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Heterosis Studies for Yield attributing traits and Oil Content in Sunflower (*Helianthus Annuus* L.)

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Abstract
A study was undertaken to assess the extent of heterosis and combining ability in sunflower using six CMS lines and seven restorer lines, crossed in a line × tester mating design during the Kharif 2024 season. The resulting hybrids were evaluated in the Rabi 2024-25 season at the Oilseeds Research Station, Latur. The cross CMS-10A × LT-05 (19.74%), exhibited the highest and significant average heterosis for seed yield per plant and other yield-related traits, closely followed by followed by CMS-82A × LT-07 (17.08%), CMS-852A × LT-04 (14.24%). For heterobeltiosis, the maximum and significant expression was recorded in CMS-10A x LT-05 (15.93 %), with the next best being CMS-852A x LT-01 (6.26 %). With respect to standard heterosis over the best check KBSH-90, the cross CMS-112A × LT-02 (46.64%), followed by CMS-10A × LT-05 (38.00%). For oil content, Among the 42 hybrids, the crosses CMS-112A × LT-02 (16.98%, 18.94%, 10.94%), CMS-82A × LT-01 (15.64%, 17.58%, 9.23%), CMS-82A × LT-03 (13.64%, 15.55%, 7.34%), CMS-112A × LT-06 (12.76%, 14.65%, 6.51%) and CMS-852A × LT-06 (13.60%, 15.51%, 7.30%) consistently exhibited significant positive standard heterosis over all three checks (LSFH-171, KBSH-44 and KBSH-90).Considering the overall mean performance along with heterosis, heterobeltiosis, and standard heterosis, five cross combinations viz: CMS-112A × LT-02, CMS-10A × LT-05, CMS-82A × LT-07, CMS-82A × LT-01, CMS-82A × LT-02 were identified as promising crosses.

Keywords: Sunflower, line x tester, Heterosis, Heterobeltiosis and Standard Heterosis

Introduction

Sunflower (*Helianthus annuus L.; 2n = 2x = 34*) stands as a globally important oilseed crop, primarily cultivated for its nutrient-rich edible oil, known for its abundance of essential fatty acids and antioxidants. Its remarkable adaptability to diverse soil types and resilience against abiotic stresses have positioned it as a key crop across various agro-climatic regions. Originally native to North America, sunflower was formally introduced into Indian agriculture in the late 1960s to diversify oilseed production and address the rising demand for vegetable oils.

Currently, sunflower ranks as the fourth major oilseed crop in India, trailing groundnut, mustard and soybean. According to projections for 2024-25 from the Indian Institute of Oilseeds Research (IIOR) and the Government of India, the crop covers approximately 2.28 lakh hectares, yielding 2.13 lakh tonnes with an average productivity of 934 kg/ha (IIOR, 2024). The declining area and production of sunflower in recent years can largely be attributed to the prevalence of low-yielding genotypes and hybrids. To address this challenge, breeders have increasingly focused on hybrid development through heterosis breeding a strategy made feasible by Leclercq's (1969) discovery of cytoplasmic male sterility and Kinman's (1970) identification of a fertility restoration system. This study aimed to enhance sunflower productivity by improving hybrid seed yield and oil content. Effective utilization of heterosis in breeding programs requires the development of robust inbred lines, incorporation of diverse genetic sources and deployment of reliable restorer lines. The current investigation assessed the magnitude of heterosis including average heterosis, heterobeltiosis and standard heterosis across various traits within the genetic variability of the crosses studied. These findings provide valuable insights for shaping future breeding strategies to further advance sunflower improvement.

Material and Methods

The present investigation was carried out at the Oilseeds Research Station, Latur (18.40° N latitude and 76.57° E longitude). The field trial was conducted during the *Rabi* 2024-25 season following hybridization during *Kharif* 2024. The study aimed to evaluate heterosis and combining ability in sunflower using six cytoplasmic male sterile (CMS) lines and seven restorer (R) lines of diverse genetic backgrounds. A total of 42 hybrids were developed using the line × tester mating design as proposed. A total of 42 hybrids, along with 13 parental lines and three standard checks (LSFH-171, KBSH-90 and KBSH-44), were evaluated in a randomized block design comprising two replications, with a spacing of 60 cm between rows and 30 cm between plants.

