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STUDY OF COMBINING ABILITY AND GENE ACTION FOR SEED YIELD IN SUNFLOWER (*Helianthus annuus* L.) USING LINE X TESTER

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ABSTRACT

The present investigation was carried out at Post Graduation farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra. The present study comprises of four females or B lines and ten males or restorers. Total 40 crosses which made by Line $\times$ Tester mating design during *Rabi* 2021. The hybrids (40) along with parents (14) and (2) checks were grown and tested in RBD with three replications during *kharif* 2022. The characters or traits studied in this research are Days to 50% flowering, Days to maturity, plant height, head diameter, number of filled seeds per head, 100-seed weight, seed filling %, seed yield per plant, seed yield p/ha and oil content %. Highly significant mean sum of square due to parents vs crosses were observed for all the traits. Estimation of σ^2_{sca} were greater than the corresponding σ^2_{gca} for all the characters indicated the predominance of non-additive gene effects. The study confirms that lines, CMS-7-1-A, CMS-ND2A, CMS 234A and tester GMU 1199 and NO-2 are best for development of hybrids. The cross CMS234A $\times$ GMU 242, CMS ND2A $\times$ NO-2 and CMS 89A $\times$ PR64 NB is the most significant cross resulted as best for most of the traits due to its more specific combining ability of crosses involved. These crosses also recorded highly significant mean yield per plant and significant sca effect with high $\times$ high and low $\times$ high general combiner parent involve.

Key words: General combining ability, Specific combining ability, Gene action, Line x Tester.

Introduction

India is the producer of the oil seeds; the country is facing an acute shortage of edible oil. India is 2nd most consuming edible oil in world. It imports 1.9-2.5 million tonnes of crude sunflower oil, of which almost 85 per cent comes from Ukraine and Russia. Yield is an important character involving number of components each of which is polygenically controlled and thus susceptible to environmental fluctuations. To develop sunflower hybrids with improved yield potential, the choice of parents through careful and critical evaluation is of paramount importance in order to improve productivity and total production. Combining ability is defined as the cultivars or parents ability to combine among each other during hybridization process such that desirable genes or characters are transmitted to their progenies. The

estimation of general combining ability (GCA) and specific combining ability (SCA) helps in identifying the potential parents in the production of superior hybrids for seed yield and oil content. The experiment was conducted with ideas for knowing the type of gene action controlling various characters and development of suitable breeding strategies.

Material and Method

The experiments was conducted at PGI Farm, Department of Agril. Botany, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *kharif* season. Crossing work was done in *Rabi* 2020 and evaluation of parents and F1's was taken in *kharif* 2021, resultant forty hybrids along with their fourteen parents (4CMS lines and 10 restorers) and two checks; total 56 genotypes were evaluated in Randomized Block Design with three

replications. The inbred lines were collected from ARS, Savlivihi. The observations on days to 50 per cent flowering, days to maturity, head diameter, plant height, number of filled seeds per head, per cent seed filling, 100 - seed weight, seed yield per plant and seed yield/ha were recorded. The data was subjected to genetic analysis. The analysis of combining ability (GCA and SCA) effect was done by using the Line $\times$ Tester analysis method given by Kempthorne (1957).

The individual effects of General Combining Ability (GCA) and Specific Combining Ability (SCA) were estimated by calculating the two-way table of female and male parents, and then summing the values obtained over multiple replications.

(a) GCA effects of A^{th} line

$$Gi = \frac{\sum xA}{Lr} - \frac{\sum x}{LT}$$

(b) GCA effects of B^{th} tester

$$Gj = \frac{\sum xB}{Lr} - \frac{\sum x}{LT}$$

(c) SCA effects of AB^{th} cross

$$Sij = \frac{\sum xAb}{r} - \frac{\sum xA}{T} - \frac{\sum xB}{L} - \frac{\sum x}{LT}$$

Where,

$\sum x$ = total sum of all crosses,

$\sum xA$ = total sum of A^{th} lines over all testers and replications

$\sum xB$ = total of B^{th} tester over all lines and replications,

$\sum xAB$ = AB^{th} line $\times$ tester combination total over all replications,

r = No. of replications,

L and T = No. of lines and testers.

