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RESEARCH ARTICLE

Assessment of combining ability and heterosis for seed yield and its attributes in Sunflower (*Helianthus annuus* L.)

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Abstract

The present study employed three lines and fifteen testers to assess the combining ability and standard heterosis of forty-five hybrids developed through a line × tester mating design. The analysis of variance for combining ability revealed significant variation in the mean sum of squares of parents, testers and the interaction between lines and testers regarding seed yield per plant and its related traits. Among the parents, testers GMU 498 and RHA 378 exhibited superior performance for seed yield/plant. In the hybrids, COSF 6A×CSFI 1862, HA 89A×GMU 1000 and HA 89A×RHA 378 demonstrated significantly better seed yield per plant compared to the checks. The variance for specific combining ability (SCA) exceeded that for general combining ability (GCA), indicating that all traits were governed by non-additive gene action. Among the lines, COSF 12A was identified as a good general combiner for yield-contributing traits, while the testers CSFI 1862, GMU 1000 and GMU 498 were recognized as good general combiners for seed yield per plant. Five hybrids, namely HA 89A × RHA 378, HA 89A × GMU 1000, COSF 12A × CSFI 1855, COSF 6A × CSFI 1862 and COSF 12A × GMU 311, exhibited significantly positive SCA for seed yield per plant. Heterosis over the standard checks (DRSH 1, COH 3 and GK 2002) was estimated and the hybrids HA 89A × GMU 1000 and COSF 6A × CSFI 1862 showed positive significant heterosis for seed yield per plant and related traits. The promising hybrids HA 89A × GMU 1000, HA 89A × RHA 378 and COSF 6A × CSFI 1862 were selected based on their mean performance, SCA effects and standard heterosis for seed yield per plant and its attributes.

Keywords

sunflower; line × tester; combining ability; standard heterosis; seed yield/plant

Introduction

The sunflower (*Helianthus annuus* L.) is a vital crop recognized for its high-quality oil and adaptability to various agroclimatic conditions. The genus name, *Helianthus*, is derived from the Greek words "*helios*", signifying sun, and "*anthos*" meaning flower. Native to North America, sunflowers were introduced to India in 1969 (1). In India, sunflower ranks fourth among cultivated vegetable oilseeds, following soybean, mustard and safflower (2). In year 2019-2020, sunflower cultivation covered an area of 0.22 million hectares, yielding 0.21 million tonnes, with a productivity of 931 kilograms per hectare (3). Sunflower is mainly grown for its oil, which is valued for its high oleic acid content, making it a healthy and versatile cooking oil.

In recent years, farmers have increasingly preferred hybrids for sunflower production due to their higher yields and improved productivity. Consequently, the primary objective of sunflower breeding has shifted towards developing hybrids. Hybrid vigor, or heterosis, the phenomenon where hybrid offspring exhibit superior performance compared to their parents, has been widely recognized in sunflowers and extensively utilized to enhance yield and other agronomic traits (4). Over the past decade, hybrids have accounted for over 95 % of sunflower production (5). Line × tester analysis is utilized to assess inbred lines and identify promising hybrid combinations. The variance associated with Specific combining ability and General combining ability are essential for understanding the nature of gene action for various traits. Therefore, understanding the genetic architecture of yield and yield-contributing traits is crucial for designing effective breeding strategies aimed at developing high-yielding sunflower hybrids. Thus, the present study aims to investigate heterosis and identify the best general and specific combiners for yield and yield-related traits.

Materials and Methods

Three CMS lines (COSF 6A, COSF 12A, HA 89A) were utilized as female parents, and fifteen testers (RCR 19-12, RCR 19-25, CSFI 1862, CSFI 1855, AKSFI 174, GMU 1000, RHA 83R-6, GP 6-374, CB 19-05, RCB 19-11, GMU 498, GMU 311, GMU 500, RHA 378, GMU 379) served as male parents in *Kharif* 2023 to generate 45 hybrids through a line × tester mating design. The resulting F_1 hybrids, along with their 18 parents and three checks *viz.* DRSH 1, COH3 and GK 2002 were evaluated in a randomized complete block design with two replications at the Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore, during *Rabi* 2023-24. Each entry was planted in a single row measuring 5 m in length, with a spacing of 60 × 30 cm.

Observations were recorded on five randomly selected plants from each entry for fourteen quantitative traits, including days to 50% flowering, days to maturity, plant height (cm), Leaf area index, SCMR - SPAD Chlorophyll Meter Reading, Soluble protein content (mg/g), relative water content, no. of leaves/plant, head diameter (cm), volume weight (g/100ml), hull content (%), hundred seed weight (g), oil content (%) and seed yield/plant (g). Soluble protein content was estimated using Lowry's method with leaf samples collected from the hybrids, parents and checks. The oil content of the seeds was estimated using the Soxhlet apparatus (6). The study utilized Baker's equation $GCA = (2 \times \sigma^2 GCA) / (2\sigma^2 GCA + \sigma^2 SCA)$, to assess the relative importance of additive and non-additive gene actions for the traits. These findings were reported by (7). Analysis of variance, combining ability analysis and heterosis were conducted using the TNAUSTAT software package, (8) which facilitated a comprehensive evaluation of genetic variation, the general and specific combining ability effects of parents and hybrids and the standard heterosis of the hybrids compared to the checks.

Results and Discussion

The analysis of variance (ANOVA) for the parents and their hybrids concerning all the quantitative traits studied revealed significant differences, indicating that the parents exhibited adequate variability within the population. The ANOVA results for various yield-related traits are presented in Table 1. The variance comparison between parents and hybrids demonstrated significant differences for all traits, confirming the presence of heterosis in the crosses. The combining ability ANOVA and variance components are outlined in Table 2. Significant differences were observed among the testers for seed yield per plant, oil content, and all other yield-contributing traits, indicating that the testers could be identified as the best combiners for yield and its attributes. However, no significant differences were noted among the lines for seed yield per plant, suggesting that the lines were not effective combiners for this trait.

The predominance of specific combining ability (SCA) variance over general combining ability (GCA) variance across all traits indicates that non-additive gene action governs these characters. This finding aligns with earlier reports (5, 9, 10). The proportional contributions of lines, testers and line × testers interaction are illustrated in Fig 1. Among the fourteen traits, the testers contributed the most variance for days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), days to maturity, volume weight (g/100ml), hundred seed weight (g), hull content (%), relative water

Table 1. Analysis of Variance (ANOVA) for various yield related traits in Sunflower

SV	DF	DFF	DM	PH	LAI	SCMR	SPC	RWC	NOL	HD	VW	HC	HSW	OC	SYP
Replication	1	2.86	132.07**	1115.05**	0.01	1.94	23.41**	3.36	140.38**	4.40	6.25	8.23	0.05	4.23	2.18
Parents (P)	17	25.67**	19.05*	545.76**	0.70**	14.01**	63.16**	24.61**	16.11**	9.75**	41.41**	37.68**	2.46**	24.36**	6.18**
Hybrids (H)	44	13.74**	23.69**	424.63**	1.80**	4.75**	48.7**	43.35*	31.32**	3.67**	15.33**	30.33**	1.56**	20.88**	7.89**
P vs H	1	80.76**	7.31	47533.30**	66.89**	18.03*	422.01**	181.89*	2497.67**	95.91**	358.26**	338.05**	9.54**	343.88**	6.14*
Error	62	1.34	10.18	40.09	0.06	2.16	1.14	2.21	4.17	1.55	1.35	2.01	0.66	0.53	25.3

(*: Significant at P = 0.05, **: Significant at P = 0.01, SV- Source of variation, DF-Degrees of freedom, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading, SPC - Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP-Seed yield/plant).

Table 2. ANOVA for combining ability for different characters, variance components and proportional contribution of fourteen traits.

SV	DF	DFF	DM	PH	LAI	SCMR	SPC	RWC	NOL	HD	VW	HC	HSW	OC	SYP
Replication	1	2.17	127.21**	913.68**	0.00	1.21	10.47**	0.36	136.9**	9.24**	12.56	11.35	0.23	8.97	74.11**
Lines (L)	2	18.97**	22.43	1744.36**	0.83**	6.23	35.93**	38.99**	30.53**	2.03	17.85**	41.41**	1.50	54.77**	18.81
Testers (T)	14	36.33**	46.6**	897.22**	4.31**	10.42**	60.04**	21.97**	57.88**	7.13**	30.28**	66.72**	2.68**	14.32**	282.66**
Line × tester (L × T)	28	2.07	12.32	94.06*	0.61**	1.80	43.95**	54.35*	18.10**	2.06	7.68**	11.35**	1.00	21.74**	171.88**
Crosses	44	13.74**	23.69**	424.63**	1.80**	4.75*	48.70**	43.35**	31.32**	3.67**	15.33*	30.33**	1.56**	20.88**	200.17**
Error	44	1.58	8.62	45.94	0.02	2.66	0.36	4.36	3.62	1.22	2.58	3.14	0.66	2.32	33.6
General and Specific combining ability variance components for quantitative traits in sunflower															
GCA		0.22	0.21	6.31	0.02	0.05	0.09	-0.21	0.25	0.03	0.14	0.36	0.01	-0.01	0.48
SCA		0.24	1.85	24.06	0.29	-1.13	21.79	12.62	7.23	0.41	-0.59	1.12	0.16	8.71	69.13
GCA/SCA		0.65	0.19	0.34	0.12	-0.10	0.01	-0.03	0.06	0.13	-0.90	0.39	0.11	0.00	0.01

(*: Significant at P = 0.05, **: Significant at P = 0.01, SV - Source of variation, DF-Degrees of freedom, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading, SPC - Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP-Seed yield/plant).

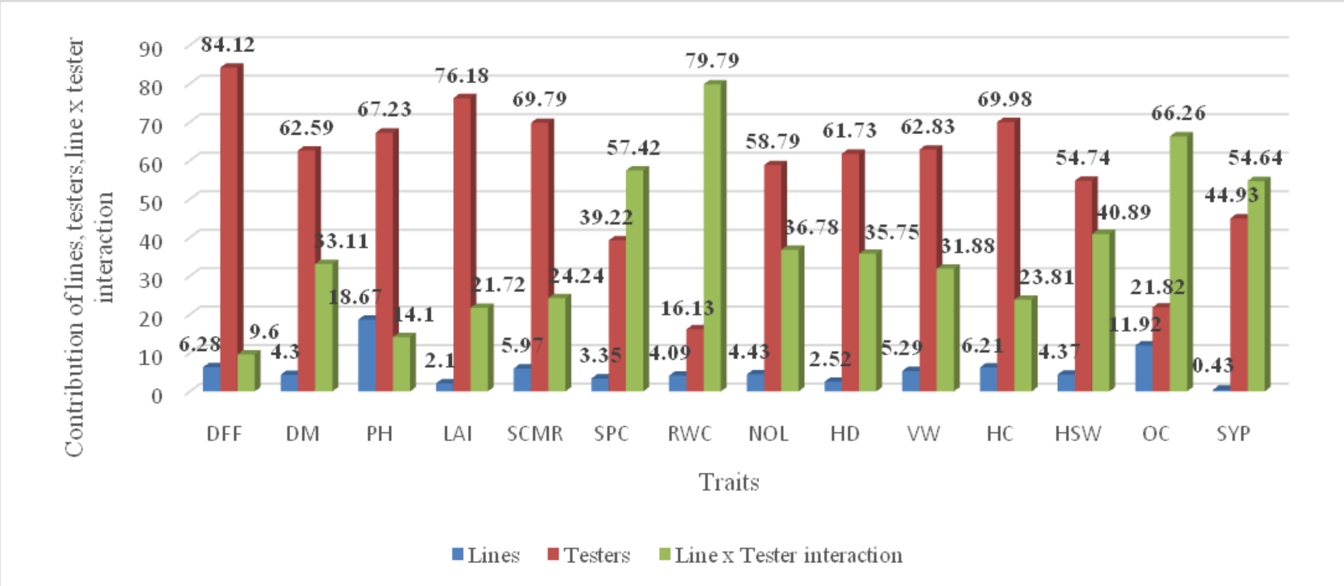

Fig. 1. Proportional contribution of lines, testers, line x tester interaction

content, SCMR - SPAD Chlorophyll Meter Reading, Leaf area index and the no. of leaves/plant, except for seed yield/plant, oil content, relative water content and soluble protein content which played a significant role. Overall, the lines did not contribute to any of the traits. The influence of lines × tester interactions was more pronounced for seed yield/plant, oil content, relative water content and soluble protein content, confirming findings from previous studies (11).

