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Assessment of Combining Ability for Yield and Associated Traits in Sunflower (*Helianthus annuus* L.)

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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 study was carried out at the Oilseeds Research Station, Latur. During *kharif* 2023, crosses were produced and during *Rabi* 2023–24, evaluation was conducted to assess the combining ability for seed yield and component traits in parents and hybrids in sunflower. In this study, 48 F_1 hybrids were produced through Line x Tester mating design during *Kharif* 2023 using six CMS lines (DSF-2 A, CMS 148A, CMS 47A, CMS 597A, CMS 103A, CMS 112A) and eight testers (RHA-1055, EC-601951-1, EC-601924, R-274, LTRR-341, AKSF-15R, BK-R-1, R-856). These hybrids were assessed using a Randomized Block Design with two replications at the Oilseeds Research Station in Latur during *Rabi* 2023–24, together with their 14 parent lines and two commercial checks (LSFH-171 and KBSH-44). The observations were recorded on five randomly selected plants and the average value of these data was calculated for ten quantitative attributes. The analysis of combining ability (GCA and SCA) effect was came out by using the Line x Tester analysis method suggested by Kempthorne [1]. The significance of GCA and SCA effects was determined at the

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0.05 and 0.01 level using the t-test [2]. All characteristics had substantial significant variance due to line x tester effects. The existence of non-additive gene action for days to maturity, head diameter, seed filling, 100 seed weight and seed yield per plant were recorded. The per cent contribution of testers towards total variance was greater than lines for all the characters except plant height. Among the parents, two lines CMS-597 A and CMS-47 A and four testers RHA-1055, EC-601924, R-274 and AKSF-15R were found to be superior general combiners for seed yield per plant and most of the yield contributing traits. On the basis of mean performance, SCA effects of crosses and GCA effects of the parents, the crosses *viz.*, CMS-112 A x AKSF-15R, CMS-148 A x RHA-1055, CMS-597 A x R-856, CMS-47 A x R-274, CMS-597 A x LTRR-341, CMS-112 A x EC-601924 and CMS-597 A x EC-601951-1 recorded high SCA effect with low x high, low x high and high x high GCA status of parents for seed yield per plant.

Keywords: Sunflower; general combining ability; specific combining ability; heterosis; hybrid; gene action.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in the world and ranked third after soybean and rapeseed in the production of oil globally. During the year 2020-21 area under sunflower cultivation in India was 218.18 lakh ha with production of 365.65 lakh tonnes and productivity of 1269 kg/ha. In Maharashtra area under sunflower cultivation was 0.02 million ha with production of about 0.01 million tonnes and average productivity of 507 kg/ha [3]. With the increase in demand for edible oils, there is need to develop new sunflower hybrids suited to different agro-climatic zones of Maharashtra with improved seed yield and oil content. The selection of parents through meticulous and critical evaluation is vital to producing sunflower hybrids with increased yield potential in order to increase productivity and overall production. The traits that contribute to seed yield and yield attributing characters exhibit polygenic inheritance, which makes them vulnerable to changes in the environment. The choice of parents for hybridization is therefore a challenging issue.

Both additive and non-additive gene effects are revealed by the concepts of general combining ability and specific combining ability (Sprague and Tatum, 1942). This helps the breeders to assess the parents for adoption in heterosis breeding programme. The choice of the parents is determined by their individual performance of parents and behaviour of parents in their respective hybrid combinations. Parents' individual performance, especially with regard to yield components, can provide some insight on their usefulness (Gilbert, 1958). The mode of gene action depends upon the genetic structure and extent of divergence between the parents involved. In order to determine the genetic potentialities of the parents in hybrid combinations, rigorous research on both general and specialized combining abilities is required. In view of the above facts, the present study was undertaken to estimate general combining ability and specific combining ability for seed yield and yield contributing characters. This study uses eight fertility restorer lines and six cytoplasmic male sterile (CMS) lines to assess combining ability in sunflower hybrids. The analysis of combining ability of Griffing (1956 b), method II, model 1 was employed in the present investigation to get an overview of genetic architecture of yield and its components.