Estimation of variances of GCA and SCA

Estimation of variance of GCA and SCA was calculated by formulae (Singh and Chaudhary, 1977).

$$\sigma^2_{GCA} = \frac{(M.L. + M.T. - 2.M.L.T.)}{r(L+T)}$$

$$\sigma^2_{SCA} = \frac{(M.L.T. - M.r)}{r(L+T)}$$

Where,

$M.L$ = Mean squares of female lines,

$M.T$ = Mean squares of male testers,

$M.L.T$ = Mean squares of line $\times$ tester (cross),

L and T = number of lines and testers,

r = number of replications.

Contribution of line, testers and their interactions to total variance

Proportional contribution of line, testers and their interactions to total variance computed as per (Singh and Chaudhary, 1977).

$$\text{Contribution of line} = \frac{S.S. (L)}{S.S. (Crosses)} \times 100$$

$$\text{Contribution of Tester} = \frac{S.S. (T)}{S.S. (Crosses)} \times 100$$

$$\text{Contribution of Line} \times \text{Tester} = \frac{S.S. (L \times T)}{S.S. (Crosses)} \times 100$$

Where,

$S.S.L$ = sum squares of lines

$S.S.T$ = sum squares of testers

$S.S. crosses$ = sum squares of crosses

$S.S. Line \times Tester$ = sum squares of line $\times$ tester

Result and Discussion

The analysis of variance for combining ability for ten different characters have been presented in Table 1. It revealed that mean sum of square due to genotypes found significant for all the characters studied indicated presence of desirable amount of variation. The highest variance is reported for the traits like total seeds per head (3810.37), plant height (616.30) and days to maturity (25.86) and all the subsequent mentioned traits are highly significant. The least but significant trait or character is 100 seed weight (0.28). The highest variance is achieved by traits like total seeds per head (21414.57) and the least variance is with the trait of oil content (1.04) and all the fore-mentioned traits except head diameter and 100 seed weight are highly significant. The crossing of lines and testers, the variance is clearly visible with all the characters involved and none of the characters or traits devoid of significance i.e., all the traits are under significant. Higher variance is achieved by total seeds per head (13560.53), plant height (633.18), seed filling %

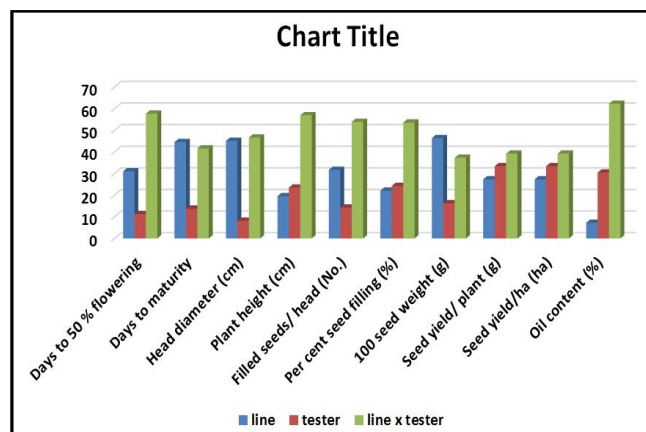


Fig. 1: Contribution of Line, Tester and Line $\times$ Tester.

Table 1: Analysis of variance for combining ability analysis for ten characters in sunflower.

S.	Genotypes	d.f.	DTF	DM	PH	HD	TSP	SF	SW	SYP	SY	OC
1.	Replications	2	0.93	2.00	15.05	0.95	9.82	0.36	0.01	0.47	0.14	0.04
2.	Genotypes	53	6.84**	27.00**	1257.53**	15.47**	28990.11**	37.92**	2.19**	181.77**	56.10**	16.09**
3.	Parents (P)	13	12.18**	32.49**	707.98**	5.33**	5286.13**	32.79**	0.50**	12.95**	4.00**	15.57**
4.	Female (F)	3	12.11**	57.88**	881.30**	13.08**	4337.26**	13.90**	1.33**	15.52**	4.79**	5.22**
5.	Male (M)	9	11.87**	25.86**	616.30**	3.34**	3810.37**	19.75**	0.28**	11.08**	3.42**	20.64**
6.	M × F	1	15.23**	16.00**	1013.08**	0.02	21414.57**	206.90**	0.03	22.10**	6.81**	1.04**
7.	Crosss (C)	39	5.15**	15.19**	939.5**	7.24**	17397.02**	30.60**	2.15**	41.72**	12.88**	16.30**
8.	Line (L)	3	20.80**	88.06**	5512.60**	18.38*	71818.53**	87.96*	13.01**	148.43**	45.82**	15.35
9.	Tester (T)	9	2.50	9.05	334.10	7.38	10766.53	32.22	1.52	60.41*	18.64*	21.52
10.	L × T	27	4.29**	9.14**	633.18**	5.96**	13560.53**	23.69**	1.16**	23.64**	7.29**	14.67**
11.	Parent vs crosses	1	3.68**	416.10**	20804.65**	468.34**	789272.30**	389.89**	25.55**	7838.32**	2419.21**	14.73**
12.	Error	106	0.49	0.97	13.27	0.54	19.59	0.24	0.06	2.68	0.82	0.10