Mean performance of parents and hybrids

The mean performance of parents and hybrids is presented in Table 3. Significant variation is observed in the mean performance for all traits, except hull content, among the parents. Testers GMU 498 and RHA 378 documented superior performance in seed yield per plant compared to the grand mean of the parents. Line HA 89A and tester RCR 19-12 exhibited higher oil content than the grand mean. Lines COSF 12A and HA 89A, along with the testers GMU 500, AKSFI 174 and GMU 379, were identified as good combiners for days to 50% flowering, as they possess genes associated with early flowering. Additionally, testers GMU 498 and RCB 19-11 outperform the grand mean for yield and yield contributing traits. Similar findings were also reported by (11)

The mean performance of all traits among the hybrids was evaluated. Six hybrids (COSF 6A × CSFI 1862, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 12A × CSFI 1855, HA 89A × CSFI 1862, COSF 12A × CB 19-05) recorded superior mean performance in seed yield/plant compared to the checks. Additionally, three hybrids (HA 89A × GMU 311, COSF 12A × GMU 379, HA 89A × RHA 378) exhibited higher mean performance for oil content, with the hybrid HA 89A × RHA 378 showing the best performance for both seed yield/plant and oil content. Five hybrids exhibited superior mean performance in terms of plant height, while six hybrids showed superior mean performance in head diameter. Moreover, three hybrids demonstrated superior mean performance for volume weight and the hybrids HA 89A × CSFI 1855, HA 89A × GMU 1000 showed better mean performance for hull content and hundred seed weight, respectively. The hybrids COSF 6A × CSFI 1862, HA 89A × GMU 1000and HA 89A × RHA 378 achieved superior mean performance for seed yield/plant and other major yield attributing traits. Similar findings were also reported by (12).

Table 3. Mean performance of parents and sunflower hybrids (F_1) for yield contributing traits.

S. No		DFF	DM	PH	LAI	SCMR	SPC	RWC	NOL	HD	VW	HC	HSW	OC	SYP
								Lines							
1	COSF6A	57.50	97.00	121.70	2.65*	37.84	38.46	76.33	19.00	14.53	32.88	23.64	3.69	36.23	24.64
2	COSF 12A	54.50*	96.00	76.78	1.67	39.28	42.67*	82.17	17.00	16.93	28.65	30.79	5.21	35.67	24.75
3	HA 89A	56.00*	97.00	85.75	1.29	37.22	37.14	74.59	17.00	16.25	28.75	32.27	5.28	39.24*	26.71
								Testers							
1	RCR 19-12	56.50	91.00	117.80	2.15	39.40	25.12	77.31	17.50	11.25	40.72*	18.50	3.58	39.22*	20.98
2	RCR 19-25	65.00	99.50	118.50	1.45	35.79	32.24	74.69	16.50	16.75	40.75*	29.87	5.09	30.08	34.37
3	CSFI 1862	62.00	96.00	117.40	1.42	37.40	40.07*	77.51	21.00	10.20	30.80	29.87	3.42	31.79	20.05
4	CSFI 1855	58.00	94.00	129.47*	2.19	38.56	31.01	71.65	22.50*	9.96	33.80	30.57	2.65	35.54	11.81
5	AKSFI 174	54.50*	89.00	108.00	1.56	37.68	33.09	83.31	13.50	14.02	34.65	26.24	5.28	29.96	28.21
6	GMU 1000	60.00	94.50	112.51	2.74*	41.38	39.77*	78.78	21.00	15.75	32.43	31.26	4.79	28.95	36.55
7	RHA 83R-6	63.50	100.50	119.00	2.13	37.05	41.38*	75.32	21.00	13.35	38.20	32.91	3.81	30.44	30.55
8	GP6-374	58.00	95.50	110.01	2.00	37.98	41.70*	82.09	18.00	15.69	28.63	33.80	4.03	30.89	28.01
9	CB 19-05	65.00	99.50	130.42*	2.05	38.19	35.16	73.76	23.00*	15.93	39.45*	31.84	4.86	32.37	31.97
10	RCB 19-11	60.00	94.00	124.70*	2.25	38.15	24.98	72.06	17.50	14.29	36.53	32.71	6.20*	32.19	35.37
11	GMU 498	57.50	98.00	127.36*	2.30	48.36*	35.72	76.33	19.50	16.68	30.75	35.00	6.70*	29.42	47.85*
12	GMU 311	56.50	92.50	80.30	0.95	38.98	45.47*	73.49	14.00	14.08	27.65	35.66	3.33	34.68	28.26
13	GMU 500	53.00*	93.00	94.68	1.93	38.50	37.75	73.49	20.00	14.65	28.70	34.96	5.93	28.53	40.35
14	RHA 378	60.50	93.00	116.34	3.20*	38.80	39.45*	72.38	20.00	17.09*	27.50	34.72	4.60	32.52	44.88*
15	GMU 379	55.50*	93.00	120.70	1.10	39.28	38.82*	76.24	14.00	13.54	30.90	31.76	3.62	27.91	35.17
	Mean of parents	58.53	95.17	111.74	1.94	38.88	36.67	76.19	18.44	14.50	32.87	30.91	4.56	32.53	30.69
	CD @ 5%	2.29	6.31	12.53	0.50	3.97	2.11	10.19	4.04	2.46	6.39	6.13	1.61	3.97	9.96
	Grand mean	56.24	88.86	124.27	2.44	42.85	38.78	86.38	22.48	16.96	39.26	37.04	6.17	36.50	40.65
								Hybrids							
1	COSF 6A × RCR 19-12	55.50	95.00	141.90	2.59	38.35	25.08	79.02	25.50	15.15	40.73*	26.67	4.90	33.86	60.68
2	COSF 6A × RCR 19-25	52.00*	89.00*	131.80	3.00	36.35	20.05	76.54	24.50	14.54	37.85	27.86	4.12	38.24	38.61
3	COSF 6A × CSFI 1862	58.00	102.00	159.60	4.78*	38.21	38.21*	68.80	31.00*	18.30*	30.98	29.51	5.30	38.47	73.14*
4	COSF 6A × CSFI 1855	56.50	96.50	149.40	3.21	37.20	34.11	71.62	29.00*	17.63	36.91	27.70	4.12	37.98	46.82
5	COSF 6A × AKSFI 174	53.50*	92.00	142.90	3.24	36.48	29.02	72.40	26.00	16.80	38.55	22.74	4.83	28.95	44.15
6	COSF 6A × GMU 1000	63.50	103.00	152.24	5.46*	37.97	29.91	77.08	32.50*	19.10*	38.65	28.35	4.95	28.60	47.80
7	COSF 6A × RHA 83R-6	54.50*	92.00	127.30	2.36	36.00	34.58*	78.81	29.50*	14.95	33.73	29.73	3.81	36.52	52.96
8	COSF 6A × GP6-374	57.00	95.00	154.50	3.03	37.30	41.05*	71.89	27.00	15.90	30.98	17.40	4.73	35.61	49.23
9	COSF 6A × CB 19-05	58.00	94.50	140.70	2.83	36.55	31.00	80.71	25.50	15.40	40.25	23.84	4.80	33.19	60.51
10	COSF 6A × RCB 19-11	58.50	94.00	149.00	2.63	37.40	29.27	75.03	32.00*	15.60	39.05	27.29	4.66	36.32	44.97

