.79**	2.09**	-2.44**	1.27**	-9.05**	-1.72*	-4.46**
RCR CMS 38A	0.98	1.67	1.48**	1.59*	-0.33	0.20	11.01**	-0.78	3.06
Testers									
IR 6	4.65**	12.01**	0.84**	4.61**	1.48**	-0.71**	6.28**	1.81**	3.59**
CSFI 99	-1.40**	8.71**	-0.21	-1.24**	2.13**	-0.05	1.51	0.46	0.50
RHA-1-1	-3.80**	-11.07**	-0.03	-3.94**	-0.86	0.57**	-6.36**	-1.21*	-3.39**
LTRR 341	0.55	-9.65**	-0.61**	0.56	-2.76**	0.18	-1.43	-1.06*	-0.70
SE (gca lines)	0.68	1.16	0.27	0.70	0.79	0.25	2.47	0.75	1.52
SE (gca tester)	0.43	0.73	0.17	0.44	0.50	0.16	1.56	0.48	0.96

* and **: significant effect at 0.05 and 0.01 probability.

Table 5. Specific combining ability (*sca*) effects in sunflower hybrids

Crosses	Days to 50% flowering	Plant height	Head diameter	Days to maturity	Volume weight	100 seed weight	Seed yield / plant	Oil content	Oil yield / plant
COSF 6A x IR 6	-0.28	1.55	-2.49**	0.89	3.03	0.16	-11.09*	4.60**	-3.74
COSF 6A x CSFI 99	0.27	10.81**	2.51**	0.74	1.62	0.75	3.26	0.56	0.31
COSF 6A x RHA-1-1	0.17	7.13**	0.21	-1.56	2.07	0.62	24.05**	-2.8	5.56
COSF 6A x LTRR 341	-0.18	-19.49**	-0.24	-0.06	-6.73**	-1.54**	-16.22**	-2.36	-2.13
COSF 10A x IR 6	4.35**	-1.17	-0.81	3.51*	-0.78	-0.19	-16.08**	-2.95	-1.55
COSF 10A x CSFI 99	-1.1	-5.13*	-0.53	-0.14	-2.78	0.53	6.72	-1.23	-0.24
COSF 10A x RHA-1-1	-2.7	5.51*	1.98**	-2.94*	-0.64	0.72	-3.45	1.31	-3.83
COSF 10A x LTRR 341	-0.55	0.79	-0.64	-0.44	4.21*	-1.07*	12.81*	2.87	5.61
COSF 12A x IR 6	2.1	3.9	2.93**	1.89	-3.06	0.25	14.20**	-2.37	1.92
COSF 12A x CSFI 99	1.65	4.98*	-0.66	0.74	4.30**	0.38	-15.67**	0.19	-5.61
COSF 12A x RHA-1-1	-3.95**	-28.77**	-2.35**	-2.56	-3.57*	-0.45	-11.31*	0.52	-1.22
COSF 12A x LTRR 341	0.2	19.88**	0.07	-0.06	2.33	-0.18	12.78*	1.66	4.91
COSF 13A x IR 6	-0.4	3.72	1.13*	0.26	-4.38**	0.11	8.41	-2.39	2.13
COSF 13A x CSFI 99	-0.85	2.05	1.36*	-2.39	3.72*	0.58	-2.28	1.77	1.07
COSF 13A x RHA-1-1	-0.45	-2.15	-2.37**	-0.69	3.26*	-0.14	-7.58	2.42	-2.28
COSF 13A x LTRR 341	1.7	-3.62	-0.12	2.81*	-2.59	-0.54	1.45	-1.81	-0.92
CMS 104A x IR 6	1.72	1.57	-1.36*	3.39*	-0.9	0.03	-7.39	-0.65	-3.57
CMS 104A x CSFI 99	-2.22	-9.32**	1.51**	-2.26	-2.84	-0.79	8.95	-2.23	2.36
CMS 104A x RHA-1-1	-1.33	-2.1	-1.49**	-1.56	0.34	-0.09	-12.69*	-0.61	-4.51
CMS 104A x LTRR 341	1.83	9.85**	1.34*	0.44	3.39*	0.85	11.13*	3.49*	5.71
CMS 112A x IR 6	0.35	-8.77**	-1.74**	-0.49	0.22	-0.55	2.98	1.23	2.21
CMS 112A x CSFI 99	3.40*	-1.07	2.45**	2.86*	-4.68**	-0.57	6.88	-2.07	1.45+

