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Early Generation Testing of New Restorer Lines in Sunflower (*Helianthus annuus* L.) for Earliness and High Oil Content

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A B S T R A C T

An investigation was carried out to assess the general combining ability effect (*gca*), specific combining ability effect (*sca*) of the hybrids for earliness and high oil content by crossing six CMS lines with sixteen testers *viz.*,10 R × R S_3 high oil content restorer lines and 6 R × R S_4 early restorer lines following line × tester mating design. The resulting 96 hybrids along with four checks (KBSH-44, KBSH-53, KBSH-78 and RSFH-1887) were evaluated in a simple lattice design, simultaneously parents were also evaluated in RCBD design at Main Agricultural Research Station, Hebbal, Bangalore during summer 2020-21. Among the sixteen testers, high oil content tester *viz.*, 44-2-1[H] and early maturing tester *viz.*, 2-3-1-2[E] (75 days) were identified as good general combiners for earliness, seed yield plant^{-1} and oil content. Out of six CMS lines, CMS 903 B was found to be good general combiners for earliness whereas, NDCMS 2B is for seed yield plant^{-1} with oil content. Among the 96 hybrids CMS 1103A × 25-2-4-2 [E] (79 days), CMS 1103A × 21-9-5-2 [E] (80 days) and CMS 903A × 5-2-1 [H] (79.50 days) were identified as desirable specific combiner for earliness. Whereas, CMS 911A × 8-5-5-1 [E], CMS 911A × 21-9-5-2 [E] and NDCMS 4A × 31-1-1[H]were recorded high *sca* effect for seed yield. Whereas, NDCMS 2A × 30-10-1[H] (41.63%), CMS 911A × 25-2-4-2 [E] (41.11%) and NDCMS 4A × 11-4-1[H] (39.73%) showed high *sca* effect for oil content.

Introduction

Sunflower (*Helianthus annuus* L.) has become very important edible oilseed crop in India due to its wider adaptability, short duration (85-100 days), higher yielding potential, less photosensitivity, cross pollinated nature and remunerative market price (Virupakshappa *et al.*, 1997). It is originated in North America and belongs to family Asteraceae. 67 species of this genus *Helianthus* are recognized, of which only 2 species, a diploid annual *H. annuus* (2n=2x=34) and hexaploidy perennial *H. tuberosus* (2n=6x=102) are cultivated (Jarwar *et al.*, 2017).

Oilseed varieties of sunflower contains 38-50 *per cent* oil and it contains high concentration of Poly unsaturated fatty acid (PUFA), which has rich source of linoleic acid of 64% and oleic acid is about 25% to 30%. These helps in reducing the risk of coronary diseases (Patil *et al.*, 2017).

In India, it stands the fourth place with respect to edible vegetable oilseed crop after soybean, groundnut and mustard contributing to an area about 2.28 lakh ha with production of 2.13 (lakh tonnes) and the productivity of 931 kg/ha (Anon., 2019-20). Karnataka contributes an area about 1.29 lakh ha with the production of 1.03 lakh tonnes and productivity is about 802 kg/ha (Anon, 2019-20).

With the introduction of the cytoplasmic male sterility the hybridization has taken the new era in sunflower breeding. One of the most effectual method to inflate the yield is the utilization. of heterosis by using three-line hybrids. The performance of heterotic. hybrid is dependent on combining ability of its parents (Allard, 1960 and Kadkol *et al.*, 1984).

A hybrid sunflower breeding system that could measures the GCA of inbreds or the parental lines and SCA of the hybrids at an early stage in their development would clearly be useful. As the inbred lines in the breeding program increases, the size and financial limitations prevent the testing of all possible hybrid combinations. Hence, an early generation testing system enables plant breeders to discard almost undesirable inbreds and it allows greater expenditure of resources on most promising and helps in identification and production of superior hybrids (Bernardo, 2010; Ali *et al.*, 2011; Ai-Zhi and Zheng, 2012).

The analysis of the Line × Tester method (Kempthorne, 1957) is the one which is simplest, efficient and most amply. used design for assessing the large number of inbreds as well as parents for their GCA providing knowledge on the respective principal of its *gca* and *sca* effects, for elucidating the genetic basis of crucial plant characters. Therefore, the selection of parents. with good combining ability is very essential to produce the superior hybrids for seed and oil yield (Jarwar *et al.*, 2017). Keeping the above in view, current investigation was carried out with an objective to identify S_4 restorer and S_3 restorer lines with desirable general combining ability (*gca*) for early maturity and high oil content respectively and also to identify specific combining ability (*sca*) effects of the hybrids for early maturity and high oil content.

