Original Research Article

**Study of Combining Ability and Gene Action for Seed Yield in Sunflower (*Helianthus annuus* L.) using Line x Tester Analysis**

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ABSTRACT

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| The choice of suitable parental lines is vital in crop improvement programs, as the performance of the resulting hybrids reflects their relative advantages. Therefore, selecting parents with strong combining ability is a key component in the success of any breeding effort. A study was undertaken to assess the extent of heterosis and combining ability in sunflower using six cytoplasmic male sterile (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. Observations were recorded for ten agronomic traits, including days to 50% flowering, days to maturity, plant height, head diameter, seed filling percentage, 100-seed weight, volume weight, hull content, oil content and seed yield per plant. Among the female lines, CMS-82A exhibited significant GCA effects for days to 50% flowering, seed filling percentage, volume weight, hull content and oil content, whereas CMS-852A was found to be a strong general combiner for seed yield per plant, oil content and seed filling percentage. Among the male lines, LT-02 showed favorable GCA for days to 50% flowering, head diameter, seed filling percentage, hull content, oil content and seed yield per plant. LT-07 also emerged as a promising general combiner for days to 50% flowering, seed filling percentage, 100-seed weight, volume weight, hull content, oil content and seed yield. LT-01 was specifically identified for its strong GCA for seed yield. Notable hybrids with significant SCA effects for seed yield and other desirable traits included CMS-112A × LT-02 and CMS-10A × LT-05. These crosses exhibited Specific combining ability (SCA) variance that was greater than general combining ability (GCA) variance for all the studied traits, indicating the predominance of non-additive gene action in trait expression. Thus, the study confirms that utilizing parents with high GCA and selecting crosses with favorable specific combining ability (SCA) effects is an effective approach for evolving superior sunflower hybrids. |

*Keywords: Sunflower; line x tester; cross; general combining ability; specific combining ability*

1. INTRODUCTION

Sunflower (*Helianthus annuus L.; 2n = 2x = 34*) is 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 (Patel *et al*., 2023). 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 (Deshmukh *et al*., 2022).

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).

In recent decades, hybrid technology has driven significant progress in sunflower breeding. The utilization of *cytoplasmic male sterility (CMS)* systems along with compatible restorer lines has facilitated the development of high-yielding hybrids characterized by improved uniformity, oil quality and resistance to various diseases (Singh *et al*., 2021). The commercial release of hybrid sunflower cultivars began in the early 1970s and quickly gained momentum worldwide due to their superior agronomic performance. In India, hybrids now account for over 95% of total sunflower cultivation, with predominant production in states such as Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu (IIOR, 2024) The *Line × Tester mating design* remains a widely employed method in sunflower genetics to evaluate *general combining ability (GCA)* and *specific combining ability (SCA),* facilitating the identification of superior parental combinations for hybrid development (Rambilash *et al*., 2023). The present study focuses on assessing these combining abilities in sunflower for key yield-related traits.

2. 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 by Kempthorne (1957). A total of 42 hybrids, along with 13 parental lines and three standard checks (LSFH-171, KBSH-90and KBSH-44), were evaluated in a Randomized Complete Block Design (RCBD) with two replications, using 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) as described by Gomez and Gomez (1984). Combining ability analysis was carried out using the line × tester method to estimate general combining ability (GCA) and specific combining ability (SCA) effects. The nature of gene action was determined based on the ratio of GCA to SCA variances. All statistical analyses were performed using TNAUSTAT software (Manivannan, 2014).

3. results and discussion

The analysis of variances for combining ability revealed significant differences among treatments, parents, crosses and L x T for all the characters, indicating the presence of adequate variability in the experimental population, while parents vs crosses also showed significant differences for all the characters except hull content **(Table 1)**. Line × tester analysis revealed significant variance for all traits due to line effects and for most traits due to tester effects except head diameter and volume weight. Interactions between lines and testers were significant for all characters except plant height **(Table 2)**. General combining ability (GCA) effects were supported by significant mean squares for both lines and testers (Binodh *et al.*, 2008; Andarkhor *et al*., 2011; Jondhale *et al*., 2012; Choudhary 2018; Sharma and Shadakshari, 2021; Dhanalakshami *et al*., 2022.