Observations were recorded on five randomly selected plants for ten quantitative traits: days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), seed filling percentage, 100-seed weight (g), volume weight (g/100 ml), hull content (%), oil content (%) and seed yield per plant (g). The recorded data were subjected to analysis of variance (ANOVA) suitable for randomized block design as described. Heterosis was measured by calculating how much better the F_1 hybrid performed compared to a standard check variety for each trait. Measuring heterosis over the better parent gives some information about gene interactions, but it is less useful than comparing it to a standard check. So, it's more meaningful to evaluate heterosis based on how much better the hybrid is than the check hybrid. All statistical analyses were performed using TNAUSTAT software.

Results and Discussion

The estimates of average heterosis (MP), heterobeltiosis (BP) and standard heterosis over checks for the studied characters *viz:* Head diameter, 100 seed weight, Seed filling %, Hull content %, Oil content % and Seed yield per plant, are presented in Table 2, Table 3 and Table 4 respectively. In sunflower, positive heterosis is desirable for studied traits, with the exception of hull content, where negative heterosis is preferred.

In table 1: For head diameter, average heterosis varied from -37.00 % to 12.78 %. The highest significant positive heterosis was observed in the cross CMS 10 x LT01 (12.78%) followed by CMS 10 x LT01 (12.13%). Heterobeltiosis for head diameter ranged -40.94% to 10.57%, recorded in CMS 10 x LT05 (10.57%) followed by CMS 82 x LT02. Standard heterosis ranged between -5.10 and 35.75% over best check KBSH-44, with CMS 10 x LT05 exhibiting the highest value (35.75%). Similar findings have been reported earlier. For 100-seed weight, CMS 10 x LT01 (12.78%) exhibited the highest positive average heterosis, followed by CMS 10 x LT05 (12.13%). The maximum heterobeltiosis was also recorded in CMS 10 x LT05 (10.57%), followed by CMS 82 x LT02 (5.86%). Standard heterosis over best check KBSH-44 for this trait ranged between -5.10 and 35.75%, with CMS 10 x LT05 (35.75%) and CMS 10 x LT05 (26.18%) recording the highest values. These observations corroborate earlier reports by Gangappa *et al*. (1997), Radhika *et al*. (2001) and Halaswamy *et al*. (2003) [4, 6].

In Table 2: For seed filling percentage, CMS 10 x LT05 (18.26%) showed the maximum average heterosis, while heterobeltiosis was highest in CMS 10 x LT04 (26.64%) and CMS 10 x LT04 (26.37%). These findings are in line with Madrap and Makne (1993), who reported high heterosis for this trait. In the case of hull content, significant negative heterosis was desirable and observed. CMS 82 x LT05 (-23.38%) showed the highest negative average heterosis, while CMS 82 x LT05 (-30.95%) and CMS 10 x LT05 (-19.52%) recorded the highest heterobeltiosis. The cross, CMS 852 x LT06 (-24.89%) also exhibited maximum negative standard heterosis, confirming its suitability for reducing hull content.

In Table 3: For oil content, average heterosis ranged from -15.24 to 14.59% and heterobeltiosis from -24.10 to 11.37%. CMS 82 x LT05 (14.59%) and CMS 10 x LT07 (12.93%) exhibited the highest positive average heterosis. The crosses CMS 82 x LT05 (11.37%) and CMS 82 x LT05 (10.54%) also showed the highest heterobeltiosis. Standard heterosis ranged from -8.65 to 18.94%, CMS 112 x LT02 (18.94%), CMS 82 x LT01 (10.22%) and CMS 82 x LT06 (15.65%) showing significant positive heterosis over best check KBSH-44. These results are supported by earlier findings of Nehru *et al*. (2000) and Dudhe (2004). For seed yield per plant, average heterosis ranged from -70.08 to 19.74%, with the highest values in CMS 10 x LT05 (19.74%), CMS 82 x LT07 (17.08%) and CMS 852 x LT04 (14.24%). Heterobeltiosis ranged from -74.09 to 15.93%, with maximum values recorded in CMS 10 x LT05 (15.93%) and CMS 852 x LT01 (6.26%). Standard heterosis ranged from -45.36 to 46.64%, with the highest value in CMS 112 x LT02 (46.64%), followed by CMS 10 x LT05 (38.00%). These results are consistent with earlier reports (Madrap and Makne, 1993; Nehru *et al*., 2000; Phad *et al*., 2002; Singh and Singh, 2003; Vishwanath, 2003; Dudhe, 2004; Ahmad *et al*., 2005; Patil, 2005; Anwar *et al*., 2006; Patil *et al*., 2007; Misal, 2009; Dutta *et al*., 2011).