Materials and Methods

Material for the study comprised of six cytoplasmic male sterile lines,10 R × R S_3high oil content restorer lines and 6 R × RS_4 early restorer lines as testers and four check hybrids KBSH- 44 (National check), KBSH-53 (Local check), KBSH-78 (Local check) and RSFH-1887 (Regional check). 6 CMS lines, 16 testers and 4 check hybrids were procured from the AICRP on sunflower, UAS, GKVK, Bengaluru.

Crossing programme: Late *kharif* – 2020

All the six CMS lines and 16 testers (10 R× R S_3 high oi content and 6 R × R S_4 early restorer lines) were sown in the field to effect crossing in a Line × Tester fashion (Kempthorne, 1957) during late *kharif* 2020 in order to obtain F_1's at the experimental plot of Zonal Agricultural Research Station, UAS, GKVK, Bengaluru.

Evaluation of hybrids

The experimental material consisting of 96 hybrids along with their 22 parents (6 CMS lines and 16 testers *i.e.* 10 R × R S_3 high oil content and 6 R × R S_4 early restorer lines) and 4 check hybrids (KBSH-44, KBSH-53, KBSH-78 and RSFH-1887) were used for field evaluation to assess the seed yield and its attributing traits. The resultant 96 F_1 hybrids along with four check hybrids (KBSH-44, KBSH-53, KBSH-78 and RSFH-1887) were evaluated following simple lattice design (10×10 involving hybrids and checks) with two replications during summer 2020-21. While 22 parental lines were evaluated separately following RCBD with two replications during summer 2020-21 at the experimental plot of Main Agricultural Research station, Hebbal, Bengaluru. Each genotype was sown in two rows of 3-meter length with a spacing of 60 cm between rows and 30 cm between plants within a row. All the recommended package of practices was followed for raising a crop under protective irrigation. Observations were recorded in each entry on randomly selected five plants for ten characters *viz*; days to 50 *per cent* flowering, days to maturity, plant height (cm), head diameter (cm), stem diameter (cm), volume weight (g/100 ml), seed yield plant^{-1} (g), 100 grain weight, hull content (%), oil content (%) and oil yield (kg/ha).The gene action for yield and yield components besides general and specific combining ability effects of the parents were assessed by line × tester analysis (Kempthorne, 1957).

Results and Discussion

Analysis of variance for combining ability

Combining ability analysis is an important step in the evaluation of sunflower breeding lines for their performance in hybrid breeding programme. Analysis of variance for combining ability (Table 1) revealed that variance due to crosses were recorded highly significant for all the characters understudy.

The variances due to lines were significant for days to 50% flowering, days to maturity, head diameter and 100 seed weight. Variances due to testers were significant for all the traits. The line × tester interaction variance was highly significant for all the traits under the study. It is evident that the variance due to lines, testers, line × tester interaction showed significant for the most of the traits indicating both gca and sca variance to be equally important in inheritance of all the characters. The significance due to line × tester variance specified the presence of heterosis was also reported by Mohanasundaram *et al.,* (2010); Nandini (2013); Meena *et al.,* (2013); Tyagi (2013); Singh and Kumar (2017); Budihal (2017); Divya (2018) and Niharika (2019).

General combining ability (GCA) of seed parents and testers

General combining ability is the average performance of a line or genotype in a hybrid combination. The breeding value expressed as the deviation from the population mean is called as *gca* effects (gi), which takes into account the additive effects of the genes and also expressed in terms of GCA variance (σ^2g) and it is fixable on selfing. The results obtained on general combining ability for various traits are discussed here under.

The *gca* effects of parental lines (Table 2a) revealed the line CMS 903 B exhibited good general combiner as it recorded significant *gca* effects for days to 50 *per cent* flowering, days to maturity and hundred seed weight (g) in desirable direction. On the other hand, NDCMS 2B (Table 7a) showed good general combiner for plant height, oil content and seed yield plant^{-1} in desirable direction. For simultaneous improvement of earliness, seed yield and oil content in the hybrids, either the male or female parent should possess good *gca* for these traits together or the parents involved in the cross combinations should have good *gca* for one of the traits and able to nick well in the hybrids to produce superior heterosis and high *sca*.