Examination of general combining ability (GCA) estimates in Table 3, revealed that lines CMS-148A, CMS-112A and testers LT-02 and LT-07 had significant negative GCA effects for days to 50% flowering, indicating their usefulness in breeding for early flowering. This aligns with findings by Dhanalakshmi *et al*. (2022) and Ramaraju *et al*. (2021). For days to maturity, CMS-148A, CMS-82A and testers LT-03, LT-04 and LT-05 showed favorable GCA effects. CMS-148A, CMS-112A and LT-07 were superior for reducing plant height, supporting the results by Farrokhi *et al*. (2008). Positive GCA effects for head diameter were recorded in LT-02, CMS-852A, CMS-10A and CMS-82A. Seed filling percentage showed strong GCA effects in CMS-852A, CMS-10A, CMS-82A, CMS-COSF-6 A and testers LT-01, LT-02 and LT-07. Noteworthy GCA effect for 100-seed weight and volume weight were seen in CMS-852A, CMS-82A, CMS-10A, CMS-148A and LT-07 which is consistent with reports by Patil *et al*. (2012), Shinde *et al.* (2016). CMS-10A, CMS-82A, CMS-COSF-6A, LT-01 and LT-02 showed favorable GCA effects for hull and oil content, corroborating Kaya and Atakisi (2004). For seed yield per plant and oil content, the genotypes viz; CMS-852A, CMS-10A, CMS-82A, LT-01, LT-02, LT-05 and LT-07 were identified as excellent combiners, consistent with Shinde *et al*. (2016).

**In table 4**, Analysis of specific combining ability (SCA) effects identified several promising sunflower hybrids exhibiting significant and desirable performance across key traits. Negative SCA effects for days to 50% flowering, maturity, plant height and hull content were found beneficial, with crosses like CMS-10A × LT-02, CMS-COSF-6A × LT-01 and CMS-82A × LT-02 exhibiting favorable earliness (Kulkarni and Supriya, 2017).The hybrids such as, CMS-852A × LT-07 and CMS-82A × LT-02 also showed desirable SCA for early maturity, while CMS-COSF-6A × LT-04 and CMS-852A × LT-01 proved superior for reduced plant height. For head diameter, seed filling and volume weight, hybrids such as CMS-COSF-6A × LT-02, CMS-10A × LT-07 and CMS-148A × LT-04 exhibited positive SCA effects, which is consistent with reports by Vairam *et al.* (2016), Ghodekar *et al.* (2021). CMS-10A × LT-05, CMS-82A × LT-07 and CMS-COSF-6A × LT-02 showed strong SCA for 100-seed weight, aligning with Vairam *et al.* (2016) and Lakshman *et al.* (2021). Hull content and oil content were significantly improved in CMS-148A × LT-05, CMS-82A × LT-01 and CMS-112A × LT-02, corroborating findings by Nehru *et al.* (2021), Salem and Ali (2012) and Varalakshami and Neelima (2019). Exceptional yield performance was recorded in CMS-112A × LT-02, CMS-COSF-6A × LT-06 and CMS-82A × LT-07, with parental GCA combinations indicating both additive and non-additive gene action (Sujatha and Reddy, 2009; Sreedhar *et al.*, 2010). Top-performing hybrids showed superiority over commercial checks in seed yield, oil content, 100-seed weight and head diameter, supported by Rukminidevi *et al.* (2006), Ingle *et al.* (2017), Salke *et al.* (2018) and Kale *et al.* (2018). These findings reinforce the importance of GCA and SCA effects in developing heterotic hybrids with enhanced yield and quality traits (Kaya and Atakisi, 2004; Chandra *et al.*, 2013).

4. Conclusion

The study established significant GCA and SCA variances across key sunflower traits, confirming robust genetic diversity and hybrid potential. CMS-82A, CMS-852A, LT-02 and LT-07 are the good combiner. Hybrids like CMS-112A × LT-02 and CMS-82A × LT-07 consistently outperformed checks in yield and quality traits. The findings affirm that selecting parents with high × high or low × high GCA enables successful heterosis breeding through additive and non-additive gene action. Furthermore, the predominance of non-additive genetic effects reinforces the utility of selective intermating and recurrent selection approaches in capturing diverse gene actions and accelerating genetic gain in sunflower breeding programs.