*Significant 0.1 % level, ** Significant 0.05 % level.

DTF: Days to50 %flowering; DM: Days to maturity; PH: Plant height (cm); HD: Head diameter (cm); TSP: Total seeds per head; SP: Seed filling (%); SW: 100seed weight (g); SYP: Seed yield/ plant (g); SY: Seed yield/ha (q); OC: Oil content (%)

(23.69). the least variance is attained by 100 seed weight (1.16) and days to 50 % flowering (4.29). While all the characters taken for the study got the significance. were also reported by Khan *et al.*, (2003), Raghavendra (2004), Habib, *et al.*, (2006) and Dudhe *et al.*, (2009).

GCA and SCA effects for parents and their crosses

The estimates of general combining ability effects of parents and specific combining ability effects for the hybrids were presented in Table 2 and 3 respectively.

Combining ability analysis showed significant mean squares due to lines and testers for most of the traits studied indicated significant contribution to GCA. Significant variances due to line × tester effect for all the traits indicated significant contribution to SCA.

In sunflower, positive SCA effects are desirable for all the traits studied except for days to 50% flowering, days to maturity and plant height for which negative SCA effects are desirable.

Table 2: Estimate of General Combining Ability effects (GCA) for ten characters in sunflower.

S.	Genotypes	DTF	DM	PH	HD	NSH	SF	SW	SYP	SY	OC
Lines											
1	89B	-0.15**	-1.50**	-13.12**	-1.01**	-48.18**	-1.55**	-0.69**	-2.15**	-1.19**	0.94**
2	ND2B	-0.85**	-0.53**	-9.30**	0.19**	40.67**	2.43**	-0.35**	-0.83**	-0.46**	-0.75**
3	234B	-0.12**	-0.43**	6.69**	-0.06**	-36.10**	-0.61**	0.27**	-0.09**	-0.05**	0.05**
4	7-1-B	1.14**	2.46**	15.73**	0.88**	43.61**	-0.27**	0.78**	3.08**	1.71**	-0.25**
	SE±	0.12	0.18	0.66	0.13	0.80	0.09	0.04	0.29	0.16	0.05
Testers											
1	GMU-42	0.44**	0.70**	-7.70**	-0.20**	-0.74**	-0.94**	-0.06**	2.35**	1.30**	0.25**
2	AKS 190 B	0.19*	-1.71**	-3.61**	0.59**	-15.55**	0.70**	-0.06**	-1.85**	-1.03**	2.16**
3	GMU830	-0.47**	-0.13**	1.80	-1.15**	31.44**	0.62**	-0.34**	-3.23**	-1.79**	0.64**
4	NO-2	-0.05**	-0.63**	0.28	-0.18**	20.12**	1.26**	-0.19**	1.67**	0.93**	-1.14**
5	PR-64-NB	0.35**	-0.55**	6.54*	-0.34**	1.17	0.61**	0.24**	2.65**	1.47**	-1.61**
6	GMU1131	-0.72**	0.45*	-0.45**	-0.94**	-60.55**	-2.42**	-0.21**	-0.98**	-0.54**	2.15**
7	GMU242	0.69**	0.20	-3.24**	-0.08**	-37.96**	-2.22**	0.44**	1.05*	0.58**	-0.77**
8	GMU336	-0.47**	0.20	-4.53**	0.36**	24.26**	-0.97**	-0.48**	-2.25**	-1.25**	0.13**
9	GMU1199	-0.14**	-0.05**	9.98**	1.56**	15.40**	2.91**	0.65**	2.38**	1.32**	-0.62**
10	GP6-271	0.19*	1.53**	0.92	0.40**	22.40**	0.45**	0.03**	-1.80**	-1.00**	-1.19**
	SE±	0.20	0.28	1.05	0.21	1.27	0.14	0.07	0.47	0.26	0.09

*Significant 0.1 % level, ** Significant 0.05 % level.

