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Unlocking the Genetic Potential by Assessing Combining Ability and Heterosis for Yield and its Component Traits in Sunflower (*Helianthus annuus* L.)

B.V. Ravi Prakash Reddy [a*], S. Neelima [a], K. Venkataramanamma [a], K. Prabhakar [a], K. Amarnath [a] and B. Chandra Reddy [a]

[a] Acharya N. G. Ranga Agricultural University, Regional Agricultural Research Station, Nandyal, Andhra Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was executed with two lines and 12 testers along with 24 F_1s and check NDSH 1012 for six yield and its component traits to ascertain the combining ability and heterosis. The analysis of variances showed highly significant differences among the parents for all the characters except for seed yield per plant and oil content implying the presence of significant

**Corresponding author: E-mail: bvr.prakashreddy@angrau.ac.in;*

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variability and diversity among the parents. Among the two lines, ARM-243A was observed as best general combiner for head diameter, seed yield per plant and oil content. The tester, NDI-56 was found ato be good general combiner for head diameter and seed yield per plant. Out of 24 F_1s evaluated, two crosses *viz.,* CMS-17A X NDI-35 and CMS-17A X NDI-52 were recorded as good specific combiners for seed yield per plant and head diameter, respectively. The heterosis analysis revealed that 10 hybrids recorded positive significant mid parent, better parent and standard heterosis for seed yield per plant. Hence, the crosses CMS-17A X NDI-35 and CMS-17A X NDI-52 are advanced for direct selection to increase vigour gain.

Keywords: Sunflower; line x tester; combining ability; heterosis and seed yield.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) originated in North America is the most popular global edible oilseed crop due to its high-quality edible oil and wider adaptability to different agro-climatic regions and soil types. It occupies the fourth position in the oilseed category after groundnut, mustard and soybean in India. The crop was introduced for the first time in India from North America in 1969 [1]. Now a days, the seed requirement and per capita consumption of sunflower oil for edible purpose is increasing. As a consequence, hybrid seed production with increased seed and oil yield is one of basic step to achieve this goal. In camparison to other oilseed crop, sunflower possesses several advantages *i.e.,* short duration (90-110 days), high yield potential with higher percentage of edible oil and having wider adaptability to different soil and climatic conditions [2].

The main objectives of sunflower breeding include improvement of seed yield, oil content, sink capacity, harvest index, resistance to major diseases and pests. Breeders frequently struggle with the issue of creating the top criteria for selecting parents before initiating a hybridization program. Hence, there is a constant need to screen germplasm to isolate potential combining lines and desirable cross combinations. The approach of combining ability analysis has significant practical implications in plant breeding. Combining ability analysis reveals the comparative performance of lines in hybrid combinations for the prediction of relative parental performance.

The average performance of a given inbred in a series of hybrid combinations is General combining ability (GCA) while the output of a specific inbred combination in a particular cross is specific combining ability (SCA). The SCA and GCA variance indicates non-additive and additive gene action estimation, respectively [3]. SCA effects judged the advantage of a particular hybrid in exploiting heterosis. Higher SCA values represent the dominant gene effects whereas the higher GCA effects denote a greater contribution of additive gene effects controlling various traits studied. If both the GCA and SCA values are not significant then epistatic gene effects occupy major role in determining the various traits [4,5-7].

Line x tester analysis is the most efficient technique for evaluating combining ability [8]. It gives an idea to select parents with good GCA effects, hybrids with good SCA effects and to found the nature of gene action governing the inheritance of important quantitative traits. The heterosis assumes importance in breeding as heterotic crosses have the potential to throw out superior segregants in subsequent generations. The heterosis reveal details about the type of gene action responsible for expression of yield and its components traits. The heterosis also essential to create an effective breeding program for the crop improvement. The objective of this investigation is to study the combining ability and heterosis in sunflower for yield and its component traits along with gene action controlling these characters.