2. MATERIALS AND METHODS

Six CMS lines *viz*., DSF-2 A, CMS-148 A, CMS-47 A, CMS-597 A, CMS-103 A, CMS-112 A and eight restorer lines *viz.*, RHA-1055, EC-601951-1, EC-601924, R-274, LTRR-341, AKSF-15R, BK-R-1, R-856 were planted during *Kharif*-2023 at Oilseeds Research Station, Latur and crossing was performed in Line x Tester fashion to produce 48 hybrids. During evaluation, the 48 hybrids along with their parents and two standard checks *viz.*, LSFH-171 and KBSH-44 were evaluated in a Randomized Block Design replicated twice during *Rabi* 2023-2024.Observations were recorded for ten quantitative characters in each entry on randomly selected five plants *viz.* plant height (cm), head diameter (cm), seed filling (%), 100 seed weight, volume weight (g/100 ml), hull content (%) oil content (%) and seed yield per plant (g) except days to 50 per cent flowering and days to maturity which were recorded on plot basis. Data obtained were subjected to Line x Tester analysis [1]. The analysis of combining ability (GCA and SCA) effect was came out by using the Line x Tester analysis method suggested by Kempthorne [1]. The significance of GCA and SCA effects was determined at the 0.05 and 0.01 level using the t-test [2].

3. RESULTS AND DISCUSSION

Days to 50 per cent flowering, days to maturity, plant height, head diameter, seed filling, 100 seed weight, volume weight, hull content, oil content and seed yield per plant were the ten traits for which the variance resulting from crosses was noteworthy (Table 1). All characters, with the exception of days to maturity, head diameter and volume weight had significant variance due to line effects. Except for days to maturity, all characters had substantial variance owing to tester effects. All characteristics had substantial significant variance due to line x tester effects. These results earlier reported by Sharma and Shadakshari [4], Salke et al. [5], Ghodekar et al. [6], Dake et al. [7], Aditi et al. (2022), Doke et al. [8].

The variance components estimate showed that, for every character except days to maturity, head diameter, seed filling percentage, 100 seed weight and seed yield per plant, the SCA variance was smaller than the corresponding GCA variance. When the GCA/SCA ratio is less than unity, it indicates that the genes controlling these traits were behaving non additively, which can be taken advantage through heterosis breeding. Days to 50 per cent flowering, plant height, volume weight, hull content and oil content were found to have GCA variance greater than SCA variance and the ratio of GCA/SCA greater than unity indicated that additive gene action played a significant role in inheritance of these traits. Therefore, pedigree breeding can be used to improve inbreds with the desired direction. The existence of non-additive gene action for days to maturity, head diameter, seed filling, 100 seed weight and seed yield per plant, have also been reported by Rukminidevi et al. [9], Shinde et al. [10], Borde et al. [11], Thorat et al. [12] and Biradar et al. [13], Lakshaman et al. [14], Dake et al. [7].

Proportional contribution of lines, testers and line x testers of crosses revealed that the per cent contribution of testers towards total variance was greater than lines for all the characters except plant height (Table 2). The results were in accordance with Varalaxmi and Neelima [15] for plant height and by Shinde et al. [10] for all remaining characters. The proportional contribution of line x tester interaction was found to be greater than lines and testers for days to maturity and head diameter, indicating that interaction of genes played a major role in hybrid combination for expression of these traits. The present results were in consonance with the findings of Tyagi and Dhillon [16], Shinde et al. [10], Doke et al. [8].

A sequence of hybrid combinations consisting of the combination of parental lines is reflected in an estimate of GCA impacts. Character development is most influenced by parents with higher GCA effects. Table 3 illustrate the parental lines exhibiting a considerable or desirable GCA effect for different traits. A review of the GCA estimates of the parental lines showed that the lines DSF-2 A, CMS-47 A and the testers RHA-1055, R-274 and EC-601924 showed a substantial negative GCA effect for days to 50 per cent flowering. These lines are thought to be beneficial for early flowering in breeding programmes. Similarly, there were notable favourable GCA impacts for maturity in line CMS-103 A and testers RHA-1055. Similar reports of GCA effects for days to 50 per cent blooming and maturity were also reported earlier by Dhanlakshami et al. [17] and Ramraju et al. [18], Aditi et al. (2022).