**Table 1 : Analysis of variance for combing ability for different characters in sunflower**

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| **Source of variation** |
| **Characters**  | **Replication****MSS** | **Treatments****MSS** | **Parents****MSS** |  **Lines** **MSS** | **Tester****MSS** |  **Crosses****MSS** | **L x T** **MSS** | **Parents *v/s*****Crosses MSS** | **Error****MSS** |
| Days to 50 % flowering | 0.736 | 30.201\*\* | 8.153\*\* | 3.35\* | 13.404\*\* | 13.946\*\* | 7.52\*\* | 961.19\*\* | 1.032 |
| Days to maturity | 1.31 | 76.411\*\* | 7.05 \* | 0.133 | 4.904 \* | 46.196 \*\* | 2.679 | 2147.54 \*\* | 1.420 |
| Plant Height (cm) | 91.875 | 1090.411\*\* | 47.497 \*\* | 4.304 | 68.913 | 1382.75\*\* | 746.430\*\* | 1619.515\*\* | 78.349 |
| Head diameter (cm) | 0.49 | 7.004\* | 3.725\* | 6.220\* | 2.245 | 7.147\* | 10.078\*\* | 40.454\*\* | 0.859 |
| Seed Filling (%) | 16.83 | 373.028\*\* | 159.971\*\* | 192.35\*\* | 157.429\*\* | 349.231\*\* | 54.988 \* | 3905.406\*\* | 4.769 |
| 100-seed weight (g) | 0.017 | 0.680\*\* | 0.602\*\* | 0.854\*\* | 0.484\*\* | 0.711\*\* | 2.851\*\* | 0.325\* | 0.050 |
| Volume weight (g/100ml) | 0.327 | 13.791\*\* | 14.782\*\* | 5.283\* | 13.619\*\* | 12.897\*\* | 32.813\*\* | 38.569\*\* | 1.031 |
| Hull content (%) | 1.961 | 21.538\*\* | 10.687\*\* | 9.926\*\* | 12.720\*\* | 25.176\*\* | 0.001 | 2.608 | 0.979 |
| Oil content (%) | 1.120 | 10.138\*\* | 10.928\*\* | 3.765\*\* | 10.468\*\* | 9.862\*\* | 0.004 | 11.929\*\* | 0.333 |
| Seed yield /plant (g) | 2.377 | 156.666\*\* | 64.319\*\* | 82.597\*\* | 57.886\*\* | 144.901\*\* | 37.667\* | 1747.163\*\* | 4.839 |

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

**Table 2 : Analysis of variance for line** $×$ **tester sets for different characters in Sunflower**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sources of variation** | **d.f** | **Days to** **50 %****flowering** | **Days** **to maturity** | **Plant height****(cm)** | **Head diameter****(cm)** | **Seed Filling****(%)** | **100-Seed weight (g)** | **Volume weight****(g/100ml)** | **Hull content****(%)** | **Oil content****(%)** | **Seed yield / plant (g)** |
| **Replicates** | 1 | 0.42 | 0.29 | 149.68 | 0.61 | 13.44 | 0.0072 | 0.58 | 3.6 | 0.85 | 0.56 |
| **Crosses** | 41 | 36.43\*\* | 96.80\*\* | 282.96\*\* | 2.19\* | 178.25\*\* | 0.53\*\* | 9.19\*\* | 10.06\*\* | 8.63\*\* | 91.30\*\* |
| **Line effect** | 5 | 252.96\*\* | 618.21\*\* | 1316.53\*\* | 4.05\*\* | 474.55\*\* | 0.60\*\* | 27.90\* | 16.91\*\* | 28.96\*\* | 355.11\*\* |
| **Tester Effect** | 6 | 9.88\*\* | 59.63\*\* | 257.16\*\* | 1.27 |  206.14\*\* | 0.31\* | 2.70 | 15.42\*\* | 12.60\*\* | 38.71\* |
| **L x T Eff.** | 30 | 5.65\*\* | 17.33\*\* | 115.85 | 2.06\* | 123.29\*\* | 0.56\*\* | 7.36\*\* | 7.85\*\* | 4.45\*\* | 57.84\*\* |
| **Error** | 41 | 1.03 | 1.54 | 84.86 | 0.97 | 5.43 | 0.06 | 1.04 | 0.79 | 0.32 | 6.06 |
| **Estimates of variance components** |
| **σ2 GCA**  | 0.15 | 0.45 | 21.45 | 0.01 | 4.59 | 0.002 | 0.04 | 0.23 | 0.10 | 1.71 |
| **σ2 (SCA)** | 3.22 | 13.08 | 203.71 | 1.01 | 77.51 | 0.28 | 4.97 | 7.11 | 2.53 | 34.71 |
| **GCA/SCA** | 0.04 | 0.03 | 0.10 | 0.009 | 0.05 | 0.007 | 0.008 | 0.03 | 0.039 | 0.04 |