Table 1: Heterosis (%) over mid parent (MP), better parent (BP) and standard checks of head diameter and 100 Seed Weight (g)

Sr. No	Hybrids	Head Diameter (cm)					100 Seed Weight (g)				
		MP	BP	LSFH-171	KBSH-44	KBSH-90	MP	BP	LSFH-171	KBSH-44	KBSH-90
1	CMS 148 x LT01	-22.44 **	-31.99 **	-8.24	4.39	2.37	-6.00	-16.32 **	0.13	-9.29	-3.63
2	CMS 148 x LT02	-21.02 **	-27.06 **	-14.04 *	-2.21	-4.11	-15.31 **	-17.66 **	-17.92 **	-25.65**	-21.00 **
3	CMS 148 x LT03	-0.41	-9.78	-5.91	7.04	4.96	3.54	-5.26	0.39	-9.06	-3.37
4	CMS 148 x LT04	-22.09 **	-31.75 **	-2.68	10.72	8.57	12.34 **	10.73	3.64	-6.12	-0.25
5	CMS 148 x LT05	-37.00 **	-40.94 **	-4.31	8.86	6.75	-34.36 **	-36.97 **	-4.81	-13.76 *	-8.38
6	CMS 148 x LT06	-19.21 **	-22.79 **	-3.58	9.69	7.56	-15.38 **	-15.44 *	4.42	-5.41	0.50
7	CMS 148 x LT07	-27.72 **	-33.53 **	-8.76	3.80	1.78	-23.71 **	-32.19 **	-14.81 **	-22.82**	-18.00 **
8	CMS 112 x LT01	-30.84 **	-33.03 **	-0.52	13.17	10.97	-23.70 **	-25.98 **	19.48 **	8.24	15.00 *
9	CMS 112 x LT02	4.11	1.51	1.98	16.01 *	13.77	5.40	-0.98	22.73 **	11.18	18.12 **
10	CMS 112 x LT03	-21.43**	-21.79 **	-1.53	12.02	9.85	-25.18 **	-25.18 **	-5.71	-14.59 *	-9.25
11	CMS 112 x LT04	-34.11 **	-36.26 **	0.35	14.16	11.94	-16.15 **	-22.25 **	-0.26	-9.65	-4.00

12	CMS 112 x LT05	-31.33 **	-34.09 **	3.51	17.75 *	15.47 *	-18.50 **	-28.12 **	18.31 **	7.18	13.88 *
13	CMS 112 x LT06	-20.44 **	-25.11 **	-1.49	12.06	9.89	-15.89 **	-22.98 **	0.65	-8.82	-3.13
14	CMS 112 x LT07	-9.64	-11.50 **	0.80	14.67	12.45	-8.81	-11.68 **	10.91	0.47	6.75
15	CMS COSF-6 x LT01	-20.47 **	-22.35 **	-6.71	6.13	4.07	-19.39 **	-27.36 **	-9.74	-18.24**	-13.13 *
16	CMS COSF-6 x LT02	-7.74	-10.78	14.70 *	30.49 **	27.96 **	9.10 ns	7.51	12.21	1.65	8.00
17	CMS COSF-6 x LT03	-6.51	-7.71	-1.88	11.63	9.46	5.28 ns	-2.44	-3.90	-12.94 *	-7.50
18	CMS COSF-6 x LT04	-11.55 *	-13.73 *	-1.18	12.42	10.24	4.94	4.86	-2.60	-11.76 *	-6.25
19	CMS COSF-6 x LT05	-3.96	-8.57	2.82	16.96 *	14.70	21.54 **	15.19 *	-14.81 *	-22.82**	-18.00 **
20	CMS COSF-6 x LT06	-7.36	-13.48 *	5.42	19.93 *	17.60 *	-4.79	-6.02	11.04	0.59	6.88
21	CMS COSF-6 x LT07	-2.88	-5.67	-4.17	9.02	6.90	17.12 **	5.38	-26.62 **	-33.53**	-29.37 **