Medium tall genotypes combined with the negative GCA effect may be helpful for increasing yield since medium tall height is desired for obtaining a greater yield. Line DSF-2 A, CMS-103 A and testers R-274 and BK-R-1 to have significant GCA effect turned out to be better combiners for reduced plant height. Expression of Significant GCA in suitable direction was observed for plant height [19].

For head diameter, testers EC-601924 and AKSF-15R as well as line CMS-597 A recorded the desired positive GCA effect. For the percentage of seed filling, the GCA effect was found to be positive by line CMS-47 A, CMS-597 A and substantial by testers EC-601924, and AKSF-15R. The following lines were determined to be effective combiners for 100 seed weight: CMS-47 A, CMS-597 A, CMS-112 A and testers RHA-1055, EC-601951-1, EC-601924 and AKSF-15R. The testers RHA-1055, EC-601924, R-274 and CMS-148 A and CMS-47 A were determined to be superior general combiners for volume weight. For comparable features, these results were consistent with past studies by Patil et al. [20], Shinde et al. [10] and Telangre et al. [21].

Table 1. Analysis of variance for combining ability for different characters in sunflower

Source of variation	Replicates	Crosses	Line effect	Tester Effect	L x T Eff.	Error	total	σ^2 GCA	σ^2 (SCA)	GCA/SCA
d.f	1	47	5	7	35	47	95	-	-	-
Days to 50 % flowering	6	11.03**	26.80**	34.98**	3.99**	1.02	6.02	2.118	1.379	1.54
Days to maturity	11.34	1.89**	1.33	3.3	1.75**	0.93	1.52	0.062	0.309	0.20
Plant height	13.35	390.07**	2106.7**	612.07**	100.44**	31.98	208.94	90.979	6.327	14.38
Head diameter	1.17	3.96**	3.22	9.72**	2.92**	1.36	2.65	0.382	0.897	0.43
Seed filling 9%)	2.29	189.61**	307.77**	615.48**	87.55**	15.12	101.31	31.192	37.487	0.83
100 Seed weight	0.004	1.60**	3.61**	4.64**	0.71**	0.029	0.808	0.293	0.343	0.85
Volume weight	8.76	37.1**	27.06	171.70**	11.87**	3.37	20.21	6.847	4.168	1.64
Hull content (%)	7.41	211.70**	368.50**	688.08**	93.97**	7.908	108.709	1.012	0.622	1.63
Oil content (%)	2.142	22.60**	27.80**	95.30**	7.34**	0.536	11.481	4.363	3.414	1.28
Seed yield per plant	3.5	22.60**	27.90**	95.30**	7.30**	0.507	11.481	37.117	42.649	0.87

**Significant at 5 % level and ** at 1% level*

In terms of hull content, line CMS-47 A and testers RHA-1055, EC-601924, and R-274 shown notable favourable GCA impacts and have the potential to be effective combiners. Good combiners for hull content and oil content were mentioned by Kaya et al. [22] and Asif et al. [23].

Good general combiners for the trait oil content were found to be the parental lines CMS-47 A, CMS-103 A, RHA-1055, EC-601924, R-274, and AKSF-15R. The testers RHA-1055, EC-601924, R-274 and AKSF-15R, as well as the lines CMS-597 A and CMS-47 A, were determined to be superior general combiners for seed yield per plant. Significant GCA effects were found for both oil content and seed output per plant using the CMS-47 and tester EC-601924, RHA-1055. Good combiners for oil content and seed output per plant were identified in earlier studies by Shinde et al. [10].

Table 4a and 4b summarizes the specific combining ability effects of hybrids for various characters. According to Kulkarni and Supriya [24], the hybrids that show significantly unfavourable SCA effects for days to flowering, maturity and plant height also contribute favourable additive genes for earliness and shorter plant height. For days to 50 per cent flowering, days to maturity, plant height and hull content in sunflowers, negative SCA effects are thought to be advantageous.

For days to 50 per cent flowering, the crosses CMS-112 x RHA-1055, CMS-103 x R-856, CMS-47 x RHA-1055, CMS-148 x EC-601951-1 and CMS-112 x EC-601951-1 showed a strong favourable negative SCA effect. The crosses CMS-112 x LTRR-341(-1.49), CMS-103 x R-274 (-1.365), CMS-112 x AKSF-15R (-1.24), CMS-148 x EC-601924 (-1.198) and CMS-597 x EC-601924 (-1.01) were having desirable SCA effects for maturity with involvement of low x high, low x low, high x high GCA status of the parents respectively.