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

**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 | CMS-148A | -0.74\* | -2.27\*\* | -34.54\*\* | -2.63\*\* | -16.81\*\* | -0.50\*\* | -1.88\*\* | 2.92\*\* | -1.75\*\* | -9.85\*\* |
| 2 | CMS-112A | -0.74\* | -0.13 | -23.06\*\* | -1.39\*\* | -8.56\*\* | -0.34\*\* | -0.74\* | 3.61\*\* | -1.92\*\* | -5.54\*\* |
| 3 | CMS-COSF-6A | 0.55 | 2.65\*\* | 5.22\* | 0.49 | 1.68\*\* | 0.11 | -1.02\*\* |  -1.46\*\* | -0.67\*\* | -1.60\*\* |
| 4 | CMS-852A | 1.55\*\* | 2.73\*\* | 26.52\*\* | 1.24\*\* | 9.39\*\* | 0.36\*\* | 0.90\*\* | -0.08 | 1.40\*\* | 7.27\*\* |
| 5 | CMS-10A | 2.26\*\* | 2.94\*\* | 9.22\*\* | 1.57\*\* | 5.45\*\* | 0.04 | 1.55\*\* | -1.96\*\* | 1.36\*\* | 4.98\*\* |
| 6 | CMS-82A | -2.88\*\* | -5.92\*\* | 16.65\*\* | 0.72\*\* | 8.85\*\* | 0.32\*\* | 1.19\*\* | -3.03\*\* | 1.58\*\* | 4.74\*\* |
|  |  SE ± | 0.39 | 0.43 | 3.45 | 0.36 | 0.67 | 0.08 | 0.39 | 0.39 | 0.21 | 0.78 |
|  |  CD at 5 % | 0.78 | 0.87 | 6.93 | 0.73 | 1.36 | 0.16 | 0.78 | 0.79 | 0.44 | 1.57 |
| **Testers** |
| 7 | LT-01 | 1.95\*\* | 2.95\*\* | 1.74 | -0.03 | 6.19\*\* | 0.02 | 0.21 | -1.13\*\* | 1.40\*\* | 3.17\*\* |
| 8 | LT-02 | -0.80\* | 0.87\* | 9.64\*\* | 0.64\* | 5.55\*\* | 0.11 | 0.30 | -0.61\* | 0.26 | 1.35\* |
| 9 | LT-03 | 0.29 | -1.30\*\* | -3.25 | 0.33 | -3.49\*\* | 0.04 | 0.71\* | 0.14 | 0.02 | -0.75 |
| 10 | LT-04 | 0.79\* | -1.55\*\* | -1.84 | -0.13 | -0.51 | -0.05 | -0.45 | 0.57 | -1.31\*\* | -0.14 |
| 11 | LT-05 | -0.05 | -0.96\*\* | -4.61 | -0.61\* | -4.15\*\* | -0.05 | -1.79\*\* | -0.02 | 0.51\*\* | -2.68\*\* |
| 12 | LT-06 | -0.30 | -0.63 | -7.08\*\* | -0.41 | -6.55\*\* | -0.30\*\* | -0.04 | 1.60\*\* | -0.43\* | -3.78\*\* |
| 13 | LT-07 | -1.88\*\* | 0.62 | 5.40\* | 0.21 | 2.94\*\* | 0.23\*\* | 1.05\*\* | -0.54 | -0.46\*\* | 2.83\*\* |
|  | SE ± | 0.42 | 0.46 | 3.72 | 0.39 | 0.73 | 0.08 | 0.42 | 0.42 | 0.23 | 0.84 |
|  | CD at 5 % | 0.84 | 0.94 | 7.49 | 0.79 | 1.47 | 0.17 | 0.84 | 0.86 | 0.47 | 1.70 |