11	COSF 6A × GMU 498	58.50	99.50	153.04	5.54*	38.48	36.32*	82.41	27.00	17.30	39.08	27.10	6.27	36.05	55.90
12	COSF 6A × GMU 311	60.50	93.50	126.47	2.54	41.5*	20.38	88.02*	22.50	13.99	38.07	29.13	6.63	37.25	29.04
13	COSF 6A × GMU 500	56.50	93.50	140.00	2.54	36.48	34.67*	87.31*	28.00	15.55	33.70	30.13	4.53	37.15	48.64
14	COSF 6A × RHA 378	61.50	99.50	169.69	3.57	37.29	33.00	82.21	27.50	16.75	39.45	24.26	5.73	34.66	40.37
15	COSF 6A × GMU 379	61.00	95.00	162.41	3.94	38.05	34.47*	76.62	32.00*	16.80	35.15	24.38	4.76	26.89	53.83
16	COSF 12A × RCR 19-12	53.50*	92.00	154.22	2.47	40.35	30.79	79.67	26.00	17.05	38.58	26.46	4.99	38.74	54.51
17	COSF 12A × RCR 19-25	54.50*	95.00	134.72	1.54	36.15	33.85	79.16	25.00	14.25	38.70	27.96	4.24	35.68	50.37
18	COSF 12A × CSFI 1862	57.00	96.00	162.73	3.65	38.93	28.98	87.09*	25.00	17.45	32.43	34.07	4.96	34.78	51.20
19	COSF 12A × CSFI 1855	56.00	96.00	150.22	3.17	36.64	33.09	86.19*	29.50*	16.80	38.85	29.39	5.95	32.03	67.99*
20	COSF 12A × AKSFI 174	53.50*	90.50	156.89	3.40	37.78	30.51	79.95	22.00	16.71	39.52	26.28	4.35	35.74	50.18
21	COSF 12A × GMU 1000	59.00	96.00	177.83*	4.73*	40.16	25.06	83.45	34.50*	16.80	40.48*	28.06	6.46	40.56	60.23
22	COSF 12A × RHA 83R-6	53.00*	89.00*	142.20	2.67	37.87	31.82	75.60	25.00	15.00	34.50	31.87	4.27	36.26	40.83
23	COSF 12A × GP6-374	55.50	92.00	163.78	3.76	36.36	31.90	79.13	25.00	17.10	38.55	16.88	5.89	37.80	47.07
24	COSF 12A × CB 19-05	57.50	96.00	162.54	3.25	36.77	39.36*	74.19	31.5*	18.25*	37.13	21.88	4.92	34.78	63.39*
25	COSF 12A × RCB 19-11	57.00	93.50	163.60	3.89	38.34	32.08	74.67	28.50	15.67	35.35	21.31	4.88	38.13	41.51
26	COSF 12A × GMU 498	57.00	93.50	170.30	4.20*	40.05	39.71*	75.86	34.50*	17.99	36.00	27.02	5.47	37.28	48.99
27	COSF 12A × GMU 311	57.00	92.00	169.71	3.99*	41.35*	37.06*	73.11	33.00*	17.97	37.27	28.31	4.06	37.93	50.03
28	COSF 12A × GMU 500	55.00	95.50	156.89	3.20	38.83	26.43	77.97	34.50*	16.57	36.63	29.45	6.04	38.89	42.15
29	COSF 12A × RHA 378	59.50	98.50	177.30*	4.39*	36.76	31.14	77.09	35.00*	16.77	38.77	22.06	6.38	37.99	49.13
30	COSF 12A × GMU 379	58.00	93.50	184.70*	4.36*	40.92	41.84*	75.02	32.50*	16.53	35.38	31.44	4.60	40.91*	46.73
31	HA 89A × RCR 19-12	54.00*	92.00	150.46	2.62	38.01	33.30	78.23	26.50	16.91	40.35	28.63	4.98	40.24	46.84
32	HA 89A × RCR 19-25	52.00*	89.00*	133.51	2.09	37.34	30.02	75.51	23.00	15.03	34.50	27.44	6.09	34.92	37.91
33	HA 89A × CSFI 1862	57.00	95.50	166.86	3.42	36.43	39.13*	78.73	26.00	18.70*	33.43	33.44	5.60	34.28	64.27*
34	HA 89A × CSFI 1855	55.50	97.00	146.30	2.66	38.27	34.67*	82.49	22.00	15.95	35.08	34.21*	5.16	33.17	48.24
35	HA 89A × AKSFI 174	55.50	95.00	153.50	3.35	37.38	34.25	83.62	25.00	16.25	39.85	28.72	4.66	35.10	46.15
36	HA 89A × GMU 1000	61.00	104.00	184.90*	5.27*	38.13	34.44*	85.75*	33.00*	19.70*	36.15	27.55	7.61*	40.58	72.22*
37	HA 89A × RHA 83R-6	53.50*	95.00	135.40	2.38	37.25	37.20*	77.88	24.50	15.08	31.92	32.37	3.95	40.25	37.03
38	HA 89A × GP6-374	56.50	94.00	157.50	4.55*	37.03	28.80	76.48	21.50	16.37	31.77	25.11	4.99	35.86	51.17
39	HA 89A × CB 19-05	58.50	92.50	161.70	3.78	36.95	29.24	81.89	26.50	15.55	34.90	21.06	4.56	36.65	39.83
40	HA 89A × RCB 19-11	55.50	90.00	149.30	4.13*	36.98	33.67	85.58*	30.00*	15.03	41.02*	27.19	4.62	31.20	45.71
41	HA 89A × GMU 498	57.00	93.50	161.60	4.97*	39.60	41.94*	85.70*	34.00*	16.35	35.63	29.97	6.07	35.08	61.43*
42	HA 89A × GMU 311	58.50	96.00	150.06	4.15*	40.00	30.26	75.37	26.50	15.22	34.95	26.31	4.88	41.11*	43.55
43	HA 89A × GMU 500	53.50*	94.50	143.99	3.65	37.10	28.96	77.48	28.50	14.62	36.15	27.11	6.26	36.71	35.29
44	HA 89A × RHA 378	60.00	98.00	178.80*	4.48*	38.82	32.09	82.14	35.00*	18.60*	36.65	27.40	7.11	40.78*	69.35*
45	HA 89A × GMU 379	58.00	89.50	161.70	4.60*	41.80*	35.13*	74.88	30.50*	15.25	33.70	32.77	4.32	35.43	42.73
	Mean of checks	57.66	95.00	160.02	3.65	38.86	33.13	79.06	25.16	15.93	37.38	30.52	5.62	40.33	49.96
	CD (P=0.05)	2.68	5.80	13.59	0.32	2.35	1.19	6.49	3.75	2.21	3.04	3.56	1.62	0.44	11.31

(* - Significant over the check mean, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading , SPC - Soluble protein content , RWC - Relative water content , NOL - No. of leaves ,HD - Head diameter, VW - Volume weight, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP-Seed yield/plant).

General combining ability effects

General combining ability (GCA) effects have proven to be an effective tool for selecting parents based on the performance of their progenies in the F_1 generations. The GCA of the parental genotypes is presented in Table 4. None of the three lines exhibited significant GCA effects on seed yield per plant, indicating that no line is a good combiner for this trait. However, lines COSF 12A and HA 89A showed significant GCA effects for several specific yield-attributing traits. Specifically, COSF 12A demonstrated good general combining ability for days to fifty percent flowering, plant height, oil content, number of leaves per plant and soluble protein content. In contrast, HA 89A exhibited significant GCA effects for hull content, soluble protein content, and leaf area index. Similar findings were reported by previous studies (4). Therefore, these lines can be utilized as parents for heterosis breeding to enhance desirable yield-attributing traits.

The testers CSFI 1862, GMU 1000 and GMU 498 displayed favourable GCA effects for seed yield per plant, making them suitable candidates for maximizing seed yield in sunflower breeding programs. Tester GMU 311 demonstrated good general combining ability for oil content. Testers RCR 19-12, RCR 19-25, AKSFI 174, RHA 83R-6 and GMU 500 exhibited desirable GCA effects for days to 50% flowering. RHA 378 and GMU 1000 also showed favourable GCA effects for traits such as plant height, head diameter, hundred seed weight, leaf area index and number of leaves. Similar findings regarding yield-related traits have been reported in previous studies (13-16). The high GCA effects of the parents indicate effective gene flow from parents to offspring, reflecting the additive gene effects for the traits studied.

Table 4. General combining ability effects (*gca*) of lines and testers for various characters in Sunflower

S. NO		DFF	DM	PH	LAI	SCMR	SPC	RWC	NOL	HD	VW	HC	HSW	OC	SYP
	Lines														
1	COSF 6A	0.91**	0.97	-8.06**	-0.14**	-0.47	-1.21**	-0.95	-0.33	-0.18	0.27	-0.88	-0.22	-1.54**	-0.28
2	COSF 12A	-0.56 *	-0.70	7.10**	-0.04	0.44	0.29*	-0.31	1.13**	0.30	0.60	-0.45	0.00	0.98*	0.89
3	HA 89A	-0.36	-0.27	0.97	0.18**	0.03	0.92**	1.26	-0.80*	-0.12	-0.87	1.33*	0.23	0.57	-0.61
	Testers														
1	RCR 19-12	-2.42**	-1.63	-5.88*	-1.00**	0.86	-2.90**	0.12	-2.30**	-0.06	3.28**	-0.03	-0.21	1.42	3.95
2	RCR 19-25	-3.92**	-3.63**	-21.38**	-1.35**	-1.43	-4.65**	-1.78	-4.13**	-1.82**	0.41	0.47	-0.35	0.09	-7.76**
3	CSFI 1862	0.58	3.20*	8.33**	0.40**	-0.19	2.82**	-0.64	-0.97	1.72**	-4.33**	5.05**	0.12	-0.35	12.81**
4	CSFI 1855	-0.76	1.87	-6.11*	-0.54**	-0.67	1.34**	1.25	-1.47	0.36	0.34	3.15*	-0.09	-1.80*	4.29
5	AKSFI 174	-2.59**	-2.13	-3.91	-0.23**	-0.83	-1.36**	-0.20	-3.97**	0.16	2.70*	-1.37	-0.55	-2.93**	-3.23
6	GMU 1000	4.41**	6.37**	16.92**	1.60**	0.71	-2.81**	3.24	5.03**	2.11**	1.82	0.70	1.17**	0.39	10.02**
7	RHA 83R-6	-3.09**	-2.63*	-19.77**	-1.09**	-1.01	1.91**	-1.42	-1.97*	-1.42**	-3.22*	4.04**	-1.15**	1.48	-6.45**
8	GP6-374	-0.42	-0.97	3.86	0.22**	-1.15	1.30**	-3.02	-3.80**	0.03	-2.84*	-7.49**	0.04	0.24	-0.90
9	CB 19-05	1.24*	-0.30	0.24	-0.27**	-1.28	0.58*	0.08	-0.47	-0.03	0.82	-5.03**	-0.41	-1.32	4.52
10	RCB 19-11	0.24	-2.13	-0.77	-0.01	-0.47	-0.95**	-0.42	1.87*	-0.99*	1.87	-2.02	-0.45	-0.98	-6.00 *
11	GMU 498	0.74	0.87	6.91 *	1.35**	1.33	6.71**	2.47	3.53**	0.79	0.29	0.74	0.77*	-0.06	5.38 *
12	GMU 311	1.91**	-0.80	-5.99*	0.00	2.91**	-3.39**	-0.02	-0.97	-0.70	0.16	0.63	0.03	2.57**	-9.18**
13	GMU 500	-1.76**	-0.13	-7.82**	-0.43**	-0.58	-2.60**	2.07	2.03*	-0.85	-1.11	1.61	0.45	1.39	-8.03**
14	RHA 378	3.58**	4.03**	20.53**	0.59**	-0.42	-0.54*	1.63	4.20**	0.95*	1.69	-2.71*	1.24**	1.62	2.89
15	GMU 379	2.24**	-1.97	14.87**	0.74**	2.22**	4.53**	-3.35	3.37**	-0.23	-1.86	2.24	-0.61	-1.78*	-2.29
	SE (*gca*lines)	0.23	0.53	1.23	0.02	0.36	0.11	0.98	0.34	0.20	0.54	0.55	0.14	0.37	1.05
	SE (*gca*testers)	0.51	1.19	2.76	0.06	0.82	0.24	2.20	0.77	0.45	1.21	1.23	0.33	0.84	2.36

(*: Significant at P = 0.05, **: Significant at P = 0.01, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR -SPAD Chlorophyll Meter Reading, SPC-Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight, HC - Hull content, HSW-Hundred seed weight, OC - Oil content, SYP-Seed yield/plant)

Specific combining ability effects

The estimates of specific combining ability (SCA) effects for the 45 hybrids are presented in Table 5. The hybrids HA 89A × RHA 378, HA 89A × GMU 1000, COSF 12A × CSFI 1855, COSF 6A × CSFI 1862, COSF 12A × GMU 311 and COSF 6A × RHA 83R -6 exhibited significantly positive SCA effects for seed yield per plant. Among these, the hybrid COSF 12A × CSFI 1855 had both parents with positive general combining ability (GCA) effects, indicating a cumulative effect of additive genes from both parents for this trait. Conversely, some hybrids, such as HA 89A × RHA 378, HA 89A × GMU 1000 and COSF 6A × CSFI 1862, had positive SCA effects for seed yield per plant, with at least one parent showing positive GCA effects while the other exhibited negative GCA effects. This may suggest an additive gene effect from the positive GCA parent, along with epistatic interactions from the negative GCA parent. The hybrid COSF 6A × RHA 83R-6, which had parents with negative GCA effects for seed yield per plant, may reflect epistatic interactions between the parents.