Hybrids, CMS-112 x LTRR-341, CMS-47 x RHA-1055 and DSF-2 x LTRR-341 had high SCA effect in desirable direction for plant height. Crosses CMS-112 x EC-601951-1 and CMS-597 x R-856 were found to have significant high SCA effect for head diameter. Significant and desirable SCA effects were recorded in crosses, CMS-112 x AKSF-15R, CMS-148 x RHA-1055, CMS-597 x R-856, CMS-103 x R-274, CMS-47 x R-274 and CMS-597 x LTRR-341 for seed filling per cent.

High significant and favourable SCA impact was seen for 100 seed weight in the crosses CMS-47 x EC-601924, CMS-597 x R-274, DSF-2 x AKSF-15R, CMS-597 x EC-601951-1, DSF-2 x R-856, CMS-103 x BK-R-1 and CMS-103 x R-274. For volume weight, CMS-148 x R-856, CMS-112 x BK-R-1 and CMS-47 x RHA-1055 all exhibited a highly significant and positive SCA impact. With low x low, high x high, and low x low paternal GCA included in the combination for the trait hull content, it was observed that the hybrids CMS-112 x LTRR-341, CMS-103 x R-856, DSF-2 x RHA-1055 and CMS-597 x R-274 had a strong desired SCA effect. With respect to oil content, the crosses CMS-112 x LTRR-341, CMS-103 x R-856, DSF-2 x RHA-1055, CMS-597 x R-274, and CMS-148 x AKSF-15R showed a noteworthy and desired SCA effect.

Table 2. Per cent contribution by lines, testers and line x tester interaction

Characters	Lines	Testers	Line x Tester
Days to 50 per cent flowering	25.84 %	47.22 %	26.94 %
Days to maturity	7.07 %	22.47 %	70.46 %
Plant height (cm)	57.47 %	23.39 %	19.14 %
Head diameter (cm)	8.66 %	36.53 %	54.81 %
Seed Filling (%)	16.74 %	48.48 %	34.78 %
100 seed weight (g)	23.92 %	43.08 %	33.00 %
Volume weight (g/100ml)	7.72 %	68.58 %	23.70 %
Hull content (%)	13.87 %	61.08 %	25.05 %
Oil content (%)	13.10 %	62.74 %	62.74 %
Seed yield / plant (g)	18.52 %	48.42 %	33.06 %

Table 3. Estimates of general combining ability (GCA) effects of lines and testers for ten different characters in sunflower

Sr. No.	Characters	Days to 50 % Flowering	Days to Maturity	Plant height	Head diameter	Seed filling	100 seed weight	Volume weight	Hull content	Oil content	Seed yield/ plant
					CMS Lines						
1	DSF-2	-1.938**	0.010	-7.113**	0.391	0.081	-0.618**	0.281	0.747**	-1.421**	-0.111
2	CMS- CMS-148	0.688*	0.198	-2.463	-0.673*	-5.056**	-0.387**	1.281**	0.828**	-1.586**	-5.784**
3	CMS-47	-1.188**	0.260	7.250**	-0.360	4.777**	0.756**	0.969*	-0.903**	1.860**	5.414**
4	CMS-597	0.625*	0.010	15.288**	0.506	5.667**	0.102*	0.719	-0.197	0.449*	6.052**
5	CMS-103	0.313	-0.552*	-17.238**	0.132	-2.130*	0.042	-1.656**	-0.322	0.713**	-2.443**
6	CMS-112	1.500**	0.073	4.275**	0.003	-3.338**	0.106*	-1.594**	-0.153	-0.015	-3.128**
	SE ±	0.277	0.255	2.340	0.265	0.858	0.039	0.469	0.192	0.178	0.736
	CCD at 5 %	0.558	0.514	4.710	0.533	1.727	0.080	0.945	0.387	0.360	1.481
					Testers						
7	RHA-1055	-2.375**	-0.677*	-2.417	0.381	1.595	0.345 **	3.260**	-1.216**	2.493**	1.802*
8	EC-601951-1	2.208**	0.240	7.367**	-0.117	-3.496**	0.117 *	-2.156**	1.309**	-2.838**	-3.298**
9	EC-601924	-1.458**	-0.427	-1.833	0.918**	10.013**	0.927 **	1.177*	-2.266**	4.614**	10.302**
10	R-274	-2.042**	-0.510	-10.667**	-0.404	0.699	-0.175**	7.344**	-0.449 *	0.982**	1.802*
11	LTRR-341	0.958**	-0.010	2.183	-0.930**	-2.074*	-0.436**	-1.573**	0.493 *	-0.917**	-1.315
12	AKSF-15R	0.958**	0.740 *	9.517**	1.474**	9.971**	0.668 **	-0.823	-0.632**	1.314**	9.742**
13	BK-R-1	0.542	0.490	-8.233**	-1.210**	-8.708**	-0.728**	-3.990**	1.176**	-2.291**	-9.305**
14	R-856	1.208**	0.156	4.083*	-0.117	-7.998**	-0.718**	-3.240**	1.584**	-3.356**	-9.730**
	SE ±	0.320	0.295	2.703	0.306	0.991	0.0458	0.542	0.222	0.206	0.850
	CCD at 5 per cent	0.645	0.594	5.438	0.616	1.994	0.092	1.092	0.447	0.415	1.710