*and ** indicated significance at 5 and 1 percent level, respectively

Sr. No	Hybrids	Head Diameter (cm)					100 Seed Weight (g)				
		MP	**BP**	**LSFH-171**	**KBSH-44**	**KBSH-90**	**MP**	**BP**	**LSFH-171**	**KBSH-44**	**KBSH-90**
22	CMS 852 x LT01	-11.33 *	-14.54 **	-2.68	10.72	8.57	0.00	-7.35	2.47	-7.18	-1.38
23	CMS 852 x LT02	-9.59	-17.48 **	-7.61	5.10	3.06	-16.50 **	-28.82 **	-16.75 *	-24.59**	-19.87**
24	CMS 852 x LT03	-9.63	-15.90 **	4.28	18.62 *	16.32 *	-16.43 **	-24.71 **	19.48 **	8.24	15.00 *
25	CMS 852 x LT04	-10.08 *	-13.25 *	-10.78	1.50	-0.47	5.99	-10.69 *	-0.26	-9.65	-4.00
26	CMS 852 x LT05	-8.23	-17.45 **	-8.48	4.11	2.09	-5.78	-24.02 **	-14.94 *	-22.94**	-18.12**
27	CMS 852 x LT06	-4.39	-15.53 **	-5.01	8.07	5.97	0.47	-16.27 **	18.44 **	7.29	14.00 *
28	CMS 852 x LT07	-14.70 **	-21.82 **	-7.68	5.02	2.99	-26.57 **	-31.86 **	2.60	-7.06	-1.25
29	CMS 10 x LT01	12.78 *	3.61	6.57	21.23 **	18.88 *	10.20 *	-0.69	20.78 **	9.41	16.25 *
30	CMS 10 x LT02	2.64	-0.39	-16.58 *	-5.10	-6.94	4.45	2.92	-11.82	-20.12**	-15.13 *
31	CMS 10 x LT03	1.12	-3.82	3.68	17.95 *	15.66 *	-1.06	-8.31	6.23	-3.76	2.25
32	CMS 10 x LT04	0.99	-7.30	5.46	19.97 *	17.64 *	-6.08	-6.15	-9.35	-17.88**	-12.75 *
33	CMS 10 x LT05	12.13 *	10.57	19.33 **	35.75 **	33.11 **	29.25 **	22.49 **	32.47 **	20.00 **	27.50 **
34	CMS 10 x LT06	4.04	3.37	-7.30	5.46	3.41	-18.00 **	-19.05 **	-9.35	-17.88**	-12.75 *
35	CMS 10 x LT07	1.32	-2.10	-2.68	10.72	8.57	0.45	-9.62	-5.84	-14.71 *	-9.38
36	CMS 82 x LT01	-11.18 *	-16.55 **	10.71	25.94 **	23.50 **	-19.62 **	-26.32 **	12.99 *	2.35	8.75
37	CMS 82 x LT02	6.50	5.86	-1.49	12.06	9.89	27.42 **	26.90 **	-6.62	-15.41 *	-10.12
38	CMS 82 x LT03	-10.81	-13.16 *	2.75	16.88 *	14.62	-0.45	-6.11	6.23	-3.76	2.25
39	CMS 82 x LT04	-12.10 *	-17.49 **	10.91	26.18 **	23.73 **	-8.01	-9.66	-9.22	-17.76**	-12.62 *
40	CMS 82 x LT05	-1.39	-2.39	-4.66	8.46	6.36	35.11 **	25.79 **	-18.83 **	-26.47**	-21.88**
41	CMS 82 x LT06	-2.23	-5.14	-8.48	4.11	2.09	12.46 *	8.97	-11.69	-20.00**	-15.00 *
42	CMS 82 x LT07	8.34	7.20	-0.59	13.09	10.90	16.40 **	6.53	13.38 *	2.71	9.13

*and ** indicated significance at 5 and 1 percent level, respectively

Table 2: Heterosis (%) over mid parent (MP), better parent (BP) and standard checks (SC) of Seed Filling (%) and Hull content (%)