DTF: Days to50 %flowering; DM: Days to maturity; PH: Plant height (cm); HD: Head diameter (cm); NSH: Number of filled Seeds per head; SF: Seed filling (%); SW: 100seed weight (g); SYP: Seed yield/ plant (g); SY: Seed yield/ha (q); OC: Oil content (%)

Table 3: Estimate of specific combining ability (SCA) for ten characters in sunflower.

S.	Genotypes	DTF	DM	PH	HD	NSH	SF	SW	SYP	SY	OC
1.	89A × GMU42	-1.84**	3.33**	-17.75**	-0.02	-20.62**	-0.47	0.20	-0.13	-0.07	-1.01**
2.	89A × AKSF 190B	-0.59	-0.58	-26.44**	-1.75**	27.33**	2.35**	-0.09	0.77	0.43	0.37*
3.	89A × GMU 830	-0.25	-0.50	-11.23**	0.17	-99.72**	-4.15**	0.29	0.23	0.12	2.09**
4.	89A × NO 2	0.32	0.33	7.78**	-0.25	2.48	-3.77**	-0.55**	1.46	0.81	-2.22**
5.	89 × PR 64NB	-1.09**	0.58	8.92**	-0.66	-63.42**	1.10**	-0.44**	-2.24*	-1.24*	3.09**
6.	89A × GMU 1131	0.32	0.25	-3.70	0.45	-23.38**	2.84**	0.35*	1.92*	1.06*	-1.41**
7.	89A × GMU 242	0.57	-1.16*	12.18***	0.55	43.84**	-3.29**	-0.09	-2.46*	-1.36*	1.26**
8.	89A × GMU 336	2.07**	-2.5**	13.37***	-0.61	18.24**	1.32**	0.43**	-0.96	-0.53	-1.85**
9.	89A × GMU 1199	0.40	-2.25**	9.02***	2.50**	9151**	1.69**	0.00	3.07**	1.70**	-1.81**
10.	89A × GP-6-271	0.07	2.50**	7.85***	0.75	23.73**	2.37**	-0.09	-1.65	-0.92	1.50**
11.	ND 2A × GMU 42	-0.14	-2.63**	27.55***	-0.14	-76.40**	-1.35**	-0.35*	-1.84	-1.02	-0.33
12.	ND 2A × AKSF 190B	0.77	-0.88	10.16***	2.15**	-7.79**	0.22	-0.04	0.94	0.52	2.17**
13.	ND 2A × GMU 830	-0.89*	3.2**	2.84	-1.04*	-44.50**	-0.34	-0.20	-0.07	-0.04	-1.52**
14.	ND 2A × NO 2	1.69**	-0.96	-3.90	0.05	-14.90**	1.39**	0.20	4.28**	2.37**	-1.56**
15.	ND 2A × PR 64NB	0.60	-1.05	4.33*	-0.84	111.56**	2.01**	-0.03	-2.78**	-1.54**	-1.39**
16.	ND 2A × GMU 1131	-0.64	0.61	2.50	-0.85*	42.45**	2.03**	0.53**	0.45	0.25	0.00
17.	ND 2A × GMU 242	1.27**	2.53**	-31.03**	-0.47	-85.52**	-0.13	-0.48**	-0.54	-0.30	1.40—
18.	ND 2A × GMU 336	-1.55**	0.86	-16.24***	2.51**	53.36**	2.75**	0.03	1.78	0.99	-0.08
19.	ND 2A × GMU 1199	-0.55	-0.21	-5.03*	-1.58**	59.54**	-3.08**	-0.28	-3.41**	-1.89**	1.34**