Among the high oil content testers (Table 2b), 44-2-1 [H] was found to be good general combiner for traits like days to 50% flowering, days to maturity, seed yield plant^{-1} and oil content.

Another well performing high oil content tester was 31-1-1[H] for traits like head diameter, seed yield plant^{-1}, 100 ml volume weight, 100 seed weight and oil content.

In reference to the early maturing testers, 2-3-1-2 [E] was appeared to be desirable general combiner. for days to 50% flowering, days to maturity, plant height, seed yield plant^{-1}, volume weight and 100 seed weight. Similar results have been also reported by Reddy and Madhavi latha (2005). The results concerned to *gca* of lines and restorers showed that none of the parents were good general combiner for across the traits. However, promising lines and testers with desirable *gca* for combination of numerous traits have been showed in the Table 2c and 2d, respectively.

Specific combining ability effects of hybrids

Specific combining ability is the better or poorer performance than expected of a given hybrid combination. It is expressed in terms of *sca* effects (sij) and SCA variance (σ^2sj). The SCA variance denotes non-additive or dominance portion of variance and genetically non-fixable on selfing but can be exploited in hybrid combination.

The results regarding specific combining ability of cross combinations indicated none of the hybrids were desirable specific combiner for all the traits. However, few of the 96 hybrids proved to be promising for various traits. The top five promising cross combinations with desirable specific combining ability for combination of traits have been presented in Table 3a, 3b and 3c. It is fascinating to note that three hybrid combinations, out of top five high oil content ([H]) crosses, CMS 903A × 5-2-1 (79.50 days), CMS 234A × 27-2-1 (82 days)and CMS 911A × 34-3-1 (81 days) showed earliness as it recorded highest significant negative *sca* effect for days to 50% flowering and days to maturity (Table 3c). Apart from top five early ([E]) hybrids, CMS 1103A × 25-2-4-2 (79 days) and CMS 1103A × 21-9-5-2 (80 days) were found to be earliness as it showed highest significant negative *sca* effect for days to 50% flowering and days to maturity.

With regards to the seed yield plant^{-1} three out of top five high oil content hybrids, NDCMS4A × 31-1-1 (62.70g), NDCMS4A × 44-2-1 (59.60g) and CMS 234A × 31-1-1 (66.20g) exhibited highest significant positive *sca* effect. In case of top 5 early hybrids, CMS 911A × 8-5-5-1 (70.60g), CMS 911A × 21-9-5-2 (60.25g) and CMS 903A × 25-2-4-2 (50.30g) manifested desirable *sca* effect.

While, for the oil content, top high oil content hybrids *viz.*, NDCMS 2A × 30-10-1 (41.63%), NDCMS4A × 11-4-1 (39.73%) and CMS 1103A × 38-4-1 (40.70%) and early hybrids *viz.*, CMS 911A × 25-2-4-2 (41.11%), CMS 911A × 21-9-5-2 (37.85%) and CMS1103A × 21-9-5-2 (36.25%) were recorded highest significant positive *sca* effect for oil content. Similar results reported by Mohan Rao (2001) and Meena *et al.*, (2013).

Apart from top five hybrids showing significant *sca* for earliness, seed yield plant^{-1} and oil content, the hybrid CMS 911A × 21-9-5-2 [E] showed significant high *sca* for plant height, head diameter, stem diameter, seed yield plant^{-1}(g), volume weight, 100 seed weight and oil content were involved L **×** L type (the lines with low *gca* effects). This may be because of over dominance and epistasis interactions or might be due to cancellation of undesirable effects of genes. The preferred crosses involving L × L type for the traits were also observed by Mohan Rao (2001) and Shinde *et al.*, (2016).