**Significant at 5 % level and ** at 1% level*

Table 4a. Estimation of specific combining ability for days to 50 per cent flowering, days to maturity, plant height, head diameter and seed filling percentage

Sr. No.	Characters	Days to 50 % Flowering	Days to Maturity	Plant height (cm)	Head diameter (cm)	Seed Filling (%)
			crosses			
1	DSF-2 x RHA-1055	0.938	0.24	11.73**	0.855	5.884*
2	DSF-2 x EC-601951-1	-1.146	0.323	-6.254	-0.257	-0.776
3	DSF-2 x EC-601924	0.521	1.49	0.946	-0.487	-3.775
4	DSF-2 x R-274	1.604 *	-0.927	9.479*	-0.544	-0.903
5	DSF-2 x LTRR-341	0.104	0.573	-9.671*	-0.598	-4.14
6	DSF-2 x AKSF-15R	-1.396	-0.177	-1.304	0.452	-0.227
7	DSF-2 x BK-R-1	0.021	-0.927	-4.354	0.031	3.763
8	DSF-2 x R-856	-0.646	-0.594	-0.571	0.548	0.173
9	CMS-148 x RHA-1055	2.313 **	0.052	2.079	0.884	11.72**
10	CMS-148 x EC-601951-1	-1.771 *	1.135	-7.504	-2.298 **	-4.202
11	CMS-148 x EC-601924	-0.104	-1.198	-7.604	-0.918	-1.788
12	CMS-148 x R-274	-0.521	-0.115	3.929	-0.056	-2.438
13	CMS-148 x LTRR-341	-1.021	0.385	3.479	1.271	2.159
14	CMS-148 x AKSF-15R	-1.021	-0.365	-2.954	0.826	-2.885
15	CMS-148 x BK-R-1	0.896	-0.115	2.296	-0.401	-0.155
16	CMS-148 x R-856	1.229	0.219	6.279	0.692	-2.411
17	CMS-47 x RHA-1055	-1.813 *	-0.01	-11.43**	-0.35	-8.553**
18	CMS-47 x EC-601951-1	3.104 **	-0.927	-0.317	-0.196	-5.039*
19	CMS-47 x EC-601924	0.271	0.24	11.98**	1.299	5.921*
20	CMS-47 x R-274	-0.646	-0.677	-3.783	0.436	7.561**
21	CMS-47 x LTRR-341	0.354	-0.177	0.667	-1.022	-2.087
22	CMS-47 x AKSF-15R	0.354	1.073	1.133	-1.327	0.799
23	CMS-47 x BK-R-1	-0.729	0.823	3.483	1.126	1.099
24	CMS-47 x R-856	-0.896	-0.344	-1.733	0.034	0.299
25	CMS-597 x RHA-1055	0.375	-0.26	-4.871	-0.985	-2.047
26	CMS-597 x EC-601951-1	-0.708	-0.677	3.046	1.008	5.678*