Sr. No	Hybrids	Seed Filling (%)					Hull content (%)				
		MP	**BP**	**LSFH-171**	**KBSH-44**	**KBSH-90**	**MP**	**BP**	**LSFH-171**	**KBSH-44**	**KBSH-90**
1	CMS 148 x LT01	-30.91 **	-36.42 **	-14.23**	-4.10	-8.33**	16.51 **	11.79 **	-1.27	-0.48	-1.99
2	CMS 148 x LT02	-37.88 **	-42.70 **	-19.05**	-9.49**	-13.48**	8.87 **	3.63	-7.27 *	-6.53 *	-7.94 **
3	CMS 148 x LT03	-27.32 **	-32.83 **	-12.76**	-2.46	-6.76*	0.01	-0.38	-9.74 **	-9.02 **	-10.40 **
4	CMS 148 x LT04	-28.97 **	-33.28 **	-11.41**	-0.94	-5.31	15.82 **	11.70 **	-6.33 *	-5.58	-7.01 *
5	CMS 148 x LT05	-45.12 **	-46.03 **	-16.21**	-6.31	-10.45**	11.31 **	1.87	-12.13**	-11.42**	-12.76 **
6	CMS 148 x LT06	-40.00 **	-40.23 **	-16.12**	-6.21	-10.35**	16.37 **	14.21 **	-8.17 **	-7.44 *	-8.84 **
7	CMS 148 x LT07	-42.15 **	-43.78 **	-18.46**	-8.82**	-12.85**	22.02 *	19.37 **	3.86	4.69	3.10
8	CMS 112 x LT01	-20.64 **	-23.29 **	-2.17	9.39**	4.56	5.94 *	-3.17	-17.55**	-16.89**	-18.15 **
9	CMS 112 x LT02	-7.35 **	-10.24 **	11.72**	24.92**	19.40**	-12.06 **	-12.19**	-12.55**	-11.85**	-13.19 **
10	CMS 112 x LT03	-44.19 **	-45.81 **	-5.61	5.55	0.88	27.47 **	21.61 **	6.55 **	7.41 **	5.78 *
11	CMS 112 x LT04	-37.49 **	-44.01 **	-14.80**	-4.73	-8.94**	0.62	-0.90	1.60	2.42	0.87
12	CMS 112 x LT05	-41.57 **	-43.56 **	8.48**	21.29**	15.94**	16.34 **	11.79 **	1.89	2.70	1.15
13	CMS 112 x LT06	-39.33 **	-42.13 **	-13.69**	-3.49	-7.75*	27.65 **	23.54 **	-11.52**	-10.81**	-12.16 **
14	CMS 112 x LT07	-16.97 **	-18.86 **	3.91	16.19**	11.05**	0.69	-2.25	-7.98 **	-7.25 *	-8.65 **

15	CMS COSF-6 x LT01	-24.57 **	-28.53 **	-19.03**	-9.46**	-13.46**	1.66	-6.15	-4.78	-4.02	-5.47
16	CMS COSF-6 x LT02	-18.51 **	-22.61 **	3.44	15.66**	10.55**	-9.51 **	-10.36**	-11.95 **	-11.25**	-12.59 **
17	CMS COSF-6 x LT03	-17.06 **	-21.07 **	-9.26**	1.46	-3.02	-1.67	-5.20	-10.90 **	-10.19**	-11.55 **
18	CMS COSF-6 x LT04	-9.44 **	-17.35 **	-15.48**	-5.49	-9.66**	-10.68 **	-11.07**	-10.08 **	-9.36 **	-10.73 **
19	CMS COSF-6 x LT05	-16.06 **	-17.26 **	-10.62**	-0.06	-4.47	-11.87 **	-16.19**	-7.36 *	-6.62 *	-8.04 **
20	CMS COSF-6 x LT06	-17.35 **	-19.57 **	5.11	17.53**	12.34**	7.45 **	5.11	-11.82 **	-11.12**	-12.46 **
21	CMS COSF-6 x LT07	-3.27	-3.50	-36.25**	-28.72**	-31.87**	-14.97 **	-16.56**	-3.70	-2.93	-4.40