Overall specific combing ability status of crosses

It is required to confirm whether a hybrid is desired specific combining ability across the traits or not. Therefore, using the methodology to find out the overall sca status of crosses for its *sca* effects across the traits studied given by Arunachalam and Bandyopadhyay (1979) and it was slightly modified by Mohan Rao (2001). It is observed from the results that out of 96 hybrids developed, 46 cross combinations recorded overall high specific combiners for earliness, seed yield plant^{-1} and oil content. Remaining 50 crosses showed overall low specific combiners. Similar results of nearly 50% of hybrids recorded high overall *sca* status were reported by Mohan Rao (2001); Budihal (2017); Divya (2018) and Niharika (2019). Among 46 cross-combination, CMS 911A × 21-9-5-2 [E] (L×L) recorded top overall high specific combiner with a rank of 20 over the final norm for scaof 193.90 followed by NDCMS 2A × 39-2-1 [H] (H×L) and CMS 234A × 27-2-1[H] (H × L) with rank of 46 and 52 respectively. Among the lines, CMS 903A and NDCMS 2Aexhibited maximum number of overall high *sca* effect for 7 hybrid combination each, followed by CMS 234A with 6 cross combination. Among the testers, 34-3-1[H] derived highest number of heterotic hybrids (5) followed by 25-2-4-2[E] denoted 4 hybrid combination each.

Table.1 Analysis of variance for combining ability

		Mean sum of squares								
Source of variation	**Df**	**Days to 50% flowering**	**Days to maturity**	**Plant height (cm)**	**Head diameter (cm)**	**Stem diameter (cm)**	**Seed yield plant^{-1} (g)**	**Volume weight (g/100ml)**	**100 seed weight (g)**	**Oil content (%)**
Replication	1	0.75	0.63	0.10	5.13 **	0.05	14.21	41.76 ***	0.78	1.96 ** *
Crosses	95	10.53 ***	10.71 ***	356.83 ***	3.73 ***	0.10 ***	155.01 ***	28.71 ***	1.65 ***	7.14* **
Line Effect	5	11.52 **	13.21 ***	323.46	18.67***	0.14	152.52	43.96	7.94***	9.14
Tester Effect	15	49.64***	49.63 ***	1169.26***	6.12**	0.24 ***	378.26***	61.43 **	2.96 ***	12.71 *
Line × Tester Effect	75	2.64 ***	2.76***	196.58***	2.26 ***	0.07 ***	110.52 ***	21.15 ***	0.97***	5.89* **
Error	95	0.92	0.95	6.52	0.67	0.02	9.01	3.55	0.35	0.07
Total	191	5.70	5.80	180.72	2.22	0.06	81.65	16.27	1.0	3.60

* Significant @ P=0.05 **Significant @ P=0.01 *** Significant @ P=0.001

Table.2a Estimates of *gca* effects of lines for seed yield and its attributing traits

Sl. No.	**Lines**	**Days to 50% flowering**	**Days to maturity**	**Plant height (cm)**	**Head diameter (cm)**	**Stem diameter (cm)**	**Seed yield plant^{-1} (g)**	**Volume weight (g/100ml)**	**100 seed weight (g)**	**Oil content (%)**
		Gca	***gca***	***gca***	***gca***	***gca***	***gca***	***gca***	***gca***	***gca***
1	CMS 911 B	1.08 ***	1.18 ***	-0.44	1.44***	0.08**	-1.02 *	0.16	-0.26 *	0.44 ***
2	CMS 1103 B	0.33	0.34	-4.44 ***	-0.12	0.06*	2.75 ***	-0.84 *	-0.02	-1.01 ***
3	CMS 903 B	-0.45 *	-0.47 *	3.49 ***	-0.15	-0.01	-0.59	-0.29	0.99 ***	-0.11
4	CMS 234 B	-0.35	-0.38 *	3.89 ***	-0.77 ***	-0.03	0.47	2.20***	-0.29 **	0.07
5	NDCMS 2B	-0.29	-0.32	-1.52 **	0.07	0.02	1.78 ***	-0.12	-0.13	0.39 ***
6	NDCMS 4B	-0.32	-0.32	-0.98 *	-0.48**	-0.10***	-3.39 ***	-1.10 **	-0.29 **	0.22 ***
	S. Em±	0.18	0.18	0.46	0.15	0.03	0.49	0.35	0.11	0.05
	CD at P=0.05	0.36	0.36	0.91	0.30	0.05	0.98	0.69	0.21	0.11
	CD at P=0.01	0.47	0.48	1.20	0.39	0.07	1.29	0.92	0.28	0.14

* Significant @ P=0.05 **Significant @ P=0.01 *** Significant @ P=0.001

Table.2b Estimates *gca* effects of testers for seed yield and its attributing traits