2. MATERIALS AND METHODS

The present investigation was laid out during *kharif,* 2022 at Regional Agricultural Research Station, Nandyal (15.46º latitude and 78.48º longitude), Andhra Pradesh, India. The experimental material was comprised of 24 F_1s generated by crossing two female lines (CMS-17 A, ARM 243 A) with 12 male testers (NDI-24, NDI-32, NDI-34, NDI-35, NDI-36, NDI-39, NDI-43, NDI-49, NDI-50, NDI-52, NDI-55, NDI-56) in Line x Tester mating fashion in the previous season (*Rabi*, 2021-22). All these 24 F_1s and their parents along with check NDSH 1012 were studied in randomized block design (RBD) with two replications. Each F_1 hybrid and parental lines were sown in 5-meter row length with inter and intra row space of 0.6 m and 0.3 m, respectively in each plot. Five randomly selected plants from each plot were taken to record the data on days to 50% flowering, plant height, head diameter, 100 seed weight, seed yield per plant and oil content. The oil content was estimated by NMR (Nuclear Magnetic Resonance) Spectrometer from Indian Institute of Oilseed Research, Hyderabad by using a random sample of cleaned and dried seeds from each entry. The obtained data were exposed to statistical analysis including ANOVA, combining ability and heterosis using statistical software INDOSTAT 9.2 version.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance for combining ability

Analysis of variance for combining ability in a Line x Tester analysis for six yield and its component traits showed that the experimental material (14 parents and 24 F_1 crosses) registered significant differences for most of the traits studied (Table 1). The parents varied significantly for all the characters except for seed yield and oil content suggesting the presence of sufficient variability in the experimental material studied. Mean squares due to parents vs crosses differed significantly for all the characters except oil content revealing manifestation of differences among parents and their F_1 crosses in all the characters. The effect of crosses was divided into lines, testers and their interaction. The mean sum of squares due to lines was significant for days to 50% flowering, 100 seed weight and oil content suggesting higher supplement of lines towards general combining ability variance components. The mean sum of squares due to testers was also significant for all the traits except seed yield and oil content indicating significant addition of testers towards component of GCA variance. The mean squares due to Line × Tester interaction effects were significant for days to 50% flowering, head diameter and 100 seed weight showed the significant addition of crosses for specific combining ability variance components. The obtained results are in consistent with the previous report of Habib et al. [9] and Akar et al. [10].

Table 1. Analysis of variance for combining ability in a Line x Tester analysis for yield and yield components in sunflower

Source of variation	df	Mean sum of squares					
		Days to 50 % flowering	Plant Height (cm)	Head Diameter (cm)	100 seed weight (g)	Seed yield (g/plant)	Oil content (%)
Replications	1	1.60	160.49	3.29	0.96	0.188	11.43
Genotypes	37	58.10**	1116.21**	31.20**	1.56**	145.35**	9.74
Parents	13	48.96**	558.82**	8.67*	2.77**	8.61	15.00
Parents (Lines)	1	81.00**	540.56	12.25	8.97**	83.63	42.90*
Parents (Testers)	11	47.51**	590.38**	7.70*	2.16**	1.21	12.17
Parents (L vs T)	1	32.86**	229.88	15.80**	3.33*	15.06	18.28
Parents vs Crosses	1	1287.80**	19124.39**	725.98**	7.97**	2591.06**	3.93
Crosses	23	9.81**	648.30**	13.72**	0.60	116.29**	7.02
Line effect	1	82.69**	5985.33**	154.05**	0.34	1246.24**	114.79**
Tester effect	11	8.46	388.73	7.34	0.25	68.63	2.66
Line x Tester effect	11	4.55	422.68**	7.34*	0.98	61.23	1.58
Error	37	2.66	141.04	3.38	0.52	43.14	8.77

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

Table 2. Estimates of components of genetic variance for yield and yield components in sunflower

Character	Days to 50 % flowering	Plant Height (cm)	Head Diameter (cm)	100 seed weight (g)	Seed yield (g/plant)	Oil content (%)
GCA variance	1.72	124.70	3.21	0.01	25.96	2.39
SCA variance	12.52	1162.39	20.21	2.69	168.39	4.36
GCA/SCA	0.14	0.10	0.16	0.003	0.15	0.55
σ^2A	6.13	435.14	11.04	-0.03	87.76	7.14
σ^2D	0.95	140.82	1.98	0.22	9.04	-3.59
Ratio σ^2A: σ^2D	6.47	3.09	5.58	-0.15	9.70	-1.99

Table 3. Estimates of general combining ability (*GCA*) effects for yield and yield associated traits in sunflower