*and ** indicated significance at 5 and 1 percent level, respectively

Sr. No	Hybrids	Seed Filling (%)					Hull content (%)				
		MP	BP	LSFH-171	KBSH-44	KBSH-90	MP	BP	LSFH-171	KBSH-44	KBSH-90
22	CMS 852 x LT01	-1.45	-1.54	-0.24	11.55**	6.62**	-5.56	-13.91 **	-12.71 **	-12.01**	-13.34**
23	CMS 852 x LT02	-16.53 **	-16.81 **	-3.74	7.63**	2.88	5.37 *	4.91	-10.63 **	-9.92 **	-11.28**
24	CMS 852 x LT03	-24.50 **	-24.91 **	8.37**	21.18**	15.82**	5.14	0.03	-11.92 **	-11.21**	-12.56**
25	CMS 852 x LT04	10.06 **	-4.39	-15.55**	-5.57	-9.74**	2.13	0.31	-18.01 **	-17.36**	-18.61**
26	CMS 852 x LT05	-18.55 **	-23.93 **	-3.11	8.34*	3.55	-16.19 **	-19.25 **	-2.51	-1.73	-3.21
27	CMS 852 x LT06	-0.75	-8.42 **	-14.04**	-3.88	-8.13*	-6.14 *	-9.41 **	-24.35 **	-23.74**	-24.89**
28	CMS 852 x LT07	-24.45 **	-28.63 **	-11.56**	-1.11	-5.48	-3.17	-6.25	-15.81 **	-15.13**	-16.42**
29	CMS 10 x LT01	7.44 **	-8.67 **	5.96*	18.48**	13.24**	4.22	3.16	-8.94 **	-8.21 **	-9.60 **
30	CMS 10 x LT02	-5.48 *	-19.50 **	-4.79	6.46*	1.76	-4.21	-11.51 **	-9.01 **	-8.29 **	-9.67 **
31	CMS 10 x LT03	-11.74 **	-24.69 **	5.70	18.19**	12.97**	1.58	-1.94	1.00	1.81	0.27
32	CMS 10 x LT04	9.71 **	6.84 *	1.38	13.36**	8.35**	1.07	-5.43	-1.19	-0.40	-1.91
33	CMS 10 x LT05	18.26 **	6.74 *	13.46**	26.87**	21.27**	-9.53 **	-19.52 **	1.57	2.38	0.84
34	CMS 10 x LT06	-27.24 **	-33.55 **	-20.71**	-11.34**	-15.26**	7.09 *	1.91	-14.65 **	-13.97**	-15.27**
35	CMS 10 x LT07	10.74 **	-1.12	8.96**	21.83**	16.45**	-3.26	-8.23 **	-12.09 **	-11.39**	-12.73**
36	CMS 82 x LT01	-13.36 **	-15.01 **	13.26**	26.64**	21.05**	4.20	1.66	-16.38 **	-15.71**	-16.98**
37	CMS 82 x LT02	-2.22	-3.85	12.71**	26.03**	20.47**	-6.59 *	-12.52**	0.68	1.49	-0.05
38	CMS 82 x LT03	-23.64 **	-24.75 **	12.24**	25.50**	19.95**	-8.70 **	-10.59 **	-8.30 **	-7.57 *	-8.96 **
39	CMS 82 x LT04	0.60	-11.08 **	-16.34**	-6.46*	-10.59**	-4.91	-0.47	-2.05	-1.26	-2.76
40	CMS 82 x LT05	-17.12 **	-21.11 **	-1.52	10.11**	5.25	-23.38 **	-30.95 **	9.57 **	10.45 **	8.78 **
41	CMS 82 x LT06	-13.67 **	-18.83 **	-4.06	7.27**	2.53	-7.68 *	-10.90 **	-5.51	-4.75	-6.19 *
42	CMS 82 x LT07	0.98	-2.75	0.90	12.82**	7.84*	-0.49	-4.25	-4.89	-4.13	-5.58

Table 3: Heterosis (%) over mid parent (MP), better parent (BP) and standard checks (SC) of Oil content (%) and Seed Yield per plant (g)