Sr. No.	Characters	Days to 50 % Flowering	Days to Maturity	Plant height (cm)	Head diameter (cm)	Seed Filling (%)
			crosses			
27	CMS-597 x EC-601924	-0.042	-1.01	-3.854	-1.522 *	-8.170**
28	CMS-597 x R-274	-0.458	1.073	-7.221	-0.774	-4.029
29	CMS-597 x LTRR-341	-0.458	0.573	15.13**	1.127	7.506**
30	CMS-597 x AKSF-15R	2.042 *	0.323	3.696	-0.813	-11.05**
31	CMS-597 x BK-R-1	-0.542	0.573	-1.654	0.376	1.45
32	CMS-597 x R-856	-0.208	-0.594	-4.271	1.583 *	10.67**
33	CMS-103 x RHA-1055	0.688	0.802	-7.446	-1.531 *	-7.582**
34	CMS-103 x EC-601951-1	2.104 *	0.885	6.371	-0.228	-2.361
35	CMS-103 x EC-601924	-0.729	-0.448	-6.229	0.462	0.878
36	CMS-103 x R-274	-0.146	-1.365	3.304	0.979	8.046**
37	CMS-103 x LTRR-341	0.854	0.135	2.954	-0.454	-1.669
38	CMS-103 x AKSF-15R	0.354	0.385	0.321	0.136	0.513
39	CMS-103 x BK-R-1	-1.229	-0.365	2.471	1.209	5.124*
40	CMS-103 x R-856	-1.896 *	-0.031	-1.746	-0.573	-2.948
41	CMS-112 x RHA-1055	-2.50 **	-0.823	9.942*	1.128	0.58
42	CMS-112 x EC-601951-1	-1.583 *	-0.74	4.658	1.971 *	6.699**
43	CMS-112 x EC-601924	0.083	0.927	4.758	1.166	6.934**
44	CMS-112 x R-274	0.167	2.010*	-5.708	-0.041	-8.237**
45	CMS-112 x LTRR-341	0.167	-1.49	-12.56**	-0.325	-1.769
46	CMS-112 x AKSF-15R	-0.333	-1.24	-0.892	0.725	12.85**
47	CMS-112 x BK-R-1	1.583 *	0.01	-2.242	-2.341 **	-11.28**
48	CMS-112 x R-856	2.417 **	1.34	2.042	-2.284 **	-5.77*
	SE	0.46	0.20	11.67	0.33	10.17
	CD at 5per cent	1.57	1.51	8.09	1.508	4.97
	CD at 1per cent	2.10	0.97	17.77	2.013	6.52

Table 4b. Estimation of specific combining ability for 100 seed weight, volume weight, hull content, oil content and seed yield per plant

Sr. No.	Characters	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield/ plant (g)
			crosses			
1	DSF-2 x RHA-1055	0.263 *	0.052	-1.572 **	3.122**	5.211 *
2	DSF-2 x EC-601951-1	-0.83 **	-2.531	1.553 **	-2.897**	-1.589
3	DSF-2 x EC-601924	-0.45**	2.135	-0.822	1.596**	-3.289
4	DSF-2 x R-274	-1.06 **	0.469	-0.589	1.108*	0.111
5	DSF-2 x LTRR-341	0.413 **	0.885	0.97	-2.038**	-3.573
6	DSF-2 x AKSF-15R	0.904 **	1.135	-0.205	0.306	-1.029
7	DSF-2 x BK-R-1	0.071	1.302	0.236	-0.509	4.417 *
8	DSF-2 x R-856	0.676 **	-3.448 *	0.428	-0.689	-0.258
9	CMS-148 x RHA-1055	-0.019	0.552	1.347 *	-2.757**	12.58 **
10	CMS-148 x EC-601951-1	0.189	-2.031	-0.778	1.764**	-2.716
11	CMS-148 x EC-601924	0.124	-0.865	-0.853	1.657**	0.684
12	CMS-148 x R-274	0.401 **	-3.031 *	1.180 *	-2.416**	-2.716
13	CMS-148 x LTRR-341	0.687 **	1.885	-0.561	1.093*	0.401
14	CMS-148 x AKSF-15R	-0.442**	0.635	-1.086	2.086**	-3.856
15	CMS-148 x BK-R-1	-0.225	-2.698 *	0.705	-1.513**	-0.109
16	CMS-148 x R-856	-0.72 **	5.552 **	0.047	0.087	-4.274 *
17	CMS-47 x RHA-1055	-0.107	3.365 *	-0.022	-0.018	-10.51**
18	CMS-47 x EC-601951-1	-0.484**	1.281	0.803	-1.420**	-5.414 *
19	CMS-47 x EC-601924	1.066 **	-2.552	0.128	-0.305	4.786 *
20	CMS-47 x R-274	-0.227 *	1.281	-0.089	0.102	9.886 **
21	CMS-47 x LTRR-341	0.119	-0.302	-0.03	0.037	-2.298
22	CMS-47 x AKSF-15R	-0.50 **	-1.052	0.045	-0.14	3.646
23	CMS-47 x BK-R-1	-0.218	-1.885	-0.514	0.93	-1.108
24	CMS-47 x R-856	0.357 **	-0.135	-0.322	0.815	1.017
25	CMS-597 x RHA-1055	-0.64**	-4.885 **	-0.178	0.278	-0.952
26	CMS-597 x EC-601951-1	0.735 **	2.031	-0.803	1.876**	5.848 **