S. No	Genotypes	Days to 50 % flowering	Plant Height (Cm)	Head Diameter (Cm)	100 seed weight (g)	Seed yield (g/plant)	Oil content (%)
				Lines			
1	CMS-17 A	-1.31**	-11.17**	-1.79**	-0.08	-5.10**	-1.55*
2	ARM 243 A	1.31**	11.17**	1.79**	0.08	5.10**	1.55**
	SE (gi)	0.36	0.35	2.57	2.46	0.46	0.50
	CD 5%	1.08	1.04	7.55	7.25	1.35	1.47
	CD 1%	1.46	1.41	10.24	9.78	1.83	1.99
				Testers			
1	NDI-24	-0.81	-13.64*	-0.82	0.29	-4.03	0.45
2	NDI-32	-0.81	0.06	-0.32	0.05	-1.08	-0.44
3	NDI-34	-0.81	-7.84	-1.61	-0.10	-4.28	1.92
4	NDI-35	4.44**	17.76**	2.68**	-0.24	-0.83	-0.76
5	NDI-36	0.19	13.61*	0.28	0.07	-1.18	0.89
6	NDI-39	-0.06	-9.79	-1.07	-0.03	-6.93	-0.97
7	NDI-43	-0.06	-2.34	0.43	-0.01	2.87	-0.67
8	NDI-49	-0.31	-2.54	0.83	0.02	-0.23	0.14
9	NDI-50	-0.06	7.56	-1.41	-0.36	0.56	0.20
10	NDI-52	-0.56	4.46	-0.97	-0.41	3.32	-0.36
11	NDI-55	-1.06	3.76	-0.17	0.35	3.27	-0.51
12	NDI-56	-0.06	-11.04	2.13*	0.34	8.52*	0.12
	SE (gj)	0.47	3.42	0.53	0.21	1.89	0.85
	CD 5%	2.38	7.09	1.09	0.43	3.92	1.76
	CD 1%	3.23	9.62	1.50	0.59	5.32	2.39

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

3.2 Estimates of Combining Ability Variances

The SCA variance was greater than GCA variance, indicating that these traits are mostly inherited by non-additive gene inheritance (Table 2). GCA: SCA ratio estimates were less than unity for all the traits inferring the higher proportion of SCA variance responsible for the expression of major yield components. From the estimates of additive and dominance variance, the additive variance is leading for all the characters except for 100 seed weight revealing the major contribution of additive gene action. Similarly, the results are in congruence with the report of Amarnath et al. [11].

3.3 General Combining Ability (GCA) Effects

The estimates of GCA effects of the lines and testers for the six traits are furnished in Table 3. Among lines, ARM-243A was a good combiner as it displayed desirable GCA effects for head diameter, seed yield per plant and oil content. The main use of sunflower is for edible oil purpose, thus the improvement in oil content is the major objective of sunflower improvement programme by exploitation of best general combiners. The next line CMS- 17A recorded GCA effect for days to 50% flowering and plant height in desirable direction. 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 [12]. Among the testers, NDI-56 was recognized as good general combiner as it displayed high GCA effect in desired direction for head diameter and seed yield per plant. Further, the testers NDI-24 and NDI-35 had reported high GCA effect for plant height and head diameter, respectively. The above findings are in confirmation with Akar et al. [10].

3.4 Specific Combining Ability (SCA) Effects

SCA effects in sunflower hybrids for six yield and its component traits is furnished in the Table 4. In the present study, the crosses, CMS-17 A x NDI-35 and CMS -17 A x NDI-52 displayed positive and significant SCA effects for seed yield per plant and head diameter, respectively. Further, ARM-243 A x NDI-35 showed negative significant SCA effects for seed yield per plant, while the cross ARM-243A x NDI-56 rcorded negative significant SCA effects for plant height. The obtained results represents that all the types of parental combinations were noticed in the crosses [13]. Besides, most of the crosses displayed strong SCA effects as a result of either high x high or high x low GCA parents implying a genetic interaction of additive x additive or additive x dominance interaction. Similar results are confirmed by the findings of Akar et al. [10] and Ingle et al. [14].

3.5 Proportion Contribution of Lines, Testers, and Line x Tester Interaction (%) Towards Variation

It was clear that per cent contribution of lines towards variation in the F_1 crosses was higher for oil content (71.0%) followed byhead diameter (48.80%), seed yield per plant (46.59%), plant height (40.14%), compared to line x tester interaction and testers (Table 5). On the other hand, per cent contribution of line x tester interaction was higher for 100 seed weight (77.84%). Same kind of proportion contribution was also confirmed by Arzu Kose, [15].