20.	ND 2A × GP 6271	-0.55	-1.46*	8.82**	0.23	-37.91**	-3.50**	0.63**	1.21	0.67	-0.02
21.	234A × GMU 42	0.12	-1.06	-8.10**	0.64	14.57**	-1.21**	-0.68**	-1.23	-0.38	3.08**
22.	234A × AKSF 190 B	0.70	0.35	5.64**	-1.79**	52.31**	0.3	0.22	0.72	0.40	-4.55**
23.	234A × GMU 830	1.37**	-1.56**	4.38*	1.37**	68.61**	2.05**	0.83**	0.99	0.55	2.78**
24.	234A × NO 2	-1.37**	0.60	0.86	-0.69	-7.31**	-1.26**	-0.76**	-5.99**	-3.33**	2.32**
25.	234A × PR 64NB	1.20**	-0.48	8.04**	1.91**	30.97**	-1.35**	-0.21	3.47**	1.92**	-2.93**
26.	234A × GMU 1131	0.95*	0.18	-6.19**	1.66**	19.11**	-1.34**	-0.32*	1.55	0.86	0.30
27.	234A × GMU 242	-1.45**	-1.23*	12.73**	0.80	-29.36**	-0.52*	0.87**	2.78**	1.55**	-1.88**
28.	234A × GMU 336	-0.95*	2.43**	7.25**	-1.21**	-49.81**	-0.71**	0.20	1.53	0.85	0.42*
29.	234A × GMU 1199	0.37	1.83**	-2.33	-1.99**	-71.48**	1.16**	-0.40**	-3.68**	-2.04**	0.80**
30.	234A × GP 6271	-0.95*	-0.90	-22.29***	-0.70	-27.16**	2.90**	0.25	-0.15	-0.08	-0.35
31.	7-1-A × GMU 42	1.85**	0.36	-1.68	-0.47	82.45**	3.03**	0.84**	3.21**	1.78**	-1.73**
32.	7-1-A × AKSF 190B	-0.89*	1.11	10.62**	1.42**	-71.85**	-2.88***	-0.08	-2.49*	-1.35*	2.00**
33.	7-1-A × GMU 830	-0.22	-1.13	4.00	-0.49	75.62**	2.44**	-0.92**	-1.14	-0.63	-3.34**
34.	7-1-A × NO-2	-0.64	0.03	-4.74*	0.89*	19.72**	3.64**	1.11**	0.25	0.14	1.46**
35.	7-1-A × PR 64NB	-0.72	0.95	-21.30**	-0.39	-79.11**	-1.75**	0.70**	1.55	0.86	1.22**
36.	7-1-A × GMU 1131	-0.64	-1.05	7.39**	-1.26**	-38.31**	-3.53**	-0.56**	-3.92**	-2.18**	1.11**
37.	7-1-A × GMU 242	-0.39	-0.13	6.12**	0.22	71.04**	3.95**	-0.30*	0.22	0.12	-0.78**
38.	7-1-A × GMU 336	0.44	-0.80	-4.38*	-0.67	-21.78**	-3.36**	-0.68**	-2.35*	-1.30*	1.50**
39.	7-1-A × GMU 1199	-0.22	0.78	-1.64	1.07*	-79.57**	0.22	0.69**	4.02**	2.23**	-0.33
40.	7-1-A × GP 6-271	1.44**	-0.13	5.62**	-0.29	41.79**	-1.77**	-0.79**	0.59	0.32	-1.12**
	S.E. ±	0.40	0.57	2.10	0.42	2.55	0.28	0.14	0.94	0.52	0.18
	CD at 5 %	0.80	1.13	4.18	0.85	5.08	0.57	0.29	1.88	1.04	0.36