Sr. No	Hybrids	Oil content (%)					Seed Yield per plant (g)				
		MP	BP	LSFH-171	KBSH-44	KBSH-90	MP	BP	LSFH-171	KBSH-44	KBSH-90
1	CMS 148 x LT01	-11.19 **	-15.84 **	-4.11 *	-2.50	-9.43 **	-49.45 **	-58.69 **	-32.28 **	-33.95**	-21.97 *
2	CMS 148 x LT02	-9.95 **	-11.84 **	0.53	2.22	-5.05 *	-56.49 **	-64.88 **	-47.63 **	-48.92**	-39.66 **
3	CMS 148 x LT03	-5.78 **	-9.96 **	3.37	5.11 *	-2.36	-34.25 **	-46.09 **	-52.58 **	-53.75**	-45.36 **
4	CMS 148 x LT04	-14.19 **	-16.80 **	1.86	3.57	-3.78	-53.44 **	-56.50 **	-29.64 **	-31.38**	-18.93 *
5	CMS 148 x LT05	-11.46 **	-12.12 **	-10.16**	-8.65 **	-15.14**	-66.74 **	-69.88 **	-32.64 **	-34.30**	-22.38 **
6	CMS 148 x LT06	-14.27 **	-18.54 **	-3.37	-1.75	-8.73 **	-54.81 **	-57.25 **	-38.50 **	-40.02**	-29.14 **
7	CMS 148 x LT07	-5.81 **	-10.59 **	-2.50	-0.86	-7.90 **	-61.64 **	-68.91 **	-48.63 **	-49.90**	-40.81 **
8	CMS 112 x LT01	-3.85 *	-14.53 **	-0.42	1.25	-5.94 **	-40.95 **	-40.98 **	-4.38	-6.74	10.17
9	CMS 112 x LT02	3.76 *	-4.94 **	16.98 **	18.94 **	10.49 **	-15.07 **	-16.49 **	27.96 **	24.12 **	46.64 **
10	CMS 112 x LT03	-12.31 **	-21.45 **	3.37	5.11 *	-2.36	-64.87 **	-64.99 **	-26.98 **	-28.78**	-15.86
11	CMS 112 x LT04	-3.77 *	-12.64 **	-3.41	-1.79	-8.76 **	-57.81 **	-63.47 **	-17.33 *	-19.37**	-4.74
12	CMS 112 x LT05	-7.09 **	-12.58 **	-3.66	-2.04	-9.00 **	-70.08 **	-73.33 **	14.28	11.46	31.67 **
13	CMS 112 x LT06	-15.24 **	-24.10 **	12.76 **	14.65 **	6.51 **	-69.74 **	-74.09 **	-22.68 **	-24.59**	-10.91
14	CMS 112 x LT07	4.80 *	3.06	7.07 **	8.86 **	1.13	-38.97 **	-39.65 **	-5.73	-8.06	8.62
15	CMS COSF-6 x LT01	-5.98 **	-13.07 **	7.21 **	9.01 **	1.26	-50.69 **	-52.33 **	-36.99 **	-38.54**	-27.40 **
16	CMS COSF-6 x LT02	0.22	-4.36 *	9.81 **	11.65 **	3.72	-56.10 **	-58.23 **	2.75	0.22	18.40 *
17	CMS COSF-6 x LT03	-3.83 *	-10.36 **	-0.67	1.00	-6.18 **	-33.47 **	-35.44 **	-14.92 *	-17.02 *	-1.97
18	CMS COSF-6 x LT04	-13.81 **	-18.52 **	7.38 **	9.19 **	1.43	-26.31 **	-34.31 **	-22.34 **	-24.26**	-10.52
19	CMS COSF-6 x LT05	-3.48 *	-5.27 **	-1.76	-0.11	-7.20 **	-34.74 **	-40.03 **	-27.01 **	-28.81**	-15.90

20	CMS COSF-6 x LT06	-7.99 **	-14.28 **	12.62 **	14.51 **	6.37 **	-43.15 **	-14.80 *	-0.37	-2.83	14.79
21	CMS COSF-6 x LT07	4.14 *	1.40	2.32	4.04	-3.35	-10.96 *	-14.80 *	-39.77 **	-41.26**	-30.60 **