Table 5. Continued

Crosses	Days to 50% flowering	Plant height	Head diameter	Days to maturity	Volume weight	100 seed weight	Seed yield / plant	Oil content	Oil yield / plant
CMS 112A x RHA-1-1	0.3	10.83**	-1.69**	1.56	-0.19	-0.94	10.92*	1.26	4.93
CMS 112A x LTRR 341	-4.05**	-0.99	0.98	-3.94**	4.66**	2.06**	-20.78**	-0.42	-8.60**
CMS 207A x IR 6	-4.65**	-2.12	0.02	-4.99**	0.77	0.08	-21.19**	0.08	-7.88*
CMS 207A x CSFI 99	-0.1	-5.93*	-0.94	0.36	-0.78	-0.33	-13.25*	-1.73	-5.44
CMS 207A x RHA-1-1	0.3	-2.86	-0.1	-0.44	1.26	0.33	21.14**	2.22	9.62**
CMS 207A x LTRR 341	4.45**	10.91**	1.01	5.06**	-1.24	-0.08	13.30**	-0.58	3.7
CMS 519A x IR 6	-1.02	-3.57	2.09**	-0.99	1.67	0.57	5.67	0.43	1.98
CMS 519A x CSFI 99	1.53	8.37**	-1.46**	0.36	1.97	0.07	-3.32	1.5	-0.04
CMS 519A x RHA-1-1	2.42	-5.64*	-2.04**	2.06	-2.09	-0.71	0.48	-2.99	-1.08
CMS 519A x LTRR 341	-2.92*	0.84	1.41*	-1.44	-1.54	0.07	-2.83	1.06	-0.86
ARM 248A x IR 6	-1.15	7.80**	-0.78	-1.74	1.45	-1.23*	19.10**	2.26	6.43*
ARM 248A x CSFI 99	-1.1	1.31	-0.74	0.11	-0.89	-0.28	20.76**	4.03*	10.72**
ARM 248A x RHA-1-1	5.30**	15.92**	5.03**	5.81**	0.99	1.30*	-17.90**	-2.87	-7.09*
ARM 248A x LTRR 341	-3.05*	-25.02**	-3.50**	-4.19**	-1.56	0.21	-21.96**	-3.43*	-10.06**
RCR CMS 38A x IR 6	-1.03	-2.92	1	-1.74	1.99	0.75	5.36	-0.25	2.05
RCR CMS 38A x CSFI 99	-1.48	-6.04*	-3.51**	-0.39	0.35	-0.34	-12.06*	-0.8	-4.57
RCR CMS 38A x RHA-1-1	-0.08	2.11	2.82**	0.31	-1.42	-0.63	-3.65	1.54	-0.11
RCR CMS 38A x LTRR 341	2.58	6.84**	-0.32	1.81	-0.92	0.22	10.35*	-0.49	2.64
SE (sca)	1.35	2.32	0.54	1.39	1.57	0.51	4.94	1.51	3.04

* and **: significant effect at 0.05 and 0.01 probability.

Table 6. Proportional (%) contribution of lines, testers, and lines × testers to total variation

Characters	Lines	Testers	Lines x testers
Days to 50% flowering	18.14	53.33	28.53
Plant height	22.91	42.14	34.96
Head diameter	30.47	5.27	64.26
Days to maturity	21.99	50.15	27.86
Volume weight	22.31	27.21	50.49
100 seed weight	27.79	22.47	49.74
Seed yield / plant	21.28	8.97	69.75
Oil content	40.86	15.41	43.73
Oil yield / plant	23.79	16.76	59.45

Ghaffari and Shariati, (2018), Hilli *et al.* (2020) and Karande *et al*. (2020). Hence, these crosses may be exploited in the sunflower breeding programme for increasing seed yield and oil yield components.

The contribution of lines, testers and their hybrids are presented in **Table 6**. The contribution of testers was higher for the characters *viz.,* days to 50% flowering, plant height and days to maturity. Line x Tester interaction had more contribution for the rest of the characters *viz.,* head diameter, volume weight, hundred seed weight, seed yield /plant, oil content and oil yield/plant. Hence, it may be concluded that the hybrids contributed more to the total variance for most of the traits.

To conclude, three lines *viz*., COSF 12A, COSF 13A and CMS 207A and tester IR 6 were considered as good general combiners for seed and oil yield. Among the hybrids generated using good general combiners, COSF 13A x IR 6 had an additive type of gene action for seed and oil yield per plant. In general, most of the crosses had non-significant *sca* for oil yield per plant and oil content which indicates the presence of an additive type of gene action. Hence, the selection of good general combiners for oil content, seed and oil yield will help to evolve high oil yielding hybrids in sunflowers.

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