Sl.No.	Testers	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	Seed yield plant^{-1} (g)	Volume weight (g/100ml)	100 seed weight (g)	Oil content (%)
		gca	*gca*	*Gca*	*Gca*	*Gca*	*gca*	*gca*	*gca*	*gca*
1	39-2-1 [H]	4.99 ***	4.96***	9.41 ***	-0.07	0.01	-11.80 ***	-2.44 ***	-0.71***	-0.03
2	27-2-1 [H]	2.07 ***	2.05***	3.14 ***	-0.07	0.09 *	3.37 ***	-2.62***	-0.40 *	0.68***
3	3-7-1 [H]	2.49 ***	2.46***	20.21 ***	-0.15	0.03	-2.85 ***	0.84	-0.98 ***	0.11
4	11-4-1 [H]	0.49	0.55	4.77 ***	1.12 ***	0.10 *	5.94***	0.41	0.28	-0.68***
5	30-10-1 [H]	-0.18	0.05	-1.08	0.30	0.22 ***	8.81***	-0.74	0.82 ***	-0.32***
6	31-1-1 [H]	0.57	0.55	10.43 ***	0.93 ***	0.02	2.82 ***	4.22***	0.59 ***	0.58***
7	44-2-1 [H]	-0.76 *	-0.70*	4.87 ***	0.03	0.23***	-0.23	-2.72 ***	0.20	1.19***
8	5-2- 1 [H]	-0.09	-0.04	8.17 ***	-0.10	-0.06	2.27**	1.86**	-0.55 **	1.06***
9	38-4-1 [H]	0.07	0.04	-10.10 ***	-1.55 ***	-0.01	-6.76***	0.40	-0.08	1.97***
10	34-3-1 [H]	-0.26	-0.29	0.58	-0.93 ***	-0.21***	2.89 ***	0.09	-0.13	-0.42***
11	8-5-5-1 [E]	-0.51	-0.70*	-10.00 ***	-0.03	-0.09 *	4.09***	1.98 ***	0.55**	-0.79***
12	25-2-4-2 [E]	-2.26 ***	-2.29***	-0.60	1.04 ***	0.07	-6.98 ***	-2.20***	-0.08	-0.51***
13	2-3-1-2 [E]	-4.18 ***	-4.20 ***	-8.08 ***	-0.15	-0.02	4.29***	2.75 ***	0.40 *	-0.15
14	39-6-5-1 [E]	-1.34 ***	-1.37***	-18.10 ***	-0.65 **	-0.13 **	-2.96 ***	-0.34	0.28	0.16
15	4-1-3-1 [E]	-0.26	-0.29	-11.46 ***	-0.39	-0.31 ***	2.87***	2.11 ***	-0.20	-0.20*
16	21-9-5-2 [E]	-0.84 **	-0.77**	-2.17 **	0.66 **	0.05	-5.76 ***	-3.59 ***	0.01	-2.63***
	S. Em±	0.29	0.30	0.75	0.24	0.04	0.80	0.57	0.17	0.09
	CD at P=0.05	0.58	0.59	1.48	0.48	0.08	1.59	1.13	0.34	0.17
	CD at P=0.01	0.77	0.78	1.96	0.63	0.11	2.11	1.50	0.45	0.23

Note: [H] = High oil content testers [E] = Early maturing testers
* Significant @ P=0.05 **Significant @ P=0.01 *** Significant @ P=0.001

Table.2c Promising lines with good general combining abilityfor seed yield and its attributing traits

Sl. No	Lines	Traits
1	CMS 911 B	Head diameter, stem diameter, oil content
2	CMS 1103 B	Plant height, stem diameter, seed yield plant^{-1}
3	CMS 903 B	Days to 50% flowering, days to maturity, 100 seed Weight
4	CMS 234 B	Days to maturity, 100 ml volume weight
5	NDCMS 2B	Seed yield plant^{-1}, plant height, oil content
6	NDCMS 4B	Plant height, oil content

Table.2d Promising testers with good general combining ability for seed yield and its attributing traits