*Significant 0.1 % level, ** Significant 0.05 % level.

DTF: Days to 50 % flowering; DM: Days to maturity; PH: Plant height (cm); HD: Head diameter (cm); NSH: Number of filled Seeds per head; SF: Seed filling (%); SW: 100seed weight (g); SYP: Seed yield/ plant (g); SY: Seed yield/ha (q); OC: Oil content (%)

Days to 50% flowering

Negative significance is desirable for days to 50 % flowering in sunflower. The highest negative GCA is attained by lines 234B, followed by 89 B and ND-2B whereas lines 7-1-B showed significant positive GCA. Highest GCA among testers attained by NO-2, GMU

1199, GMU 336. Whereas, the lowest and negative GCA is attained by GMU-1131 and highest positive GCA attained by GP-271 and AKSF 190B, Whereas, of all the hybrids produced from the cross of lines and testers. The highest and negative SCA is achieved by CMS 89 A × GMU 42, CMS ND2A × GMU 336 and CMS 234 A ×

Table 4: Gene action for ten different characters in sunflower.

S. No.	Characters	σ^2 GCA	σ^2 SCA	σ^2 A/ σ^2 D	Nature
1.	Days to 50 % flowering	0.53**	1.26**	0.41	Non- Additive
2.	Days to maturity	2.26**	2.72**	0.83	Non- Additive
3.	Plant height (cm)	138.57**	206.63**	0.67	Non- Additive
4.	Head diameter (cm)	0.58**	1.80**	0.32	Non- Additive
5.	Filled seeds/ head (No.)	1965.36**	4513.64**	0.43	Non- Additive
6.	Per cent seed filling (%)	2.84**	7.81**	0.36	Non- Additive
7.	100 seed weight (g)	0.34**	0.36**	0.93	Non- Additive
8.	Seed yield/ plant (g)	4.84**	6.98**	0.69	Non- Additive
9.	Seed yield/ha (ha)	1.49**	2.15**	0.69	Non- Additive
10.	Oil content (%)	0.87*	4.85**	0.17	Non- Additive
*Significant 0.1 % level, ** Significant 0.05 % level.					

GMU 242 which were similarly reported by Yashpal *et al.*, (2015) and Bhavani *et al.*, (2016).

Days to maturity

The highest negative GCA is attained by lines 234B, followed by ND2B and 89B whereas lines 7-1-B showed significant positive GCA. Highest GCA among testers attained by GMU 1199, GMU 830 and PR64 NB. Whereas, the lowest and negative GCA is attained by AKSF 190B and highest positive GCA attained by GMU 1131, GMU 42 Whereas, of all the hybrids produced from the cross of lines and testers.

The highest and negative SCA was achieved by CMS ND2A $\times$ GMU 42, CMS 89 A $\times$ GMU 336 and CMS 89 A $\times$ GMU 1199. which were similar to the reported values of Pavani *et al.*, (2006), Shanker *et al.*, (2007) and Meena *et al.*, (2013), Yashpal *et al.*, (2015) Singh *et al.*, (2018).

Plant height (cm)

The highest negative GCA is attained by lines 89 B and ND-2B whereas lines 7-1-B and 234 B showed significant positive GCA. Highest GCA among testers attained by GMU 42, GMU 336 and GMU 1131. Whereas, the lowest GCA is attained by AKSF 190B and highest positive GCA attained by GMU-1199 and PR 64 NB, Whereas, of all the hybrids produced from the cross of lines and testers. The highest significant and positive SCA was achieved by CMS ND2A $\times$ GMU 42, CMS 89 A $\times$ GMU 336 and CMS 234 A $\times$ GMU 242. The significant negative GCA was findings by Imran *et al.*, (2015).

Head Diameter (cm)

The highest positive GCA is attained by lines 7-1-B and ND-2B whereas lines 89 B and 234 B showed significant negative GCA. Highest positive GCA among testers attained by GMU 1199, AKSF 190B and GMU 336. Whereas, the lowest GCA is attained by GMU-336 and highest negative GCA attained by GMU-242 and

GMU-42, Whereas, of all the hybrids produced from the cross of lines and testers. The highest and positive SCA is achieved by CMS ND2A $\times$ GMU 336, CMS 89 A $\times$ GMU 1199, CMS ND2A $\times$ AKSF 190B. Similar findings of positive GCA shown by Singh (2018) and Nehru *et al.*, (2021)

Total no. of seeds per head

The highest positive GCA is attained by lines 7-1-B and ND-2B whereas lines 234 B showed significant negative GCA. Highest positive GCA among testers attained by GMU 830 (31.44), GMU 336 and GP-6-271. Whereas, the lowest GCA is attained by PR-64-NB and GMU-1199 and highest negative GCA attained by GMU-42 and AKSF-190B, Whereas, of all the hybrids produced from the cross of lines and testers. The highest and positive SCA is achieved by, CMS ND2A $\times$ PR 64- NB, CMS 89 A $\times$ GMU 1199 and CMS 7-1-A $\times$ GMU 42 Similar findings of positive GCA shown by Singh (2018) and Nehru *et al.*, (2021).

Seed filling %

The highest positive GCA is attained by lines ND-2B whereas lines 89 B, 234B and 7-1-B showed significant negative GCA. Highest positive GCA among

Table 5: Percentage contributions of Lines, Tester and Line $\times$ Tester interaction.