For yield-related traits, the cross combinations COSF 12A × GMU 379, COSF 6A × CSFI 1855, COSF 6A × CSFI 1862, COSF 6A × RCR 19-25, HA 89A × GMU 1000 and COSF 12A × GMU 1000 for oil content all demonstrated good GCA effects. Additionally, two hybrids (COSF 12A × GMU 311 and HA 89A × GMU 1000) were significant for plant height; the hybrid COSF 6A × GMU 311 showed significant SCA effects for hundred seed weight; the hybrid COSF 12A × GMU 311 was significant for head diameter; and COSF 12A × GMU 1000 was significant for days to maturity. Furthermore, four hybrids exhibited significant SCA effects for leaf area index, while seven hybrids recorded significant SCA effects for the number of leaves per plant.

However, the hybrids COSF 12A × CSFI 1862, COSF 6A × GMU 1000 and COSF 12A × GMU 498 displayed significantly negative SCA effects, despite their testers having significant GCA effects for seed yield per plant. This indicates that these hybrids may not be valuable for improving seed yield per plant (17). The hybrids COSF 6A × CSFI 1862, HA 89A × CSFI 1862, COSF 12A × GMU 1000, COSF 6A × GMU 498, COSF 12A × GMU 498 and HA 89A × GMU 498 could be utilized in recombination breeding, as at least one parent in each combination has significant GCA effects while the other has non-significant GCA effects for seed yield per plant. Similar findings have been reported in previous studies (13, 14, 18-21). The promising hybrids with positive significant SCA effects for both seed yield per plant and oil content were HA 89A × GMU 1000 and COSF 6A × CSFI 1862, along with other yield-attributing traits.

Standard heterosis

Standard heterosis refers to the superiority of the F_1 hybrid compared to commercial check varieties. In the present investigation, three check varieties were utilized to estimate standard heterosis: DRSH 1 (national check), COH3 (local check), and GK 2002 (private hybrid), as presented in Table 6. The hybrids HA 89A × GMU 1000 and COSF 6A × CSFI 1862 exhibited significant positive standard heterosis for the trait of seed yield per plant compared to the checks. The hybrids COSF 12A × GMU 379, HA 89A × GMU 311 and HA 89A × RHA 378 demonstrated positive standard heterosis for oil content over the checks DRSH 1 and GK 2002.

Negative heterosis is desirable for days to 50% flowering, as these hybrids carry genes for early flowering. Eleven hybrids exhibited significant negative heterosis compared to all checks for this trait. Additionally, eight hybrids significantly outperformed both checks (DRSH 1 and GK 2002) in terms of head diameter. For plant height, five hybrids displayed significant positive heterosis over the checks GK 2002 and COH3. The hybrids HA 89A × GMU 1000 and HA 89A × RHA 378 surpassed the checks GK 2002 and COH3 for the trait of hundred seed weight.

Overall, ten hybrids showed significant positive standard heterosis for soluble protein content compared to the checks. Furthermore, two hybrids and fourteen hybrids exhibited positive significance over all checks for yield-contributing traits such as leaf area index and the number of leaves, respectively. Similar findings related to yield traits have been reported in previous studies (12, 22-25).

Comparison of mean performance, *sca* effects and Standard heterosis of hybrids for yield attributing traits

The selection of promising hybrids depends on their mean performance, specific combining ability (SCA) effects, and standard heterosis. A comparison of hybrids based on these criteria for various yield-attributing traits is provided in Table 7. The hybrids that exhibited superior mean performance, significant SCA effects and standard heterosis for seed yield per plant include COSF 6A × CSFI 1862, COSF 12A × CSFI 1855, HA 89A × GMU 1000 and HA 89A × RHA 378. Additionally, the hybrid COSF 12A × GMU 379 demonstrated favourable results for oil content.

However, none of the hybrids performed well across all three parameters-mean performance, SCA effects, and standard heterosis-for both seed yield per plant and oil content. This suggests a negative correlation between yield and oil content. These findings are consistent with those reported in previous studies (26).

Conclusion

The current investigation reveals a prevalence of non-additive gene action across all traits, underscoring the potential of heterosis breeding to harness hybrid vigor in sunflowers. The line COSF 12A, along with testers CSFI 1862, GMU 1000 and GMU 498, has been identified as good general combiners for seed yield, while GMU 311 excels in oil content. Thus, selecting parents with strong general combining ability for both seed yield and oil content will facilitate the development of superior sunflower hybrids with enhanced yield and oil characteristics. The hybrids HA 89A × GMU 1000, COSF 6A × CSFI 1862 and HA 89A × RHA 378 demonstrate superior mean performance, significant SCA effects and positive standard heterosis for both seed yield and yield-attributing traits. Therefore, these hybrid combinations can be effectively utilized to improve yield potential in sunflower breeding programs.

Table 5. Specific combining ability effects (*sca*) for various characters in Sunflower

S. No	Hybrids	DFF	DM	PH	LAI	SCMR	SPC	RWC	NOL	HD	VW	HC	HSW	OC	SYP
1	COSF 6A × RCR 19-12	0.26	1.03	1.10	0.17	-0.08	-3.44**	1.00	-0.17	-1.04	0.57	0.30	0.16	-2.20	6.96
2	COSF 6A × RCR 19-25	-1.74	-2.97	6.55	0.93**	0.21	-6.72**	0.42	0.67	0.11	0.57	0.99	-0.48	3.50*	-3.4
3	COSF 6A × CSFI 1862	-0.24	3.20	4.61	0.97**	0.83	3.98**	-8.45*	4.00**	0.33	-1.57	-1.95	0.24	4.16**	10.55*
4	COSF 6A × CSFI 1855	-0.41	-0.97	8.80	0.33**	0.30	1.36**	-7.53	2.50	1.01	-0.30	-1.85	-0.74	5.13**	-7.25
5	COSF 6A × AKSFI 174	-1.58	-1.47	-0.68	0.05	-0.26	-1.03*	-5.30	2.00	0.39	-1.03	-2.30	0.44	-2.77	-2.39
6	COSF 6A × GMU 1000	1.42	1.03	-11.35*	0.44**	-0.31	1.32**	-4.06	-0.50	0.74	-0.04	1.24	-1.16*	-6.44**	-12.00**
7	COSF 6A × RHA 83R-6	-0.08	-0.97	0.40	0.02	-0.57	1.25**	2.33	3.50*	0.12	0.07	-0.72	0.02	0.39	9.64*
8	COSF 6A × GP6-374	-0.24	0.37	3.97	-0.61**	0.87	8.34**	-2.99	2.83*	-0.38	-3.06	-1.52	-0.25	0.73	0.36
9	COSF 6A × CB 19-05	-0.91	-0.80	-6.22	-0.32**	0.26	-0.99*	2.74	-2.00	-0.82	2.56	2.46	0.26	-0.14	6.22
10	COSF 6A × RCB 19-11	0.59	0.53	3.10	-0.78**	0.30	-1.19**	-2.44	2.17	0.34	0.31	2.90	0.17	2.64	1.19
11	COSF 6A × GMU 498	0.09	3.03	-0.54	0.78**	-0.43	-1.79**	2.04	-4.50**	0.26	1.91	-0.05	0.56	1.45	0.74
12	COSF 6A × GMU 311	0.92	-1.30	-14.22**	-0.88**	1.02	-7.64**	10.15*	-4.50**	-1.56	1.03	2.10	1.66**	0.03	-11.55**
13	COSF 6A × GMU 500	0.59	-1.97	1.14	-0.45**	-0.52	5.86**	7.35	-2.00	0.15	-2.06	2.11	-0.85	1.11	6.9
14	COSF 6A × RHA 378	0.26	-0.13	2.49	-0.44**	0.14	2.14**	2.69	-4.67**	-0.45	0.89	0.56	-0.45	-1.61	-12.29**
15	COSF 6A × GMU 379	1.09	1.37	0.87	-0.22	-1.74	-1.46**	2.06	0.67	0.78	0.14	-4.27	0.43	-5.98**	6.35
16	COSF 12A × RCR 19-12	-0.28	-0.30	-1.73	-0.04	1.01	0.78	1.01	-1.13	0.38	-1.91	-0.34	0.03	0.15	-0.4
17	COSF 12A × RCR 19-25	2.22*	4.70*	-5.73	-0.63**	-0.91	5.59**	2.40	-0.30	-0.66	1.08	0.66	-0.57	-1.58	7.18
18	COSF 12A × CSFI 1862	0.22	-1.13	-7.43	-0.26*	0.63	-6.75**	9.19*	-3.47*	-1.00	-0.45	2.18	-0.32	-2.04	-12.56**
19	COSF 12A × CSFI 1855	0.56	0.20	-5.50	0.20	-1.18	-1.16**	6.40	1.53	-0.29	1.30	-0.59	0.87	-3.34*	12.75**
20	COSF 12A × AKSFI 174	-0.11	-1.30	-1.03	0.11	0.13	-1.04*	1.60	-3.47*	-0.18	-0.39	0.83	-0.26	1.50	2.46
21	COSF 12A × GMU 1000	-1.61	-4.30*	-0.92	-0.38**	0.97	-5.03**	1.67	0.03	-2.03*	1.45	0.53	0.12	3.01*	-0.75
22	COSF 12A × RHA 83R-6	-0.11	-2.30	0.14	0.25*	0.39	-3.00**	-1.52	-2.47	-0.31	0.51	1.00	0.26	-2.39	-3.67
23	COSF 12A × GP6-374	-0.28	-0.97	-1.91	0.02	-0.98	-2.30**	3.61	-0.63	0.34	4.18	-2.46	0.69	0.40	-2.98
24	COSF 12A × CB 19-05	0.06	2.37	0.47	0.00	-0.42	5.87**	-4.44	2.53	1.55	-0.90	0.07	0.16	-1.07	7.92
25	COSF 12A × RCB 19-11	0.56	1.70	2.54	0.38**	0.33	0.12	-3.45	-2.80*	-0.06	-3.73	-3.50	0.16	1.94	-3.44
26	COSF 12A × GMU 498	0.06	-1.30	1.56	-0.66**	0.23	0.09	-5.16	1.53	0.48	-1.50	-0.56	-0.46	0.17	-7.35
27	COSF 12A × GMU 311	-1.11	-1.13	13.87**	0.47**	-0.04	7.54**	-5.42	4.53**	1.95*	-0.09	0.85	-1.13	-1.81	8.27*
28	COSF 12A × GMU 500	0.56	1.70	2.75	0.11	0.92	-3.88**	-2.65	3.03*	0.69	0.53	1.01	0.43	0.33	-0.77
29	COSF 12A × RHA 378	-0.28	0.53	-5.06	0.29*	-1.30	-1.23**	-3.09	1.37	-0.90	-0.12	-2.06	-0.03	-0.79	-4.71
30	COSF 12A × GMU 379	-0.44	1.53	8.00	0.10	0.23	4.40**	-0.18	-0.30	0.04	0.03	2.37	0.04	5.53**	-1.93