*and ** indicated significance at 5 and 1 percent level, respectively

Sr. No	Hybrids	Oil content (%)					Seed Yield per plant (g)				
		MP	BP	LSFH-171	KBSH-44	KBSH-90	MP	BP	LSFH-171	KBSH-44	KBSH-90
22	CMS 852 x LT01	8.17 **	1.16	9.77 **	11.62 **	3.69	10.84 *	6.26	-14.50 *	-16.61 *	-1.48
23	CMS 852 x LT02	-0.94	-4.36 *	11.14 **	13.01 **	4.98 *	-37.40**	-39.03 **	-24.72 **	-26.58**	-13.26
24	CMS 852 x LT03	-9.84 **	-15.00 **	6.50 **	8.29 **	0.60	-27.72**	-30.97 **	-4.89	-7.24	9.59
25	CMS 852 x LT04	-8.63 **	-12.62 **	8.15 **	9.97 **	2.16	14.24 *	-4.59	-30.23 **	-31.95**	-19.60 *
26	CMS 852 x LT05	11.29 **	10.54 **	4.99 *	6.75 **	-0.83	-24.83**	-35.44 **	-21.19 **	-23.13**	-9.19
27	CMS 852 x LT06	-0.11	-5.87 **	13.60 **	15.51 **	7.30 **	-4.75	-21.29 **	-30.66 **	-32.37**	-20.10 *
28	CMS 852 x LT07	10.71 **	6.53 **	10.09 **	11.94 **	3.98 *	-45.68**	-47.39 **	-24.47 **	-26.33**	-12.97
29	CMS 10 x LT01	-1.20	-5.05 **	-9.60 **	-8.08 **	-14.61**	7.97	-6.47	15.07 *	12.23	32.59 **
30	CMS 10 x LT02	-5.15 **	-8.10 **	3.55	5.29 *	-2.19	-12.28**	-25.05 **	-30.29 **	-32.01**	-19.67 *
31	CMS 10 x LT03	-0.11	-5.51 **	-10.05 **	-8.54 **	-15.04**	-18.02**	-28.74 **	9.73	7.02	26.43 **
32	CMS 10 x LT04	-7.16 **	-10.90 **	-1.79	-0.14	-7.24 **	-9.20	-9.30	2.54	0.01	18.16 *
33	CMS 10 x LT05	10.75 **	10.41 **	0.63	2.32	-4.95 *	19.74 **	15.93 *	19.77 **	16.81 *	38.00 **
34	CMS 10 x LT06	-4.87 **	-10.04 **	1.37	3.07	-4.25 *	-24.07**	-25.16 **	-19.53 **	-21.51**	-7.28
35	CMS 10 x LT07	12.93 **	8.29 **	-3.73	-2.11	-9.06 **	-11.26	-23.81 **	-15.67 *	-17.75 *	-2.83
36	CMS 82 x LT01	4.89 **	3.89	15.64 **	17.58 **	9.23 **	-22.47**	-31.48 **	9.86	7.15	26.59 **
37	CMS 82 x LT02	4.23 *	-1.46	8.08 **	9.90 **	2.09	-3.86	-16.21 **	13.51	10.71	30.79 **
38	CMS 82 x LT03	3.05	-4.83 **	13.64 **	15.55 **	7.34 **	-27.81**	-35.97 **	8.98	6.29	25.57 **
39	CMS 82 x LT04	1.67	-4.78 *	10.26 **	12.12 **	4.15 *	-4.25	-6.55	-19.71 **	-21.69**	-7.48
40	CMS 82 x LT05	14.59 **	11.37 **	2.00	3.72	-3.65	-18.55**	-19.31 *	-14.07	-16.19 *	-0.98
41	CMS 82 x LT06	4.84 **	-3.21	13.74 **	15.65 **	7.44 **	-7.03	-10.43	-21.83 **	-23.76**	-9.93
42	CMS 82 x LT07	-4.49 *	-6.10 **	-6.96 **	-5.40 *	-12.12**	17.08 **	2.53	12.23	9.46	29.31 **

Conclusion

Overall, cytoplasmic male sterile lines and restorers were utilized in a line × tester mating design to estimate heterosis. Significant positive heterosis, heterobeltiosis, and standard heterosis were observed for yield and its related traits across several hybrids. Five crosses CMS-112A × LT-02 CMS-10A × LT-05 CMS-10A × LT-01 CMS-82A × LT-02 CMS-82A × LT-05 recorded highly significant standard heterosis for yield and yield-contributing characters.CMS 10A × LT05 consistently showed superiority for head diameter, 100-seed weight, and seed yield per plant. For oil content, five hybrids CMS 82 x LT01, CMS 82 x LT05, CMS 82 x LT06, CMS 10 x LT07 and CMS 112 x LT02 recorded significant positive heterosis. On the basis of mean performance, heterosis, heterobeltiosis and standard heterosis, the hybrids CMS-112A × LT-02 CMS-10A × LT-05 CMS-82A × LT-01 CMS-82A × LT-05 CMS-82A × LT-07 were identified as promising crosses for further evaluation and potential commercial exploitation.

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