No.	Characters	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield/ plant (g)
crosses						
27	CMS-597 x EC-601924	-0.62 **	0.198	0.372	-0.831	-7.75 **
28	CMS-597 x R-274	1.023 **	2.031	-1.195 *	2.309**	-4.352 *
29	CMS-597 x LTRR-341	0.133	1.948	0.314	-0.697	7.265 **
30	CMS-597 x AKSF-15R	-0.38 **	2.198	0.239	-0.523	-12.29 **
31	CMS-597 x BK-R-1	-0.104	-2.135	0.08	-0.243	1.655
32	CMS-597 x R-856	-0.154	-1.385	1.172 *	-2.169**	10.580 **
33	CMS-103 x RHA-1055	-0.008	1.49	0.547	-1.197*	-7.757 **
34	CMS-103 x EC-601951-1	0.214	-0.594	0.122	-0.026	-0.957
35	CMS-103 x EC-601924	-0.60 **	2.073	0.997	-2.073**	-0.957
36	CMS-103 x R-274	0.507 **	-1.094	-0.02	-0.025	7.543 **
37	CMS-103 x LTRR-341	-0.88 **	-2.177	1.139 *	-2.337**	-1.24
38	CMS-103 x AKSF-15R	0.229 *	0.073	-0.586	1.072*	-0.357
39	CMS-103 x BK-R-1	0.570 **	1.74	-0.445	0.869	5.050 *
40	CMS-103 x R-856	-0.03	-1.51	-1.753 **	3.717**	-1.325
41	CMS-112 x RHA-1055	0.508 **	-0.573	-0.122	0.572	1.428
42	CMS-112 x EC-601951-1	0.171	1.844	-0.897	0.703	4.828 *
43	CMS-112 x EC-601924	0.476 **	-0.99	0.178	-0.045	6.528 **
44	CMS-112 x R-274	-0.65**	0.344	0.711	-1.078*	-10.472 **
45	CMS-112 x LTRR-341	-0.47 **	-2.24	-1.830 **	3.942**	-0.555
46	CMS-112 x AKSF-15R	0.19	-2.990 *	1.595 **	-2.800**	13.888 **
47	CMS-112 x BK-R-1	-0.093	3.677 **	-0.064	0.465	-9.905 **
48	CMS-112 x R-856	-0.133	0.927	0.428	-1.76**	-5.740 **
	SE	0.08	1.37	0.21	0.85	10.92
	CD at 5 per cent	0.226	2.674	1.096	1.059	4.189
	CD at 1 per cent	0.301	3.56	1.462	1.358	5.59