31	HA 89A × RCR 19-12	0.02	-0.73	0.63	-0.13	-0.92	2.66 **	-2.01	1.30	0.66	1.34	0.04	-0.20	2.06	-6.56
32	HA 89A × RCR 19-25	-0.48	-1.73	-0.82	-0.30 **	0.70	1.13 *	-2.82	-0.37	0.54	-1.65	-1.65	1.05	-1.92	-3.77
33	HA 89A × CSFI 1862	0.02	-2.07	2.83	-0.71 **	-1.46	2.77 **	-0.74	-0.53	0.67	2.02	-0.23	0.08	-2.13	2.01
34	HA 89A × CSFI 1855	-0.14	0.77	-3.30	-0.54 **	0.88	-0.20	1.12	-4.03 **	-0.72	-1.00	2.44	-0.14	-1.79	-5.5
35	HA 89A × AKSFI 174	1.69	2.77	1.71	-0.16	0.14	2.07 **	3.70	1.47	-0.22	1.41	1.47	-0.18	1.27	-0.06
36	HA 89A × GMU 1000	0.19	3.27	12.28 *	-0.07	-0.66	3.71 **	2.39	0.47	1.29	-1.41	-1.77	1.04	3.43 *	12.75 **
37	HA 89A × RHA 83R-6	0.19	3.27	-0.53	-0.27 *	0.18	1.75 **	-0.82	-1.03	0.19	-0.59	-0.29	-0.28	2.01	-5.96
38	HA 89A × GP6-374	0.52	0.60	-2.06	0.58 **	0.10	-6.04 **	-0.61	-2.20	0.03	-1.12	3.98	-0.44	-1.13	2.62
39	HA 89A × CB 19-05	0.86	-1.57	5.75	0.31 **	0.16	-4.88 **	1.70	-0.53	-0.73	-1.66	-2.53	-0.42	1.21	-14.14 **
40	HA 89A × RCB 19-11	-1.14	-2.23	-5.63	0.40 **	-0.63	1.07 *	5.89	0.63	-0.28	3.42	0.59	-0.33	-4.58 **	2.26
41	HA 89A × GMU 498	-0.14	-1.73	-1.01	-0.12	0.20	1.70 **	3.12	2.97 *	-0.74	-0.41	0.61	-0.09	-1.62	6.6
42	HA 89A × GMU 311	0.19	2.43	0.35	0.41 **	-0.98	0.10	-4.73	-0.03	-0.38	-0.94	-2.94	-0.53	1.78	3.29
43	HA 89A × GMU 500	-1.14	0.27	-3.90	0.34 **	-0.40	-1.98 **	-4.70	-1.03	-0.84	1.53	-3.12	0.42	-1.44	-6.12
44	HA 89A × RHA 378	0.02	-0.40	2.57	0.15	1.17	-0.91 *	0.40	3.30 *	1.35	-0.77	1.49	0.47	2.40	17.01 **
45	HA 89A × GMU 379	-0.64	-2.90	-8.87	0.11	1.51	-2.94 **	-1.88	-0.37	-0.82	-0.17	1.90	-0.47	0.45	-4.42
	SE (*sca*)	0.89	2.07	4.79	0.10	1.42	0.42	3.81	1.34	0.78	2.10	2.13	0.57	1.47	4.09

(*: Significant at P = 0.05, **: Significant at P = 0.01, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading, SPC - Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP - Seed yield/plant)

Table 6. Standard Heterosis over three checks for various characters in sunflower

S.No	Crosses	DFF			DM			PH			LAI			SCMR		
		DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H1	GK 2002	COH 3
1	COSF 6A × RCR 19 -12	-3.48	-3.48	-4.31	3.83	6.15	-8.65 **	-23.73 **	5.56	-11.09 *	-31.35 **	25.67 **	-49.32	-1.02	3.79	-6.25
2	COSF 6A × RCR 19 -25	-9.57 **	-9.57 **	-10.34 **	-2.73	-0.56	-14.42 **	-29.14 **	-1.93	-17.39 **	-20.77 **	45.04 **	-41.50 **	-6.18	-1.62	-11.14 *
3	COSF 6A × CSFI 1862	0.87	0.87	0.00	11.48 **	13.97 **	-1.92	-14.21 **	18.73 **	0.01	26.59 **	131.72 **	-6.54 *	-1.38	3.41	-6.59
4	COSF 6A × CSFI 1855	-1.74	-1.74	-2.59	5.46	7.82 *	-7.21 *	-19.72 **	11.11 *	-6.41	-15.08 **	55.45 **	-37.30 **	-3.99	0.68	-9.06
5	COSF 6A × AKSFI 174	-6.96 **	-6.96 **	-7.76 **	0.55	2.79	-11.54 **	-23.63 **	5.69	-10.97 *	-14.29 **	56.90 **	-36.72 **	-5.86	-1.29	-10.83 *
6	COSF 6A × GMU 1000	10.43 **	10.43 **	9.48 **	12.57 **	15.08 **	-0.96	-18.17 **	13.25 *	-4.61	44.44 **	164.41 **	6.64 *	-2.00	2.76	-7.18
7	COSF 6A × RHA 83R-6	-5.22 *	-5.22 *	-6.03 *	0.55	2.79	-11.54 **	-31.58 **	-5.30	-20.24 **	-37.70 **	14.04	-54.00 **	-7.10	-2.58	-12.00 *
8	COSF 6A × GP6-374	-0.87	-0.87	-1.72	3.83	6.15	-8.65 **	-16.96 **	14.93 **	-3.19	-19.71 **	46.97 **	-40.72 **	-3.73	0.95	-8.81
9	COSF 6A × CB 19-05	0.87	0.87	0.00	3.28	5.59	-9.13 **	-24.38 **	4.66	-11.84 **	-25.13 **	37.05 **	-44.73 **	-5.67	-1.08	-10.65 *
10	COSF 6A × RCB 19 -11	1.74	1.74	0.86	2.73	5.03	-9.62 **	-19.91 **	10.84 *	-6.64	-30.42 **	27.36 **	-48.63 **	-3.47	1.22	-8.57
11	COSF 6A × GMU 498	1.74	1.74	0.86	8.74 **	11.17 **	-4.33	-17.74 **	13.84 **	-4.11	46.56 **	168.28 **	8.20 *	-0.70	4.13	-5.94
12	COSF 6A × GMU 311	5.22 *	5.22 *	4.31	2.19	4.47	-10.10 **	-32.03 **	-5.93	-20.76 **	-32.80 **	23.00 **	-50.39 **	7.11	12.31 *	1.45
13	COSF 6A × GMU 500	-1.74	-1.74	-2.59	2.19	4.47	-10.10 **	-24.75 **	4.14	-12.28 **	-32.80 **	23.00 **	-50.39 **	-5.86	-1.29	-10.83 *
14	COSF 6A × RHA 378	6.96 **	6.96 **	6.03 *	8.74 **	11.17 **	-4.33	-8.79 *	26.23 **	6.33	-5.69	72.64 **	-30.37 **	-3.76	0.92	-8.84
15	COSF 6A × GMU 379	6.09 *	6.09 *	5.17 *	3.83	6.15	-8.65 **	-12.70 **	20.82 **	1.77	4.37	91.04 **	-22.95 **	-1.79	2.98	-6.98

16	COSF 12A × RCR 19-12	-6.96 **	-6.96 **	-7.76 **	0.55	2.79	-11.54 **	-17.11 **	14.73 **	-3.36	-34.52 **	19.85 *	-51.66 **	4.14	9.20	-1.36
17	COSF 12A × RCR 19-25	-5.22 *	-5.22 *	-6.03 *	3.83	6.15	-8.65 **	-27.59 **	0.22	-15.58 **	-59.39 **	-25.67 **	-70.02 **	-6.71	-2.18	-11.64 *
18	COSF 12A × CSFI 1862	-0.87	-0.87	-1.72	4.92	7.26 *	-7.69 **	-12.53 **	21.05 **	1.96	-3.31	77.00 **	-28.61 **	0.46	5.35	-4.84
19	COSF 12A × CSFI 1855	-2.61	-2.61	-3.45	4.92	7.26 *	-7.69 **	-19.26 **	11.75 *	-5.87	-16.01 **	53.75 **	-37.99 **	-5.45	-0.85	-10.44 *
20	COSF 12A × AKSFI 174	-6.96 **	-6.96 **	-7.76 **	-1.09	1.12	-12.98 **	-15.67 **	16.71 **	-1.69	-10.05 *	64.65 **	-33.59 **	-2.50	2.23	-7.65
21	COSF 12A × GMU 1000	2.61	2.61	1.72	4.92	7.26 *	-7.69 **	-4.42	32.28 **	11.43 **	25.26 **	129.30 **	-7.52 *	3.65	8.69	-1.82
22	COSF 12A × RHA 83R-6	-7.83 **	-7.83 **	-8.62 **	-2.73	-0.56	-14.42 **	-23.57 **	5.78	-10.90 *	-29.23 **	29.54 **	-47.75 **	-2.26	2.49	-7.42
23	COSF 12A × GP6-374	-3.48	-3.48	-4.31	0.55	2.79	-11.54 **	-11.97 **	21.84 **	2.63	-0.53	82.08 **	-26.56 **	-6.16	-1.60	-11.11 *
24	COSF 12A × CB 19-05	0.00	0.00	-0.86	4.92	7.26 *	-7.69 **	-12.63 **	20.91 **	1.85	-14.15 **	57.14 **	-36.62 **	-5.08	-0.47	-10.10 *
25	COSF 12A × RCB 19-11	-0.87	-0.87	-1.72	2.19	4.47	-10.10 **	-12.07 **	21.70 **	2.51	2.91	88.38 **	-24.02 **	-1.03	3.78	-6.26
26	COSF 12A × GMU 498	-0.87	-0.87	-1.72	2.19	4.47	-10.10 **	-8.47 *	26.68 **	6.71	11.11 *	103.39 **	-17.97 **	3.37	8.39	-2.09
27	COSF 12A × GMU 311	-0.87	-0.87	-1.72	0.55	2.79	-11.54 **	-8.78 *	26.24 **	6.34	5.56	93.22 **	-22.07 **	6.72	11.91 *	1.09
28	COSF 12A × GMU 500	-4.35	-4.35	-5.17 *	4.37	6.70 *	-8.17 **	-15.74 **	16.62 **	-1.77	-15.34 **	54.96 **	-37.50 **	0.21	5.07	-5.08
29	COSF 12A × RHA 378	3.48	3.48	2.59	7.65 *	10.06 **	-5.29	-4.70	31.89 **	11.09 *	16.27 **	112.83 **	-14.16 **	-5.12	-0.51	-10.13 *
30	COSF 12A × GMU 379	0.87	0.87	0.00	2.19	4.47	-10.10 **	-0.73	37.39 **	15.73 **	15.34 **	111.14 **	-14.84 **	5.63	10.76 *	0.05
31	HA 89A × RCR 19-12	-6.09 *	-6.09 *	-6.90 **	0.55	2.79	-11.54 **	-19.13 **	11.92 *	-5.73	-30.82 **	26.63 **	-48.93 **	-1.90	2.87	-7.08
32	HA 89A × RCR 19-25	-9.57 **	-9.57 **	-10.34 **	-2.73	-0.56	-14.42 **	-28.24 **	-0.69	-16.35 **	-44.58 **	1.45	-59.08 **	-3.63	1.06	-8.72
33	HA 89A × CSFI 1862	-0.87	-0.87	-1.72	4.37	6.70 *	-8.17 **	-10.31 **	24.12 **	4.55	-9.39 *	65.86 **	-33.11 **	-5.99	-1.42	-10.95 *
34	HA 89A × CSFI 1855	-3.48	-3.48	-4.31	6.01	8.38 *	-6.73 *	-21.37 **	8.83	-8.33	-29.50 **	29.06 **	-47.95 **	-1.21	3.59	-6.43
35	HA 89A × AKSFI 174	-3.48	-3.48	-4.31	3.83	6.15	-8.65 **	-17.50 **	14.19 **	-3.82	-11.38 *	62.23 **	-34.57 **	-3.54	1.15	-8.63
36	HA 89A × GMU 1000	6.09 *	6.09 *	5.17 *	13.66 **	16.20 **	0.00	-0.62	37.54 **	15.86 **	39.55 **	155.45 **	3.03	-1.60	3.18	-6.80
37	HA 89A × RHA 83R-6	-6.96 **	-6.96 **	-7.76 **	3.83	6.15	-8.65 **	-27.22 **	0.72	-15.16 **	-37.04 **	15.25	-53.52 **	-3.87	0.80	-8.95
38	HA 89A × GP6-374	-1.74	-1.74	-2.59	2.73	5.03	-9.62 **	-15.35 **	17.16 **	-1.31	20.37 **	120.34 **	-11.13 **	-4.44	0.20	-9.49
39	HA 89A × CB 19-05	1.74	1.74	0.86	1.09	3.35	-11.06 **	-13.09 **	20.29 **	1.32	0.00	83.05 **	-26.17 **	-4.63	0.00	-9.67
40	HA 89A × RCB 19-11	-3.48	-3.48	-4.31	-1.64	0.56	-13.46 **	-19.75 **	11.06 *	-6.45	9.39 *	100.24 **	-19.24 **	-4.57	0.07	-9.61
41	HA 89A × GMU 498	-0.87	-0.87	-1.72	2.19	4.47	-10.10 **	-13.14 **	20.21 **	1.26	31.48 **	140.68 **	-2.93	2.21	7.17	-3.19
42	HA 89A × GMU 311	1.74	1.74	0.86	4.92	7.26 *	-7.69 **	-19.34 **	11.63 *	-5.97	9.92 *	101.21 **	-18.85 **	3.24	8.25	-2.21
43	HA 89A × GMU 500	-6.96 **	-6.96 **	-7.76 **	3.28	5.59	-9.13 **	-22.61 **	7.11	-9.78 *	-3.44	76.76 **	-28.71 **	-4.25	0.41	-9.30
44	HA 89A × RHA 378	4.35	4.35	3.45	7.10 *	9.50 **	-5.77 *	-3.90	33.01 **	12.03 **	18.52 **	116.95 **	-12.50 **	0.19	5.06	-5.10
45	HA 89A × GMU 379	0.87	0.87	0.00	-2.19	0.00	-13.94 **	-13.09 **	20.29 **	1.32	21.69 **	122.76 **	-10.16 **	7.88	13.13 *	2.19