Character	Contribution		L $\times$ T (%)
	Line (%)	Tester(%)	
Days to 50 % flowering	31.06	11.20	57.72
Days to maturity	44.58	13.76	41.65
Head diameter (cm)	45.13	8.20	46.65
Plant height (cm)	19.51	23.51	56.97
Filled seeds/ head (No.)	31.75	14.28	53.96
Per cent seed filling (%)	22.10	24.29	53.59
100 seed weight (g)	46.38	16.29	37.31
Seed yield/ plant (g)	27.36	33.40	39.22
Seed yield/ha (ha)	27.36	33.40	39.22
Oil content (%)	7.24	30.45	62.30

Table 6: Mean yield performance, GCA and SCA effects in promising crosses.

Sr. No.	Crosses	Crosses with high sca effect	SCA Effect	GCA status of parents		Mean performance
				Female	Male	
1.	Seed yield/ plant (g)	CMS ND2 A × N0-2	4.28	Low	High	34.90
		CMS 7-1-A × GMU 1199	4.02	High	High	39.27
		CMS 234 A × PR 64-NB	3.47	Low	High	35.81

testers attained by GMU 1199, NO-2, AKSF 190 B. Whereas, the lowest GCA is attained by GP-6-271 and highest negative GCA attained by GMU-42, GMU-336 and GMU-242. The lowest negative GCA observed in GMU-1131. The highest and positive SCA is achieved by CMS 7-1- A × GMU 242, CMS 7-1-A × N0-2 and CMS 7-1-A × GMU 42 were reported by Singh (2018).

100 seed weight

The highest positive GCA is attained by lines 7-1-B and 234B whereas lines 89 B, ND-2B showed significant negative GCA. Highest positive GCA among testers attained by GMU 1199, GMU 242, PR 64 NB. Whereas, the lowest GCA is attained by GP-6-271 and highest negative GCA attained by GMU-42. The lowest negative GCA observed in GMU-336. The highest and positive SCA is achieved by CMS 7-1-A × NO-2, CMS 234 A × GMU 242 and CMS 7-1-A × GMU 42 were reported by Singh *et al.*, (2018) and Nehru *et al.*, (2021).

Seed yield / plant (g)

The highest positive GCA is attained by lines 7-1-B whereas lines 89 B, ND-2B and 234-B showed significant negative GCA. In testers, the range of GCA is about - 3.23 to 2.68. Highest positive GCA among testers attained by PR 64 NB, GMU 1199, GMU 42. Whereas, the lowest GCA is attained by GMU-242 and highest negative GCA attained by GMU-1131. The lowest negative GCA observed in GMU-830. The highest and positive SCA is achieved by CMS ND2 A × N0-2, CMS 7-1-A × GMU 1199 and CMS 234 A × PR 64-NB were reported similarly by Yashpal *et al.*, (2015), Shekar *et al.*, (2000), Radhika *et al.*, (2001), Uttam *et al.*, (2005) and Vara Prasad *et al.*, (2006), Singh *et al.*, (2018) and Nehru *et al.*, (2021).

Seed yield /ha (q)

The highest positive GCA is attained by lines 7-1-B whereas lines 89 B, ND-2B and 234-B showed significant negative GCA. In testers, the range of GCA is about - 1.79 to 1.47. Highest positive GCA among testers attained by PR 64 NB, GMU 1199, GMU 42. Whereas, the lowest GCA is attained by GMU-242 and highest negative GCA attained by GMU-1131. The lowest negative GCA observed in GMU-830. The highest and positive SCA is achieved by CMS ND2 A × N0-2, CMS 7-1-A × GMU 1199 and CMS 234 A × PR 64-NB were reported similarly

by Yashpal *et al.*, (2015), Shekar *et al.*, (2000), Radhika *et al.*, (2001), Uttam *et al.*, (2005) and Vara Prasad *et al.*, (2006), Singh *et al.*, (2018) and Nehru *et al.*, (2021).