Sl. No	Testers	Traits
1	27-2-1 [H]	Stem diameter, seed yield plant^{-1}, oil content
2	30-10-1 [H]	Stem diameter, seed yield plant^{-1}, 100 seed weight
3	31-1-1 [H]	Head diameter, seed yield plant^{-1}, 100 ml volume weight, 100 seed weight, oil content
4	44-2-1 [H]	Days to 50% flowering, days to maturity, seed yield plant^{-1}, oil content
5	5-2- 1 [H]	Seed yield plant^{-1}, 100 ml volume weight, oil content
6	38-4-1 [H]	Plant height, oil content
7	34-3-1 [H]	Seed yield plant^{-1}
8	8-5-5-1 [E]	Plant height, days to maturity, seed yield plant^{-1}, 100 ml volume weight, 100 seed weight
9	25-2-4-2 [E]	Days to 50% flowering, days to maturity, head diameter
10	2-3-1-2 [E]	Days to 50% flowering, days to maturity, plant height, seed yield plant^{-1}, 100 ml volume weight, 100 seed weight
11	39-6-5-1 [E]	Days to 50% flowering, days to maturity, plant height
12	4-1-3-1- [E]	Plant height, seed yield plant^{-1}, 100 ml volume weight
13	21-9-5-2 [E]	Days to 50% flowering, days to maturity, plant height, head diameter

Table.3a Top five high oil content hybrids based on *sca* effects in respect of seed yield Plant^{-1} and oil *per cent*.

Traits	Crosses	*sca* effects	*Per se* performance
Seed yield plant^{-1} (g)	CMS 911A × 8-5-5-1 [E]	**17.29 *****	70.60
	CMS 911A × 21-9-5-2 [E]	16.79 ***	60.25
	CMS 903A × 25-2-4-2 [E]	7.63 ***	50.30
	CMS 911A × 25-2-4-2 [E]	7.35 ***	49.60
	CMS 903A × 2-3-1-2 [E]	6.69 ***	60.64
Oil content (%)	CMS 911A × 25-2-4-2 [E]	3.57***	41.11
	CMS 911A × 21-9-5-2 [E]	2.43***	37.85
	CMS1103A × 21-9-5-2 [E]	2.28***	36.25
	CMS 903A × 25-2-4-2 [E]	2.10	39.10
	CMS 911A × 4-1-3-1 [E]	1.83	39.69

Table.3b Top five early hybrids based on *sca* effects in respect of seed yield plant^{-1} and oil *per cent*.

Traits	Crosses	*sca* effects	*Per se* performance
Seed yield plant^{-1} (g)	NDCMS4A × 31-1-1 [H]	13.02 ***	62.70
	NDCMS4A × 44-2-1 [H]	12.97 ***	59.60
	CMS 234A × 31-1-1 [H]	12.66 ***	66.20
	NDCMS2A × 3-7-1 [H]	10.12 ***	59.30
	CMS 903A × 39-2-1 [H]	9.94 ***	47.80
Oil content (%)	NDCMS2A × 30-10-1 [H]	3.95***	41.63
	NDCMS4A × 11-4-1 [H]	2.57***	39.73
	CMS 1103A × 38-4-1 [H]	2.13***	40.70
	CMS 903A × 38-4-1 [H]	2.13***	41.61
	CMS 1103A × 31-1-1 [H]	1.87***	39.06

Table.3c Top high oil content hybrids and early hybrids based on *sca* effects in respect of days to 50% flowering and days to maturity