(*: Significant at P = 0.05, **: Significant at P = 0.01, DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading)

Table 6. Standard Heterosis over three checks for various characters in sunflower

S. No	Crosses	SPC			RWC			NOL			HD			VW		
		DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3	DRS H 1	GK 2002	COH 3
1	COSF 6A × RCR 19 -12	-24.32**	-28.52**	-19.61**	-0.01	-8.14	9.55	-5.56	18.60*	-5.56	-3.5	4.12	-13.72*	1.05	12.50	14.24
2	COSF 6A × RCR 19 -25	-39.51**	-42.86**	-35.73**	-3.15	-11.03	6.11	-9.26	13.95	-9.26	-7.39	-0.07	-17.20**	-6.08	4.56	6.17
3	COSF 6A × CSFI 1862	15.32**	8.92**	22.51**	-12.94	-20.02**	-4.61	14.81*	44.19**	14.81*	16.56*	25.77**	4.21	-23.14**	-14.43	-13.11
4	COSF 6A × CSFI 1855	2.93	-2.78	9.35**	-9.38	-16.75**	-0.71	7.41	34.88**	7.41	12.26	21.13**	0.37	-8.40	1.98	3.55
5	COSF 6A × AKSFI 174	-12.42**	-17.27**	-6.96**	-8.39	-15.84*	0.37	-3.70	20.93*	-3.70	7.01	15.46*	-4.33	-4.34	6.49	8.13
6	COSF 6A × GMU 1000	-9.72**	-14.72**	-4.09*	-2.47	-10.40	6.86	20.37**	51.16**	20.37**	21.66**	31.27**	8.77	-4.09	6.77	8.42
7	COSF 6A × RHA 83R-6	4.35 *	-1.44	10.85**	-0.28	-8.39	9.25	9.26	37.21**	9.26	-4.78	2.75	-14.86*	-16.32*	-6.84	-5.40
8	COSF 6A × GP6-374	23.87**	17.00**	31.60**	-9.04	-16.44**	-0.34	0.00	25.58**	0.00	1.27	9.28	-9.45	-23.14**	-14.43	-13.11
9	COSF 6A × CB 19-05	-6.44**	-11.63**	-0.61	2.13	-6.18	11.90	-5.56	18.60*	-5.56	-1.91	5.84	-12.30	-0.12	11.19	12.90
10	COSF 6A × RCB 19 -11	-11.66**	-16.56**	-6.16**	-5.06	-12.78*	4.03	18.52*	48.84**	18.52*	-0.64	7.22	-11.16	-3.10	7.87	9.54
11	COSF 6A × GMU 498	9.63**	3.55 *	16.46**	4.28	-4.20	14.25	0.00	25.58**	0.00	10.19	18.90*	-1.48	-3.04	7.94	9.61
12	COSF 6A × GMU 311	-38.49**	-41.90**	-34.66**	11.38	2.32	22.04**	-16.67*	4.65	-16.67*	-10.92	-3.88	-20.36**	-5.55	5.15	6.77
13	COSF 6A × GMU 500	4.65 *	-1.15	11.17**	10.48	1.50	21.05**	3.70	30.23**	3.70	-0.96	6.87	-11.45	-16.38*	-6.91	-5.47
14	COSF 6A × RHA 378	-0.41	-5.93**	5.80**	4.02	-4.43	13.97	1.85	27.91**	1.85	6.69	15.12	-4.61	-2.11	8.98	10.66
15	COSF 6A × GMU 379	4.04 *	-1.72	10.53**	-3.06	-10.94	6.22	18.52*	48.84**	18.52*	7.01	15.46*	-4.33	-12.78	-2.90	-1.40
16	COSF 12A × RCR 19-12	-7.08**	-12.23**	-1.28	0.82	-7.38	10.46	-3.70	20.93*	-3.70	8.6	17.18*	-2.90	-4.28	6.56	8.20
17	COSF 12A × RCR 19-25	2.16	-3.51*	8.53**	0.16	-7.98	9.75	-7.41	16.28	-7.41	-9.24	-2.06	-18.85**	-3.97	6.91	8.56
18	COSF 12A × CSFI 1862	-12.54**	-17.39**	-7.09**	10.20	1.24	20.75**	-7.41	16.28	-7.41	11.15	19.93*	-0.63	-19.54**	-10.43	-9.05
19	COSF 12A × CSFI 1855	-0.14	-5.67**	6.09**	9.07	0.20	19.50**	9.26	37.21**	9.26	7.01	15.46*	-4.33	-3.60	7.32	8.98
20	COSF 12A × AKSFI 174	-7.94**	-13.04**	-2.20	1.16	-7.06	10.84	-18.52*	2.33	-18.52*	6.43	14.85	-4.84	-1.92	9.19	10.87
21	COSF 12A × GMU 1000	-24.37**	-28.56**	-19.65**	5.60	-2.99	15.70*	27.78**	60.47**	27.78**	7.01	15.46*	-4.33	0.43	11.81	13.53

21	COSF 12A × GMU 1000	-24.37**	-28.56**	-19.65**	5.60	-2.99	15.70*	27.78**	60.47**	27.78**	7.01	15.46*	-4.33	0.43	11.81	13.53
22	COSF 12A × RHA 83R -6	-3.97*	-9.29**	2.02	-4.33	-12.11	4.82	-7.41	16.28	-7.41	-4.46	3.09	-14.58*	-14.39	-4.70	-3.23
23	COSF 12A × GP6-374	-3.73*	-9.06**	2.28	0.13	-8.02	9.70	-7.41	16.28	-7.41	8.92	17.53*	-2.62	-4.34	6.49	8.13
24	COSF 12A × CB 19-05	18.80**	12.21**	26.21**	-6.13	-13.76*	2.85	16.67*	46.51**	16.67*	16.24*	25.43**	3.93	-7.88	2.56	4.14
25	COSF 12A × RCB 19-11	-3.20	-8.57**	2.84	-5.51	-13.19*	3.53	5.56	32.56**	5.56	-0.19	7.7	-10.76	-12.28	-2.35	-0.84
26	COSF 12A × GMU 498	19.84**	13.20**	27.32**	-4.01	-11.82	5.17	27.78**	60.47**	27.78**	14.59*	23.64**	2.45	-10.67	-0.55	0.98
27	COSF 12A × GMU 311	11.85**	5.64**	18.82**	-7.49	-15.01*	1.36	22.22**	53.49**	22.22**	14.46*	23.51**	2.33	-7.51	2.97	4.56
28	COSF 12A × GMU 500	-20.24**	-24.66**	-15.26**	-1.35	-9.37	8.09	27.78**	60.47**	27.78**	5.54	13.88	-5.64	-9.12	1.17	2.73
29	COSF 12A × RHA 378	-6.04**	-11.25**	-0.18	-2.46	-10.39	6.87	29.63**	62.79**	29.63**	6.82	15.26*	-4.50	-3.78	7.11	8.77
30	COSF 12A × GMU 379	26.27**	19.27**	34.15**	-5.07	-12.79*	4.01	20.37**	51.16**	20.37**	5.29	13.61	-5.87	-12.22	-2.28	-0.77
31	HA 89A × RCR 19-12	0.50	-5.07**	6.76**	-1.01	-9.06	8.46	-1.85	23.26*	-1.85	7.71	16.22*	-3.70	0.12	11.46	13.18
32	HA 89A × RCR 19-25	-9.40**	-14.42**	-3.75	-4.45	-12.22*	4.69	-14.81*	6.98	-14.81*	-4.27	3.3	-14.41*	-14.39	-4.70	-3.23
33	HA 89A × CSFI 1862	18.08**	11.53**	25.44**	-0.38	-8.48	9.15	-3.70	20.93*	-3.70	19.11**	28.52**	6.49	-17.06*	-7.67	-6.24
34	HA 89A × CSFI 1855	4.65 *	-1.15	11.17**	4.37	-4.12	14.36	-18.52*	2.33	-18.52*	1.59	9.62	-9.17	-12.97	-3.11	-1.61
35	HA 89A × AKSFI 174	3.35	-2.38	9.79**	5.81	-2.80	15.93*	-7.41	16.28	-7.41	3.5	11.68	-7.46	-1.12	10.08	11.78
36	HA 89A × GMU 1000	3.92 *	-1.84	10.40**	8.50	-0.32	18.88*	22.22**	53.49**	22.22**	25.48**	35.40**	12.19	-10.30	-0.14	1.40
37	HA 89A × RHA 83R-6	12.27**	6.04**	19.27**	-1.46	-9.47	7.96	-9.26	13.95	-9.26	-3.95	3.64	-14.12*	-20.78**	-11.81	-10.45
38	HA 89A × GP6-374	-13.10**	-17.92**	-7.68**	-3.23	-11.10	6.03	-20.37**	0.00	-20.37**	4.27	12.51	-6.78	-21.15**	-12.22	-10.87
39	HA 89A × CB 19-05	-11.75**	-16.65**	-6.25**	3.62	-4.81	13.53	-1.85	23.26*	-1.85	-0.96	6.87	-11.45	-13.40	-3.59	-2.10
40	HA 89A × RCB 19-11	1.60	-4.03*	7.94**	8.29	-0.52	18.65*	11.11	39.53**	11.11	-4.27	3.3	-14.41*	1.80	13.33	15.08
41	HA 89A × GMU 498	26.59**	19.57**	34.48**	8.45	-0.37	18.82*	25.93**	58.14**	25.93**	4.14	12.37	-6.89	-11.60	-1.59	-0.07
42	HA 89A × GMU 311	-8.69**	-13.75**	-3.00	-4.64	-12.39*	4.48	-1.85	23.26*	-1.85	-3.06	4.6	-13.33*	-13.28	-3.45	-1.96
43	HA 89A × GMU 500	-12.60**	-17.45**	-7.15**	-1.96	-9.93	7.42	5.56	32.56**	5.56	-6.88	0.48	-16.74*	-10.30	-0.14	1.40
44	HA 89A × RHA 378	-3.15	-8.52**	2.89	3.94	-4.52	13.88	29.63**	62.79**	29.63**	18.47*	27.84**	5.92	-9.06	1.24	2.81
45	HA 89A × GMU 379	6.01**	0.13	12.62**	-5.24	-12.95*	3.82	12.96	41.86**	12.96	-2.87	4.81	-13.15*	-16.38*	-6.91	-5.47