Oil content %

The highest positive GCA is attained by lines 89B and 234 B whereas lines 7-1-B and ND-2B showed significant negative GCA. In testers, the range of GCA is about -1.61 to 2.16. Highest positive GCA among testers attained by AKSF 190 B, GMU 1131 and GMU 830. Whereas, the lowest GCA is attained by GMU-336 and highest negative GCA attained by GMU-1199. The lowest negative GCA observed in PR-64-NB. The highest and positive SCA is achieved by CMS 89 A × PR NB 65, CMS 234 A × GMU 42 and CMS 234 A × GMU 830. The parents exhibiting good gca for oil content is also reported by Ashok *et al.*, (2000), Shekhar *et al.*, (2000), Laureti and Del Gatto (2000), Parameswari *et al.*, (2004), Rukmini Devi *et al.*, (2005), Madhavi Latha (2005), Vara Prasad *et al.*, (2006), Neelima and Parameshwarappa (2009) and Andorkhor *et al.*, (2012) and Kang *et al.*, (2013) and Nehru *et al.*, (2021).

Gene action

The value of the estimates of G.C.A. and S.C.A. variance along with nature of gene action were presented in Table 4. Estimation of σ^2_{sca} were greater than the corresponding σ^2_{gca} for all the characters indicated the predominance of non-additive gene effects. The variance due to G.C.A. effects were higher for total no. of filled seeds followed by plant height and seed yield/plant whereas, the lowest GCA is attained by 100 seed weight followed by head diameter and days to 50% flowering and none of the traits shown the negative G.C.A effects. While the S.C.A effects of hybrids made by the crossing between four lines and ten testers where the traits total no. of filled seeds followed by plant height and seed yield/plant shows higher S.C.A effects and traits 100 seed weight followed by head diameter and days to 50% flowering shows lower S.C.A effects compared to rest of traits.

The ratio of gca and sca showed its significance in giving the gene action and the ratio is highest in 100 seed gm and lowest in oil content. The traits thereby give the gene action of non-additive gene action for all the traits.

Contribution Percentage contribution of females, males and female $\times$ male interaction

Percentage contribution of males, females and females $\times$ males to the sum of square of hybrids are presented in Table 5. The contribution of all the lines (female parent) and testers (male parent) were estimated under the present study gives the comprehensive involvement of both the parents under the different traits. The traits showing higher contribution of lines are 100 seed weight (46.38 %) followed by head diameter (45.13%), days to fifty percent flowering (44.58%) while lower contribution of lines in oil content % (7.24%). The contribution of testers includes higher in the traits of seed yield/plant (33.40%) followed by oil content% (30.45%), seed filling% (24.29%) and the lowest is recorded in the traits of head diameter (8.20%). While the contribution in female and male interaction gives higher in the traits of oil content % (62.30%) followed by days to 50% flowering (57.72%), plant height (56.97%) whereas the lowest recorded in 100 seed weight (37.31%).

Best promising crosses

Three promising cross combinations were identified on the basis of mean yield performance, gca and sca effects (Table 4). These crosses are CMS ND2 A $\times$ N0-2, CMS 7-1-A $\times$ GMU 1199 and CMS 234 A $\times$ PR 64-NB. The cross CMS ND2 A $\times$ N0-2 was identified as best cross combination, as it has recorded highest value of seed yield per plant (34.90g), highly significant sca effect (4.28) for seed yield with the parents involve in cross have low (poor) $\times$ high (good) general combining ability. Similarly, other identified crosses also recorded highly significant mean yield per plant and significant sca effect with high $\times$ high general combiner parent involve.

Conclusion

The present study identified promising Lines, CMS-7-1-A and CMS- ND2A as good general combiners for more than one trait such as head diameter, total filled seeds per head and CMS 234A in plant height, 100 seed weight shows desirable significant GCA effect. Among tester, GMU 1199 and NO-2 found good general combiner for days to 50 % flowering, days to maturity, seed filling and seed yield per plant and oil content.

The promising cross combinations with superior specific combining ability (sca) effects for key yield and related traits in sunflower.

The cross CMS234A $\times$ GMU 242 was most notable, excelling in early flowering and maturity, CMS ND2A $\times$ NO-2 and CMS 89A $\times$ PR64 NB showed superiority for seed yield per plant. These crosses also recorded highly

significant mean yield per plant and significant sca effect with high $\times$ high and low $\times$ high general combiner parent involve. Non-additive gene action predominantly governed yield traits, suggesting the potential of heterosis breeding for improvement. These findings provide valuable direction for exploiting heterosis and guiding future breeding programs aimed at enhancing sunflower productivity.

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