3.6 Heterosis for Yield and its Component Traits

The exploitation of heterosis for yield and its components is essential in sunflower improvement programme. In the present study, mid parent heterosis, heterobeltiosis or better parent heterosis and standard or economic heterosis over check NDSH 1012 were estimated to find potential hybrids with high degree of heterosis. Our study of the effects of heterosis of yield and yield components has shown that this phenomenon varies both by trait and by crossing combination. The negative heterosis is considered for the characters *viz*; days to 50% flowering and plant height in sunflower as early entries yields more and taller plants are prone to lodging, respectively [16]. Hence, negative heterosis is desirable for these two traits. The trait, days to 50 per cent flowering displayed desirable negatively significant mid parent, better parent and standard heterosis in all 24 crosses except CMS-17 A x NDI-35 and ARM-243A x NDI-35 (Table 6). None of the hybrids displayed desirable heterosis for the trait, plant height. The superiority of the tallness over dwarfness shows that tallness is the dominant character as reported by Vikas et al. [17]. Nine out of 24 crosses *viz*., CMS-17 A x NDI-35, ARM-243A x NDI-32, ARM-243A x NDI-35, ARM-243A x NDI-36, ARM-243A x NDI-39, ARM-243A x NDI-43, ARM-243A x NDI-49, ARM-243A x NDI-52 and ARM-243A x NDI-56 displayed significant heterosis over mid, better and standard parent for head diameter. The head diameter is desirable characteristic to increase sunflower crop yields. Patil et al. [18] also reported highest positive and significant standard heterosis for head diameter.

None of the crosses exhibited significant heterosis except CMS-17 A x NDI-35 and CMS-17 A x NDI-56 for heterosis over mid parent for 100 seed weight. Besides, eight crosses noticed negative significant standard heterosis for 100 seed weight in undesirable direction. Interestingly, 10 crosses *viz*., CMS-17 A x NDI-56, ARM-243A x NDI-24, ARM-243A x NDI-32, ARM-243A x NDI-36, ARM-243A x NDI-43, ARM-243A x NDI-49, ARM-243A x NDI-50, ARM-243A x NDI-52, ARM-243A x NDI-55 and ARM-243A x NDI-56 shown desirable highly positive significant mid parent, better parent and standard heterosis for seed yield per plant. Heterosis of seed yield per plant was much greater than that of the other traits. A similar kind of desirable heterosis was also documented by Dhootmal et al. [19] and Ailwar et al. [20]. No cross displayed desirable heterosis for oil content in all the 24 crosses. A total of 12 crosses showed negative significant standard heterosis for the trait, oil content. The results were in conformity with Reddy et al. [21].

Table 4. Specific combining ability (*SCA*) effects for different traits in sunflower