(*: Significant at P = 0.05, **: Significant at P = 0.01, SPC - Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight)

Table 6. Standard Heterosis over three checks for various characters in sunflower

S.No	Crosses	HC			HSW			OC			SYP		
		DRSH 1	GK 2002	COH3	DRSH 1	GK 2002	COH3	DRSH 1	GK 2002	COH3	DRSH 1	GK 2002	COH3
1	COSF 6A × RCR 19-12	-10.50	-18.83 *	-7.80	-31.18 **	5.15	-3.83	-10.87 *	-16.72 **	-20.01 **	28.33 *	44.89 **	-0.01
2	COSF 6A × RCR 19-25	-6.51	-15.20	-3.68	-42.21 **	-11.70	-19.23	0.64	-5.96	-9.67	-18.33	-7.80	-36.38 **
3	COSF 6A × CSFI 1862	-0.99	-10.20	2.01	-25.56 *	13.73	4.02	1.24	-5.41	-9.14	45.95 **	64.78 **	20.51 *
4	COSF 6A × CSFI 1855	-7.03	-15.67	-4.22	-42.21 **	-11.70	-19.23	-0.04	-6.60	-10.29 *	-20.71	-10.48	-22.86 *
5	COSF 6A × AKSFI 174	-23.71 *	-30.80 **	-21.40 *	-32.16 **	3.65	-5.20	-23.81 **	-28.81 **	-31.62 **	-6.43	5.65	-27.25 **
6	COSF 6A × GMU 1000	-4.88	-13.73	-2.01	-30.41 **	6.33	-2.75	-24.74 **	-29.68 **	-32.46 **	1.19	14.25	-21.24 *
7	COSF 6A × RHA 83R-6	-0.25	-9.53	2.77	-46.49 **	-18.24	-25.22	-3.88	-10.19 *	-13.74 **	12.14	26.61	-12.74
8	COSF 6A × GP6-374	-41.61 **	-47.04 **	-39.84 **	-33.50 **	1.61	-7.07	-6.26	-12.42 *	-15.87 **	4.29	17.74	-18.87 *
9	COSF 6A × CB 19-05	-20.02 *	-27.45 **	-17.60	-32.65 **	2.90	-5.89	-12.65 *	-18.38 **	-21.60 **	28.10 *	44.62 **	-0.30
10	COSF 6A × RCB 19-11	-8.42	-16.94	-5.65	-34.48 **	0.11	-8.44	-4.42	-10.70 *	-14.22 **	-5.00	7.26	-25.91 **
11	COSF 6A × GMU 498	-9.08	-17.53	-6.33	-11.94	34.55	23.06	-5.13	-11.36 *	-14.86 **	18.33	33.60 *	-7.89
12	COSF 6A × GMU 311	-2.25	-11.34	0.71	-6.81	42.38 *	30.23	-1.95	-8.39	-12.00 *	-38.57 **	-30.65 *	-52.15 **
13	COSF 6A × GMU 500	1.09	-8.31	4.15	-36.31 **	-2.68	-10.99	-2.22	-8.64	-12.25 *	2.86	16.13	-19.85 *
14	COSF 6A × RHA 378	-18.61	-26.18 **	-16.15	-19.45	23.07	12.56	-8.76	-14.75 **	-18.12 **	-14.52	-3.49	-33.47 **
15	COSF 6A × GMU 379	-18.20	-25.81 **	-15.73	-33.15 **	2.15	-6.58	-29.24 **	-33.89 **	-36.49 **	13.81	28.49	-11.30
16	COSF 12A × RCR 19-12	-11.21	-19.46 *	-8.52	-29.92 *	7.08	-2.06	1.95	-4.75	-8.50	15.48	30.38 *	-10.19
17	COSF 12A × RCR 19-25	-6.19	-14.91	-3.35	-40.45 **	-9.01	-16.78	-6.09	-12.26 *	-15.72 **	6.43	20.16	-17.00
18	COSF 12A × CSFI 1862	14.31	3.68	17.77	-30.27 *	6.55	-2.55	-8.45	-14.46 **	-17.83 **	8.33	22.31	-15.64
19	COSF 12A × CSFI 1855	-1.36	-10.53	1.62	-16.50	27.58	16.68	-15.70 **	-21.23 **	-24.34 **	23.33	39.25 *	12.03
20	COSF 12A × AKSFI 174	-11.80	-20.00 *	-9.13	-38.90 **	-6.65	-14.62	-5.95	-12.12 *	-15.59 **	6.19	19.89	-17.31
21	COSF 12A × GMU 1000	-5.84	-14.59	-2.99	-9.34	38.52 *	26.69	6.76	-0.25	-4.18	27.62 *	44.09 **	-0.76
22	COSF 12A × RHA 83R -6	6.95	-3.00	10.18	-40.03 **	-8.37	-16.19	-4.58	-10.84 *	-14.36 **	-13.57	-2.42	-32.73 **
23	COSF 12A × GP6-374	-43.36 **	-48.62 **	-41.64 **	-17.21	26.50	15.70	-0.50	-7.03	-10.70 *	-0.24	12.63	-22.43 *
24	COSF 12A × CB 19-05	-26.59 **	-33.42 **	-24.37 *	-30.97 **	5.47	-3.53	-8.46	-14.47 **	-17.85 **	34.05 *	51.34 **	4.45
25	COSF 12A × RCB 19-11	-28.47 **	-35.12 **	-26.31 *	-31.53 **	4.61	-4.32	0.36	-6.23	-9.93 *	-12.14	-0.81	-31.60 **
26	COSF 12A × GMU 498	-9.35	-17.78	-6.60	-23.17 *	17.38	7.36	-1.88	-8.32	-11.94 *	3.57	16.94	-19.29 *
27	COSF 12A × GMU 311	-5.02	-13.85	-2.14	-42.98 **	-12.88	-20.31	-0.17	-6.73	-10.41 *	5.95	19.62	-17.56
28	COSF 12A × GMU 500	-1.16	-10.35	1.83	-15.17	29.61	18.55	2.37	-4.35	-8.13	-10.95	0.54	-30.55 **
29	COSF 12A × RHA 378	-25.97 *	-32.86 **	-23.73 *	-10.46	36.80 *	25.12	0.00	-6.57	-10.25 *	3.81	17.20	-19.05 *
30	COSF 12A × GMU 379	5.50	-4.31	8.69	-35.46 **	-1.39	-9.81	7.69	0.61	-3.35	-1.19	11.56	-23.00 *
31	HA 89A × RCR 19-12	-3.93	-12.86	-1.02	-29.99 *	6.97	-2.16	5.90	-1.06	-4.96	-0.95	11.83	-22.82 *
32	HA 89A × RCR 19-25	-7.94	-16.50	-5.15	-14.47	30.69	19.53	-8.08	-14.12 **	-17.50 **	-19.76	-9.41	-37.54 **
33	HA 89A × CSFI 1862	12.21	1.78	15.61	-21.42	20.06	9.81	-9.76	-15.69 **	-19.02 **	36.19 **	53.76 **	5.90
34	HA 89A × CSFI 1855	14.80	4.12	18.27	-27.46 *	10.84	1.37	-12.70 *	-18.43 **	-21.65 **	1.90	15.05	-20.51 *
35	HA 89A × AKSFI 174	-3.64	-12.60	-0.73	-34.55 **	0.00	-8.54	-7.62	-13.68 **	-17.09 **	-2.14	10.48	-23.95 *
36	HA 89A × GMU 1000	-7.55	-16.15	-4.75	6.88	63.30 **	49.36 **	6.80	-0.21	-4.15	52.86 **	72.58 **	19.00 *
37	HA 89A × RHA 83R-6	8.62	-1.48	11.91	-44.45 **	-15.13	-22.37	5.92	-1.03	-4.94	-21.67	-11.56	-38.99 **
38	HA 89A × GP6-374	-15.74	-23.57 *	-13.19	-29.85 *	7.19	-1.96	-5.62	-11.82 *	-15.29 **	8.33	22.31	-15.69
39	HA 89A × CB 19-05	-29.31 **	-35.88 **	-27.17 *	-35.96 **	-2.15	-10.50	-3.54	-9.87	-13.43 **	-15.71	-4.84	-34.38 **
40	HA 89A × RCB 19-11	-8.74	-17.23	-5.98	-35.11 **	-0.86	-9.32	-17.88 **	-23.28 **	-26.30 **	-3.33	9.14	-24.69 *
41	HA 89A × GMU 498	0.57	-8.78	3.61	-14.75	30.26	19.14	-7.67	-13.73 **	-17.14 **	30.00 *	46.77 **	1.22
42	HA 89A × GMU 311	-11.73	-19.94 *	-9.06	-31.39 **	4.83	-4.12	8.19	1.08	-2.91	-7.86	4.03	-28.24 **
43	HA 89A × GMU 500	-9.03	-17.49	-6.27	-12.08	34.33	22.87	-3.38	-9.73	-13.29 **	-25.24	-15.59	-41.85 **
44	HA 89A × RHA 378	-8.07	-16.62	-5.29	-0.21	52.47 **	39.45 *	7.33	0.28	-3.67	46.67 **	65.59 **	14.26
45	HA 89A × GMU 379	9.95	-0.27	13.28	-39.40 **	-7.40	-15.31	-6.76	-12.89 *	-16.32 **	-11.19	0.27	-29.58 **