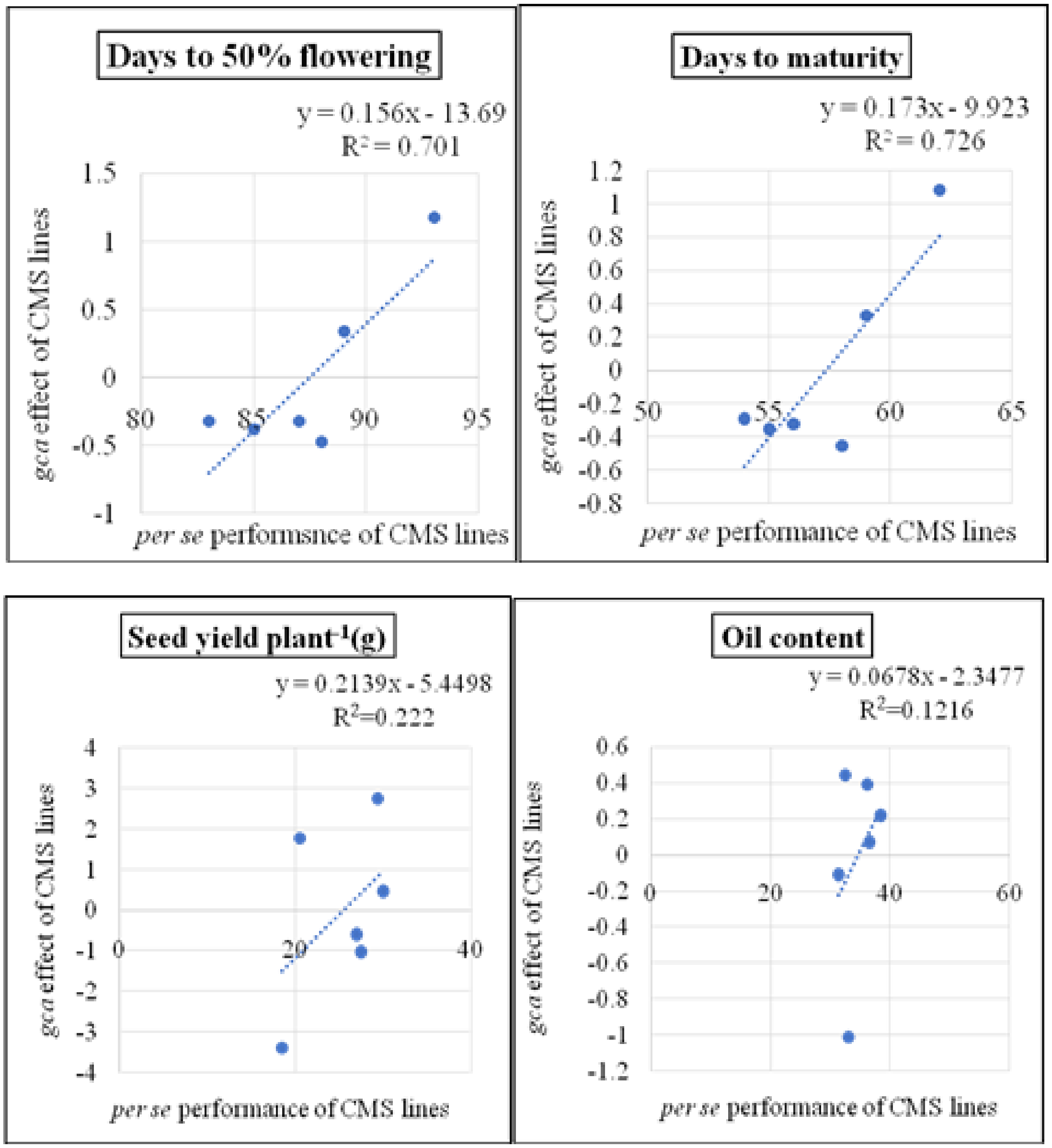
Crosses	Days to 50% flowering		Days to maturity	
	sca effects	*Per se* performance	*sca* effects	*Per se* performance
CMS 903A × 5-2-1 [H]	-1.47*	49.50	-1.53*	79.50
CMS 234A × 27-2-1 [H]	-1.73*	51.50	-1.70*	82
CMS 911A × 34-3-1 [H]	-1.83*	50.50	-1.93*	81
CMS 1103A × 25-2-4-2 [E]	-1.58*	48	-1.56*	79
CMS 1103A × 21-9-5-2 [E]	-2.00**	49	-2.06**	80

Note:[H]: High oil content hybrids [E]: Early hybrids
* Significant @ P=0.05 **Significant @ P=0.01 *** Significant @P=0.001

Table.4 Estimates of attributable variance due to general and specific combining ability effects for seed yield and its attributes

Characters	σ^2 gca	σ^2 sca	σ^2 gca/ σ^2 sca
Days to 50 % flowering	1.34 ***	0.80 ***	1.68
Days to maturity	1.38 ***	0.85 ***	1.62
Plant height (cm)	33.62 ***	94.94 ***	0.35
Head diameter (cm)	0.53***	0.78 ***	0.68
Stem diameter (cm)	0.01 ***	0.02 ***	0.5
Seed yield plant^{-1} (g)	11.71 ***	51.40 ***	0.23
Volume weight (g/100ml)	2.22 ***	8.63 ***	0.26
100 seed weight (g)	0.23 ***	0.31 ***	0.74
Oil content (%)	0.49 ***	2.90 ***	0.17

Fig.1 Correlation between *per se* performance of CMS lines with their corresponding *gca* effects for earliness, seed yield plant^{-1}& oil content



X-axis = *Per se* performance of CMS lines
Y-axis= *gca* effects of CMS lines

Based on *sca* effects, crosses are classified into H × L /L × H (female parent with high and male with low overall *gca* status or vice versa), H × H and L × L. Out of 46 crosses with high overall high *sca* effect, 9 crosses showed H × L and 17 crosses were of L × H type indicating the predominance of non-additive mode of gene action.