S. No	Genotypes	Days to 50 % flowering	Plant Height (cm)	Head Diameter (cm)	100 seed weight (g)	Seed yield (g/plant)	Oil content (%)
1	CMS-17A × NDI-24	-0.188	-0.933	-0.009	-0.303	-1.505	0.239
2	CMS-17A × NDI-32	-0.188	-10.233	-1.109	0.009	-3.855	0.394
3	CMS-17A × NDI-34	-0.188	7.567	0.291	0.409	1.845	-1.424
4	CMS-17A × NDI-35	1.563	1.267	2.491	0.872	9.995*	0.569
5	CMS-17A × NDI-36	1.313	-3.883	-0.809	-0.941	-1.655	0.204
6	CMS-17A × NDI-39	-0.938	-16.883	-1.459	0.059	-3.705	-0.589
7	CMS-17A × NDI-43	-0.938	-2.933	-0.459	-0.658	-0.505	0.109
8	CMS-17A × NDI-49	-0.688	2.267	-0.159	0.384	-0.905	0.086
9	CMS-17A × NDI-50	-0.938	-6.733	-0.506	0.159	-3.700	-0.526
10	CMS-17A × NDI-52	2.063	9.367	2.841*	-0.271	3.545	1.054
11	CMS-17A × NDI-55	0.063	-2.233	0.041	-0.041	-1.205	-0.059
12	CMS-17A × NDI-56	-0.938	23.367*	-1.159	0.322	1.645	-0.059
13	ARM-243A × NDI-24	0.188	0.933	0.009	0.303	1.505	-0.239
14	ARM-243A × NDI-32	0.188	10.233	1.109	-0.009	3.855	-0.394
15	ARM-243A × NDI-34	0.188	-7.567	-0.291	-0.409	-1.845	1.424
16	ARM-243A × NDI-35	-1.563	-1.267	-2.491	-0.872	-9.995*	-0.569
17	ARM-243A × NDI-36	-1.313	3.883	0.809	0.941	1.655	-0.204
18	ARM-243A × NDI-39	0.938	16.883	1.459	-0.059	3.705	0.589
19	ARM-243A × NDI-43	0.938	2.933	0.459	0.658	0.505	-0.109
20	ARM-243A × NDI-49	0.688	-2.267	0.159	-0.384	0.905	-0.086
21	ARM-243A × NDI-50	0.938	6.733	0.506	-0.159	3.700	0.526
22	ARM-243A × NDI-52	-2.063	-9.367	-2.841*	0.271	-3.545	-1.054
23	ARM-243A × NDI-55	-0.063	2.233	-0.041	0.041	1.205	0.059
24	ARM-243A × NDI-56	0.938	-23.367*	1.159	-0.322	-1.645	0.059
	SE (Sij)	0.81	5.94	0.92	3.28		1.48
	CD 5%	1.68	12.28	1.90	0.75	6.79	3.06
	CD 1%	2.29	16.67	2.58	1.02	9.22	4.15

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

Table 5. Proportion contribution of lines, testers, and line x tester interaction (%) towards variation in the F_1 crosses of sunflower

S. No	Character	Contribution of		
		Lines	Testers	Line x Tester interaction
1	Days to 50 % flowering	36.62	41.1	22.17
2	Plant Height (cm)	40.14	28.68	31.18
3	Head Diameter (cm)	48.80	25.59	25.61
4	100 seed weight (g)	2.46	19.70	77.84
5	Seed yield per plant (g)	46.59	28.23	25.18
6	Oil content (%)	71.07	18.13	10.81