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

**Table 4 : Estimation of specific combining ability for ten characters in sunflower (*Helianthus annuus* L.)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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** |
| 1 | CMS 148 x LT01 | -0.88 | -0.35 | -5.48 | -0.38 | -0.93 | -0.11 | 0.43 | 2.38 \*\* | -0.4 | 1.13 |
| 2 | CMS 148 x LT02 | -1.05 | 0.74 | 6.79 | -0.68 | -7.04\*\* | -0.39\* | -2.32 \*\* | -0.08 | -0.58 | -4.23 \* |
| 3 | CMS 148 x LT03 | 0.79 | -2.35\* | -1.99 | -0.1 | -1.77 | 0.05 | 0.01 | -1.78 \*\* | 1.84 \*\* | -4.68 \*\* |
| 4 | CMS 148 x LT04 | 1.04 | -1.68 | -4.06 | 0.35 | 8.81\*\* | 0.44\* | 0.26 | -0.56 | 1.11 \*\* | 4.99 \*\* |
| 5 | CMS 148 x LT05 | -0.55 | -2.18\* | -8.87 | -0.03 | -3.44\* | 0.01 | -0.99 | -3.81 \*\* | -0.87 \* | 0.88 |
| 6 | CMS 148 x LT06 | 1.2 | 3.32\*\* | 1.63 | 0.76 | 3.86\* | 0.26 | 2.10 \*\* | 0.96 | -1.72 \*\* | 2.97 |
| 7 | CMS 148 x LT07 | -0.55 | 2.49\*\* | 11.99 | 0.08 | 0.51 | -0.26 | 0.51 | 2.89 \*\* | 0.63 | -1.06 |
| 8 | CMS 112 x LT01 | 0.4 | 1.44 | 4.94 | -0.31 | -2.26 | 0.11 | -2.00 \*\* | -2.82 \*\* | -1.27 \*\* | -1.31 |
| 9 | CMS 112 x LT02 | -0.26 | 0.02 | -3.41 | 0.58 | 6.65\*\* | 0.65\*\* | 2.25 \*\* | -1.82 \*\* | 2.18 \*\* | 9.04 \*\* |
| 10 | CMS 112 x LT03 | -0.93 | -0.56 | -5.74 | -0.51 | -7.05\*\* | -0.71\*\* | -0.92 | 3.29 \*\* |  -0.08 | -7.89 \*\* |
| 11 | CMS 112 x LT04 | 2.23\*\* | 2.11\* | 12.36 | -0.25 | -4.95\*\* | -0.24 | -1.17 | 1.87 \*\* | -2.31 \*\* | -2.65 |
| 12 | CMS 112 x LT05 | -0.76 | -0.89 | -2.9 | 0.05 | 5.36\*\* | 0.38\* | 0.08 | 0.54 | -0.93 \* | 4.80 \*\* |
| 13 | CMS 112 x LT06 | -1.51\* | -3.39\*\* | -4.25 | 0.02 | -5.21\*\* | -0.40\* | 0.17 | -0.16 | 0.96 \* | -3.50 \* |
| 14 | CMS 112 x LT07 | 0.74 | 1.27 | -1 | 0.41 | 7.45\*\* | 0.21 | 1.58 \* | -0.91 | 1.44 \*\* | 1.52 |
| 15 | CMS COSF-6 x LT01 | -2.45\*\* | -0.7 | 9.78 | -1.32 | -7.78\*\* | -0.46\* | 1.79 \* | 2.15 \*\* | 0.73 | -7.28 \*\* |
| 16 | CMS COSF-6 x LT02 | 1.88\* | 0.88 | 10.67 | 2.29\*\* | 8.03\*\* | 0.80\*\* | 0.04 | -0.68 | -0.03 | 5.77 \*\* |
| 17 | CMS COSF-6 x LT03 | -0.29 | 0.8 | 5.11 | -0.68 | -1.96 | -0.09 | 1.37 | -1.26 | -1.40 \*\* | 1.06 |
| 18 | CMS COSF-6 x LT04 | 0.96 | -2.54\*\* | -12.8 | -0.6 | 2.54 | 0.23 | 1.12 | -0.86 | 0.59 | 0.59 |
| 19 | CMS COSF-6 x LT05 | 0.88 | -1.04 | -3.49 | -0.17 | -1.95 | -0.34 | -0.13 | -1.43 \* | -0.56 | -4.08 \*\* |
| 20 | CMS COSF-6 x LT06 | -0.87 | -0.04 | -1.59 | 0.89 | 17.91\*\* | 0.55\*\* | -0.05 | 0.69 | 0.74 | 8.87 \*\* |
| 21 | CMS COSF-6 x LT07 | -0.12 | 2.63\*\* | -7.71 | -0.42 | -16.79\*\* | -0.68\*\* | -4.13 \*\* | 1.39 \* | -0.08 | -4.94 \*\* |
| 22 | CMS 852 x LT01 | -0.45 | 4.58\*\* | -11 | 0.22 | 2.47 | -0.24 | 0.21 | 1.24 | 0.35 | 0.81 |
| 23 | CMS 852 x LT02 |  2.88\*\* | 5.17\*\* | 2.4 | 0.05 | -2.59 | -0.57\*\* | -1.54 \* | 1.33\* | -0.76 | -2.84 |