Variance due to general and specific combining ability effects

The variance due to *gca* and *sca* effects and the ratio among variance due to gca (σ^2A) and variance due to sca (σ^2D) for each of the characters studied are depicted in Table 11. Among the nine traits studied, the results indicated that the ratio between variance due to gca (σ^2A) and sca (σ^2D) were found to be greater than the unity for two traits *viz*., days to 50% flowering and days to maturity. While, the remaining characters were showed lesser than the unity. Highest magnitude of ratio was recorded for days to 50% flowering (1.68).

The variances ratio of gca (σ^2A) to sca (σ^2D) indicates the predominant mode of gene action governing the character. The results denoted the predominance of additive gene action for the characters *viz*., days to 50 *per cent* flowering and days to maturity. These results were in accordance with Patil *et al.,* (2017); Budihal (2017) and Divya (2018) for days to 50 *per cent* flowering. Whereas, the remaining traits *viz.*, plant height, stem diameter, head diameter, seed yield plant^{-1}, volume weight, 100 seed weight and oil content indicated prevalence of dominance gene action and these results were similar with Asif *et al.,* (2013) for plant height, head diameter, seed yield plant^{-1}, volume weight, oil content and plant height, stem diameter, head diameter, seed yield plant^{-1}, volume weight, 100 seed weight. Nandini (2013) and Tyagi (2013) on diversified CMS sources, Radhika *et al.,* (2001); Karasu *et al.,* (2010) and Mohanasundaram *et al.,* (2010) on PET-1 based sunflower for seed yield plant^{-1}. This indicated the heterosis breeding is the better choice for the traits controlled predominantly by non-additive gene action.

Relationship between *per se* performance and *gca* effects of seed parents

A review on the nature and degree of association of *gca* effects of lines with their *per se* performance assumes greater importance for selecting the parents and play a decisive role in plant breeding. High magnitude of positive significant and non-significant correlation shows good and poor predictive ability of *gca* effects based on their *per se* performance, respectively.

Positive and significant correlation between *per se* performance of CMS lines and their corresponding *gca* effects and the data is depicted in Table 6a and Fig. 1 indicated that mean performance of lines is a good indicator for their *gca* effects for days to 50% flowering and days to maturity as it showed higher correlation coefficient ($r > 0.70$) and coefficient of determination ($R^2 > 0.5$). Whereas, for seed yield plant^{-1} and oil content, mean performance of lines is poor indicator for their *gca* effects as it recorded $R^2 < 0.5$.

The line × tester analysis is fundamental strategy in evaluation of breeding value of genotypes involved in breeding program and also identification of the *gca* of the seed parents and *sca* of the hybrids for earliness, seed yield plant^{-1} and oil content. Among the sixteen testers, high oil content tester *viz.*, 44-2-1[H] and early maturing tester *viz.*, 2-3-1-2[E] (75 days) were identified as good general combiners for earliness, seed yield plant^{-1} and oil content.

The current study resulted in the identification of promising hybrids *viz.*, CMS 1103A × 25-2-4-2 [E] (79 days), CMS 1103A × 21-9-5-2 [E] (80 days) and CMS 903A × 5-2-1 [H] (79.50 days) were manifested as desirable specific combiner for earliness. Whereas, CMS 911A × 8-5-5-1 [E], CMS 911A × 21-9-5-2 [E] and NDCMS 4A × 31-1-1[H] were recorded high *sca* effect for seed yield. Whereas, NDCMS 2A × 30-10-1[H] (41.63%), CMS 911A × 25-2-4-2 [E] (41.11%) and NDCMS 4A X 11-4-1[H] (39.73%) showed good specific combiners for oil content. Hence, these crosses need to be confirmed further for their superiority by large scale testing as well as multi-location trials.

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