Table 6. Heterosis for yield and yield associated traits in sunflower

S.No	Crosses	Days to 50% flowering			Plant height (cm)		
		MPH	BPH	SH	MPH	BPH	SH
1	CMS-17 A x NDI-24	-23.60**	-27.27**	-15.79**	-6.85	-10.95	14.37
2	CMS-17 A x NDI-32	-25.09**	-27.27**	-15.79**	1.37	-6.76	19.76
3	CMS-17 A x NDI-34	-24.70**	-27.27**	-15.79**	7.80	2.67	31.87*
4	CMS-17 A x NDI-35	-11.40**	-16.67**	-3.51	19.15	17.31	55.47**
5	CMS-17 A x NDI-36	-19.83**	-23.48**	-11.40**	14.51	12.19	44.10**
6	CMS-17 A x NDI-39	-23.97**	-27.27**	-15.79**	-3.90	-22.48	-0.43
7	CMS-17 A x NDI-43	-23.98**	-27.27**	-15.79**	31.29*	-2.10	25.75
8	CMS-17 A x NDI-49	-24.94**	-27.27**	-15.79**	8.37	2.67	31.87*
9	CMS-17 A x NDI-50	-16.14**	-27.27**	-15.79**	9.47	3.71	33.21*
10	CMS-17 A x NDI-52	-11.60**	-23.48**	-11.40**	45.96**	16.10	49.11**
11	CMS-17 A x NDI-55	-24.97**	-27.27**	-15.79**	15.89	4.38	34.07*
12	CMS-17 A x NDI-56	-22.75**	-27.27**	-15.79**	27.31*	14.67	47.28**
13	ARM-243 A x NDI-24	-12.56**	-14.51**	-10.53**	32.62**	22.92	43.98**
14	ARM-243 A x NDI-32	-14.40**	-17.95**	-10.53**	65.63**	59.61**	72.11**
15	ARM-243 A x NDI-34	-13.92**	-17.07**	-10.53**	30.13*	21.05	40.67*
16	ARM-243 A x NDI-35	-5.34*	-6.28*	-4.39	54.55**	35.58**	79.69**
17	ARM-243 A x NDI-36	-13.66**	-15.80**	-11.40**	62.08**	46.80**	80.92**
18	ARM-243 A x NDI-39	-10.46**	-12.89**	-7.89*	88.16**	68.20**	68.20**
19	ARM-243 A x NDI-43	-10.47**	-12.91**	-7.89*	96.48**	60.24**	60.24**
20	ARM-243 A x NDI-49	-12.54**	-16.00**	-8.77**	42.97**	33.69*	53.64**
21	ARM-243 A x NDI-50	-0.45*	-7.89*	-7.89*	64.71**	54.02**	77.00**
22	ARM-243 A x NDI-52	-6.89*	-14.04**	-14.04**	74.57**	53.52**	53.52**
23	ARM-243 A x NDI-55	-15.09**	-18.48**	-11.40**	64.44**	62.09**	66.85**
24	ARM-243 A x NDI-56	-8.91**	-9.91*	-7.89*	15.73	14.08	17.43
	SE	1.41	1.63	1.63	10.29	11.88	11.88
	CD 5%	2.91	3.37	3.37	21.28	24.57	24.57
	CD 1%	3.96	4.57	4.57	28.87	33.34	33.34
S.No	**Crosses**	**Head diameter (cm)**			**100 seed weight (g)**		
		MPH	**BPH**	**SH**	**MPH**	**BPH**	**SH**
1	CMS-17 A x NDI-24	50.02*	43.53	1.67	-5.74	-29.28**	-20.96
2	CMS-17 A x NDI-32	34.77	33.10	-3.33	18.41	0.93	-19.85
3	CMS-17 A x NDI-34	41.82*	37.65	-2.50	20.06	0.18	-16.18
4	CMS-17 A x NDI-35	123.66**	114.12**	51.67**	36.93*	20.62	-11.40
5	CMS-17 A x NDI-36	41.56*	36.46	4.17	-19.20	-38.81**	-33.46**
6	CMS-17 A x NDI-39	8.81	-2.78	-12.50	2.26	-20.28	-20.22
7	CMS-17 A x NDI-43	69.93**	52.94*	8.33	-15.39	-35.95**	-30.29**
8	CMS-17 A x NDI-49	97.12**	61.18**	14.17	-0.81	-26.49**	-14.71
9	CMS-17 A x NDI-50	20.05	11.05	-7.46	10.58	-7.14	-23.53*
10	CMS-17 A x NDI-52	61.08**	49.00*	24.17	0.32	-15.73	-30.66**
11	CMS-17 A x NDI-55	106.07**	51.76*	7.50	22.58	3.73	-16.18
12	CMS-17 A x NDI-56	61.85**	59.09**	16.67	28.65*	8.04	-11.03
13	ARM-243 A x NDI-24	59.88**	31.67	31.67	-14.58	-19.08	-9.56
14	ARM-243 A x NDI-32	67.99**	45.00**	45.00**	-8.20	-17.65	-17.65
15	ARM-243 A x NDI-34	47.00**	22.50	22.50	-19.14	-25.74*	-25.74*
16	ARM-243 A x NDI-35	69.91**	40.00*	40.00*	-24.54*	-34.56**	-34.56**
17	ARM-243 A x NDI-36	67.30**	47.50**	47.50**	-7.36	-11.09	-3.31
18	ARM-243 A x NDI-39	49.12**	41.67*	41.67*	-19.51	-19.54	-19.49
19	ARM-243 A x NDI-43	86.17**	45.83**	45.83**	-12.32	-15.88	-8.46