Table 5. Hybrids exhibiting maximum SCA effect for different characters

Characters	Hybrids	*Per se*	SCA effect	GCA eff. of the parents
Days to 50 % flowering	CMS-47 x RHA-1055	55.00	-1.813 *	G x G
	CMS-47 x R-274	56.50	-0.646	G x G
	CMS-112 x RHA-1055	57.00	-2.500 **	P x G
Days to maturity	CMS-103 x R-274	84.50	-1.365	G x A
	CMS-112 x LTRR-341	85.50	-1.49	A x A
	CMS-112 x RHA-1055	85.50	-0.823	A x G
Plant height (cm)	CMS-103 x RHA-1055	123.70	-7.446	P x A
	CMS-103 x EC-601924	125.50	-6.229	P x A
	CMS-103 x R-274	126.20	3.304	P x G
Head diameter (cm)	DSF-2 x AKSF-15R	16.90	0.452	G x G
	CMS-112 x AKSF-15R	16.79	0.725	P x G
	CMS-112 x EC-601924	16.67	1.166	P x G
Seed filling (%)	CMS-112 x AKSF-15R	93.35	12.85**	P x G
	CMS-47 x EC-601924	93.05	5.921*	G x G
	CMS-47 x AKSF-15R	89.60	0.799	G x G
100 seed weight (g)	CMS-47 x EC-601924	7.525	1.066 **	G x G
	CMS-112 x EC-601924	6.28	0.476 **	G x G
	CMS-47 x RHA-1055	5.77	-0.107	G x G
Volume weight (g/100ml)	CMS-597 x R-274	54.00	2.031	G x G
	CMS-47 x R-274	53.50	1.281	G x G
	DSF-2 x R-274	52.00	0.469	A x G
Hull content (%)	CMS-47 x EC-601924	24.50	0.128	G x G
	DSF-2 x EC-601924	25.20	-0.822	P x G
	CMS-148 x EC-601924	25.30	-0.853	P x G
Oil content (%)	CMS-47 x EC-601924	43.72	-0.305	G x G
	DSF-2 x EC-601924	42.34	1.596**	P x G
	CMS-148 x EC-601924	42.23	1.657**	P x G
Seed yield/ plant (g)	CMS-47 x EC-601924	52.70	4.786 *	G x G
	CMS-112 x AKSF-15R	52.70	13.888 **	P x G
	CMS-47 x AKSF-15R	51.00	3.646	G x G

The crosses, CMS-112 x AKSF-15R, CMS-148 x RHA-1055, CMS-597 x R-856, CMS-47 x R-274, CMS-597 x LTRR-341, CMS-112 x EC-601924 and CMS-597 x EC-601951-1 marked high SCA effect with low x high and high x high GCA status of parents for seed yield per plant.

These results were in agreement with the results of Borde et al. [11], Kale et al. [25], Karande et al. [26] and Ghodekar et al. [6] for head diameter, Doke et al. [8] for seed filling, Vairam et al. [27] and Lakshman et al. [14] and for 100 seed weight, Shinde et al. [10] and Ingle et al. [28] for volume weight, Kale et al. [25] and Nehru et al. [29] for hull content, and Salim and Ali [30] and Varalakshami et al. [15] for oil content [31,32].

Among all the forty eight crosses; top performing specific combiners *viz*, CMS-47 x EC-601924 exhibited significant SCA effect for seed filling parentage, 100 seed weight, hull content, oil content and seed yield per plant (Table 5) and CMS-112 x EC-601951-1 for seed yield per plant also found to have significant and desirable SCA effects for other important yield contributing traits days to 50 per cent flowering, days to maturity, head diameter, seed filling percentage, volume weight, hull content. Similar finding was also reported earlier by Rukminidevi et al. [9], Ingle et al. [28], Salke et al. [5] and Kale et al. [25], Aditi et al. (2022).

4. CONCLUSION

On the basis of mean performance, SCA effects of crosses and GCA effects of the parents, the crosses *viz.*, CMS-112 A x AKSF-15R, CMS-148 A x RHA-1055, CMS-597 A x R-856, CMS-47 A x R-274, CMS-597 A x LTRR-341, CMS-112 A x EC-601924 and CMS-597 A x EC-601951-1 recorded high SCA effect with low x high, low x high and high x high GCA status of parents for seed yield per plant. Among all the forty eight crosses; top performing specific combiners *viz*, CMS-47 x EC-601924 exhibited significant SCA effect for seed filling parentage, 100 seed weight, hull content, oil content and seed yield per plant.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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