(*: Significant at P = 0.05, **: Significant at P = 0.01, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP-Seed yield/plant)

Table 7. Hybrids selected based on mean performance, *sca*, Standard heterosis

Traits	Mean performance	*sca*	Standard heterosis	Combination
DFF	COSF 6A × RCR 19-25, COSF 6A × AKSFI 174, COSF 6A × RHA 83R-6, COSF 12A × RCR 19-12, COSF 12A × RCR 19-25, COSF 12A × AKSFI 174, COSF 12A × RHA 83R-6, HA 89A × RCR 19-12, HA 89A × RCR 19-25, HA 89A × RHA 83R-6, HA 89A × GMU 500	-	COSF 6A × RCR 19-25, COSF 6A × AKSFI 174, COSF 6A × RHA 83R-6, COSF 12A × RCR 19-12, COSF 12A × RCR 19-25, COSF 12A × AKSFI 174, COSF 12A × RHA 83R-6, HA 89A × RCR 19-12, HA 89A × RCR 19-25, HA 89A × RHA 83R-6, and HA 89A × GMU 500.	-
DM	COSF 6A × RCR 19-25, COSF 12A × RHA 83R-6, HA 89A × RCR 19-25	COSF 12A × GMU 1000	-	-
PH	COSF 12A × GMU 379, COSF 12A × GMU 1000, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 12A × RHA 378	COSF 12A × GMU 311, HA 89A × GMU 1000	COSF 12A × GMU 379, COSF 12A × GMU 1000, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 12A × RHA 378	HA 89A × GMU 1000
LAI	COSF 6A × CSFI 1862, COSF 6A × GMU 1000, COSF 12A × GMU 1000, COSF 12A × GMU 311,COSF 12A × GMU 498, COSF 12A × GMU 378, COSF 12A × GMU 379, HA 89A × GMU 1000, HA 89A × GMU 498, COSF 6A × GMU 498, COSF 6A × RHA 378,COSF 6A × GMU 379, HA 89A × GP6-374, HA 89A × RCB 19-11, HA 89A × GMU 311, HA 89A × GMU 498, HA 89A × GMU 379,HA 89A × RHA 378	COSF 6A × RCR 19-25, COSF 6A × CSFI 1862, COSF 6A × CSFI 1855, COSF 6A × GMU 498, COSF 6A × GMU 1000, COSF 12A × GMU 311, COSF 12A × RHA 378, HA 89A × GP6-374, HA 89A × CB 19-05, HA 89A × RCB 19-11, HA 89A × GMU 311, HA 89A × GMU 500, COSF 12A × RHA 83R-6, COSF 12A × RCB 19-11	COSF 6A × CSFI 1862, COSF 6A × GMU 1000, COSF 12A × GMU 1000, COSF 12A × GMU 498, COSF 12A × RHA 378, COSF 12A × GMU 379, HA 89A × GMU 1000, HA 89A × GMU 498, COSF 6A × GMU 498, COSF 6A × RHA 378, COSF 6A × GMU 379, HA 89A × GP6-374, HA 89A × RCB 19-11, HA 89A × GMU 311, HA 89A × RHA 378, HA 89A × GMU 379	COSF 6A × CSFI 1862, COSF 6A × GMU 1000, HA 89A × GP6-374, HA 89A × RCB 19-11, HA 89A × GMU 311, COSF 6A × GMU 498
SCMR	COSF 6A × GMU 311, COSF 12A × GMU 311, HA 89A × GMU 379	-	COSF 6A × GMU 311, COSF 12A × GMU 311, COSF 12A × GMU 379, HA 89A × GMU 379	-
SPC	COSF 6A × CSFI 1862, COSF 6A × GP6-374, COSF 6A × RHA 83R-6, COSF 12A × GMU 311, COSF 12A × GMU 379, HA 89A × GMU 498, COSF 6A × GMU 498, COSF 12A × GMU 498, COSF 6A × GMU 500, COSF 6A × GMU 379, COSF 12A × CB 19-05, HA 89A × CSFI 1862 HA 89A × CSFI 1855, HA 89A × GMU 1000 HA 89A × RHA 83R-6, HA 89A × GMU 379	COSF 6A × CSFI 1862, COSF 6A × CSFI 1855,COSF 6A × GP6-374, COSF 12A × GMU 311, COSF 12A × GMU 379, HA 89A × GMU 498,COSF 6A × GMU 1000, COSF 6A × RHA 83R-6, COSF 6A × GP6-374, COSF 6A × GMU 500,COSF 6A × RHA 378,COSF 12A × RCR 19 -25,COSF 12A × CB 19-05,HA 89A × RCR 19-12, HA 89A × RCR 19-25,HA 89A × CSFI 1862,HA 89A × AKSFI 174,HA 89A × GMU 1000, HA 89A × RHA 83R-6,HA 89A × RCB 19-11	COSF 6A × CSFI 1862, COSF 6A × GP6-374, COSF 12A × GMU 311, COSF 12A × GMU 379, HA 89A × GMU 498, COSF 6A × GMU 498, COSF 12A × GMU 498, COSF 12A × CB 19-05, HA 89A × CSFI 1862, HA 89A × RHA 83R-6	COSF 6A × CSFI 1862, COSF 6A × GP6-374, COSF 12A × GMU 311, COSF 12A × GMU 379, HA 89A × GMU 498, COSF 12A × CB 19-05, HA 89A × CSFI 1862, HA 89A × RHA 83R-6
RWC	COSF 6A × GMU 311, COSF 6A × GMU 500, COSF 12A × CSFI 1862, COSF 12A × CSFI 1855, HA 89A × GMU 1000, HA 89A × RCB 19-11, HA 89A × GMU 498	COSF 6A × GMU 311, COSF 12A × CSFI 1862	-	-
NOL	COSF 6A × CSFI 1862, COSF 6A × CSFI 1855, COSF 6A × RHA 83R-6, COSF 6A × GMU 1000, COSF12 A × GMU 1000, HA 89A × GMU 1000, HA 89A × GMU 498, HA 89A × RHA 378, COSF 12A × CB 19-05, COSF 12A × GMU 498, COSF 12A × GMU 311, COSF 12A × GMU 500, COSF 12A × RHA 378, COSF 12A × GMU 379,COSF 6A × RCB 19-11,COSF 6A × GMU 379,COSF 12A × CSFI 1855,HA 89A × RCB 19-11,HA 89A × GMU 379	COSF 6A × CSFI 1862, HA 89A × GMU 498, HA 89A × RHA 378, COSF 12A × GMU 311, COSF 12A × GMU 500, COSF 6A × RHA 83R-6 COSF 6A × GP6-374	COSF 6A × CSFI 1862, COSF 6A × GMU 1000, COSF 12A × GMU 1000, HA 89A × GMU 1000, HA 89A × GMU 498, HA 89A × RHA 378, COSF 12A × CB 19-05, COSF 12A × RCB 19-11, COSF 12A × GMU 498, COSF 12A × GMU 311, COSF 12A × GMU 500, COSF 12A × RHA 378, COSF 12A × GMU 379	COSF 6A × CSFI 1862, HA 89A × GMU 498, HA 89A × RHA 378, COSF 12A × GMU 311, COSF 12A × GMU 500, COSF 12A × GMU 379
HD	COSF 6A × CSFI 1862, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 6A × GMU 1000, COSF 12A × CB 19-05, HA 89A × CSFI 1862	COSF 6A × CSFI 1862, COSF 12A × GMU 311, HA 89A × GMU 1000 HA 89A × RHA 378	COSF 6A × CSFI 1862, COSF 12A × GMU 311, HA89A × GMU 1000, HA89A × RHA 378, COSF 6A × CSFI 1855, COSF 6A × GMU 1000, COSF 12A × CSFI 1862, COSF 12A × CB 19-05, HA89A × CSFI 1862	COSF 6A × CSFI 1862, HA 89A × GMU 1000, HA 89A × RHA 378
VW	COSF 6A × RCR 19-12, HA 89A × RCB 19 -11, COSF 12A × GMU 1000	-	-	-
HC	HA 89A × CSFI 1855	-	-	-
HSW	HA 89A × GMU 1000	COSF 6A × GMU 311	HA 89A × GMU 1000, HA 89A × RHA 378	-
OC	COSF 12A × GMU 379, HA 89A × GMU 311, HA 89A × RHA 378	COSF 6A × RCR 19-25, COSF 6A × CSFI 1862, COSF 6A × CSFI 1855, COSF 12A × GMU 379, COSF 12A × GMU 1000, HA 89A × GMU 1000	COSF 12A × GMU 379, HA 89A × GMU 311, HA 89A × RHA 378	COSF 12A × GMU 379
SYP	COSF 6A × CSFI 1862, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 12A × CB 19-05, HA 89A × CSFI 1862, COSF 12A × CSFI 1855, HA 89A × GMU 498	COSF 6A × CSFI 1862, COSF 12A × CSFI 1855, HA89A × GMU 1000, HA89A × RHA 378, COSF 6A × RHA 83R-6, COSF 12A × GMU 311	COSF 6A × RCR 19-12, COSF 6A × CSFI 1862, COSF 12A × CSFI 1855, COSF 12A × GMU 1000, HA89A × GMU 1000, HA89A × RHA 378, COSF 6A × CB 19-05, COSF 12A × CB 19-05, HA89A × CSFI 1862, HA 89A × GMU 498	COSF 6A × CSFI 1862, HA 89A × GMU 1000, HA 89A × RHA 378, COSF 12A × CSFI 1855

(DFF-Days to fifty percent flowering, DM - Days to maturity, PH - Plant height, LAI - Leaf area index, SCMR - SPAD Chlorophyll Meter Reading, SPC - Soluble protein content, RWC - Relative water content, NOL - No. of leaves, HD - Head diameter, VW - Volume weight, HC - Hull content, HSW - Hundred seed weight, OC - Oil content, SYP-Seed yield/plant).

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Authors' contributions

K. Beenaa Sharron conducted the field and laboratory experiments and wrote the article. R. Sasikala contributed by providing concept, idea and overall supervision of the experiments and for writing the research article, R. Kalaiyarasi provided the resources needed for the study. S. Harish helped in drafting and editing of the manuscript. K. Vanitha helped in the physiological analysis and editing of the manuscript. All authors read and approved the final manuscript.

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