20	ARM-243 A x NDI-49	102.30**	46.67**	46.67**	-29.20**	-34.09**	-23.53*
21	ARM-243 A x NDI-50	42.73**	30.83	30.83	-18.55	-25.74*	-25.74*
22	ARM-243 A x NDI-52	16.36	6.67	6.67	-12.46	-20.22	-20.22
23	ARM-243 A x NDI-55	104.74**	36.67*	36.67*	-3.21	-12.50	-12.50
24	ARM-243 A x NDI-56	91.35**	65.83**	65.83**	-10.08	-18.01	-18.01
	SE	1.59	1.84	1.84	0.63	0.73	0.73
	CD 5%	3.29	3.80	3.80	1.30	1.50	1.50
	CD 1%	4.48	5.17	5.17	1.77	2.04	2.04
S.No	**Crosses**	**Seed yield (g/plant)**			**Oil content (%)**		
		MPH	**BPH**	**SH**	**MPH**	**BPH**	**SH**
1	CMS-17 A X NDI-24	4.01	-8.50	127.46	-1.86	-3.56	-17.25*
2	CMS-17 A X NDI-32	4.89	-4.58	137.21	-1.47	-2.44	-19.19*
3	CMS-17 A X NDI-34	24.34	11.76	177.82	2.42	-0.71	-17.76*
4	CMS-17 A X NDI-35	95.87*	87.58	366.29**	-0.41	-2.90	-19.57*
5	CMS-17 A X NDI-36	17.15	9.15	171.32	-3.56	-7.87	-16.20*
6	CMS-17 A X NDI-39	-37.29	-41.83	44.60	-11.04	-14.57	-23.15*
7	CMS-17 A X NDI-43	54.14	43.14	255.81*	-6.93	-9.63	-20.54*
8	CMS-17 A X NDI-49	24.96	20.26	198.94	-4.98	-8.16	-18.47*
9	CMS-17 A X NDI-50	16.15	7.19	166.45	-4.52	-5.71	-19.91*
10	CMS-17 A X NDI-52	86.97*	72.55	328.92**	-2.89	-5.54	-17.25*
11	CMS-17 A X NDI-55	58.71	41.18	250.93*	-11.58	-17.98*	-20.56*
12	CMS-17 A X NDI-56	116.35**	94.12*	382.53**	3.50	-2.10	-18.91*
13	ARM-243 A X NDI-24	206.05**	134.08*	341.92**	-3.55	-10.39	-10.39
14	ARM-243 A X NDI-32	247.69**	159.17**	428.03**	-4.14	-13.15	-13.15
15	ARM-243 A X NDI-34	157.08*	93.36	283.43*	10.05	-2.19	-2.19
16	ARM-243 A X NDI-35	87.50	34.95	207.07	-4.24	-14.44	-14.44
17	ARM-243 A X NDI-36	211.90**	128.61*	390.66**	-4.86	-9.16	-9.16
18	ARM-243 A X NDI-39	175.47**	102.52	330.54**	-7.30	-11.95	-11.95
19	ARM-243 A X NDI-43	243.54**	152.38**	437.77**	-7.41	-13.00	-13.00
20	ARM-243 A X NDI-49	199.43**	114.84*	393.91**	-5.51	-10.81	-10.81
21	ARM-243 A X NDI-50	256.01**	162.67**	452.23**	-1.64	-9.04	-9.04
22	ARM-243 A X NDI-52	208.98**	127.98*	379.29**	-9.03	-14.67	-14.67
23	ARM-243 A X NDI-55	278.42**	186.91**	455.65**	-10.75	-12.15	-12.15
24	ARM-243 A X NDI-56	299.78**	201.11**	494.64**	2.95	-10.50	-10.50
	SE	5.69	6.57	6.57	2.56	2.96	2.96
	CD 95%	11.77	13.59	13.59	5.31	6.13	6.13
	CD 99%	15.97	18.44	18.44	7.20	8.31	8.31

**Significant at 5% level; ** Significant at 1 % level; MPH- Mid Parent heterosis; BPH- Better parent heterosis; SH- Standard heterosis*

4. CONCLUSION

From the study, it is concluded that the magnitude of SCA variance was greater than GCA for all the traits indicating the presence of non-additive gene action in the expression of traits. The line ARM-243A was a good combiner with desirable GCA effects for head diameter, seed yield per plant and oil content. Among testers, NDI-56 found as best general combiner with desirable significant GCA effects for head diameter and seed yield per plant. The cross, CMS -17 A x NDI-35 showed desirable and positive SCA effects for seed yield per plant suggesting the expression of non-additive gene action. Ten hybrids namely CMS-17 A x NDI-56, ARM-243A x NDI-24, ARM-243A x NDI-32, ARM-243A x NDI-36, ARM-243A x NDI-43, ARM-243A x NDI-49, ARM-243A x NDI-50, ARM-243A x NDI-52, ARM-243A x NDI-55 and ARM-243A x NDI-56 showed desirable mid parent, better parent and standard heterosis for seed yield per plant indicating the superiority with predominance of over-dominance effects for this trait.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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