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

**Table 4 : Continued…**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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** |
| 24 | CMS 852 x LT03 | 1.21 | 2.08\* | 7.51 | 1.17 | 7.36\*\* | 0.56\*\* | -1.70 \* | 0.01 | -0.47 | 4.99 \*\* |
| 25 | CMS 852 x LT04 | -1.54\* | -1.25 | -3.89 | -1.01 | -2.36 | 0.07 | 1.55 \* | -1.77 \*\* | -0.3 | -1.47 |
| 26 | CMS 852 x LT05 | 0.38 | 0.75 | -2.98 | -0.83 | -0.77 | -0.60\*\* | 0.8 | 1.69 \*\* | 0.24 | -1.56 |
| 27 | CMS 852 x LT06 | -0.87 | -3.25\*\* | 7.52 | 0.36 | -2.32 | 0.58\*\* | -0.62 | -1.67 \* | -0.09 | -0.68 |
| 28 | CMS 852 x LT07 | -1.62\* | -8.08\*\* | 0.42 | 0.04 | -1.8 | 0.19 | 1.3 | -0.83 | 1.02 \* | 0.75 |
| 29 | CMS 10 x LT01 | 0.33 | -2.99\*\* | -2.95 | 0.6 | 1.73 | 0.40\* | 0.36 | 0.06 | -1.75 \*\* | 4.37 \* |
| 30 | CMS 10 x LT02 | -2.33\* | -3.40\*\* | -7.54 | -2.20\*\* | -9.14\*\* | -0.44\* | -3.39 \*\* | -0.53 | 0.49 | -11.01 \*\* |
| 31 | CMS 10 x LT03 | 0.5 | 0.01 | -1.8 | 0.13 | -0.5 | -0.01 | 2.44 \*\* | 1.71 \*\* | -1.77 \*\* | 3.56 \* |
| 32 | CMS 10 x LT04 | -0.75 | 3.18\*\* | 6.24 | 0.37 | 5.52\*\* | -0.35 | -0.81 | 1.16 | 0.28 | 3.17 |
| 33 | CMS 10 x LT05 | 1.17 | 2.18\* | 6.32 | 2.22\*\* | 6.83\*\* | 1.16\*\* | -0.06 | 0.61 | 2.41 \*\* | 5.81 \*\* |
| 34 | CMS 10 x LT06 | -1.08 | 0.68 | -1 | -0.93 | -13.40\*\* | -0.55\*\* | 0.52 | -0.98 | -0.16 | -3.27 |
| 35 | CMS 10 x LT07 | 2.17\*\* | 0.35 | 0.72 | -0.2 | 8.97\*\* | -0.2 | 0.94 | -2.03 \*\* | 0.5 | -2.62 |
| 36 | CMS 82 x LT01 | 3.05\*\* | -1.99\* | 4.69 | 1.18 | 6.76\*\* | 0.3 | -0.79 | -3.02 \*\* | 2.34 \*\* | 2.28 |
| 37 | CMS 82 x LT02 | -1.12 | -3.40\*\* | -8.91 | -0.04 | 4.09\* | -0.04 | 4.96 \*\* | 1.78 \*\* | -1.31 \*\* | 3.27 |
| 38 | CMS 82 x LT03 | -1.29 | 0.01 | -3.09 | -0.02 | 3.92\* | 0.19 | -1.2 | -1.96 \*\* | 1.88 \*\* | 2.96 |
| 39 | CMS 82 x LT04 | -2.04\*\* | 0.18 | 2.12 | 1.14 | -9.55\*\* | -0.14 | -0.95 | 0.15 | 0.62 | -4.62 \* |
| 40 | CMS 82 x LT05 | -1.12 | 1.18 | 11.92 | -1.25 | -6.04\*\* | -0.61\*\* | 0.3 | 2.39 \*\* | -0.29 | -5.85 \*\* |
| 41 | CMS 82 x LT06 | 3.13\*\* | 2.68\*\* | -2.31 | -1.11 | -0.85 | -0.44\* | -2.12\*\* | 1.16 | 0.27 | -4.39\* |
| 42 | CMS 82 x LT07 | -0.62 | 1.35 | -4.42 | 0.09 | 1.66 | 0.74\*\* | -0.2 | -0.5 | -3.51\*\* | 6.35\*\* |
|  | SE ± | 0.46 | 0.2 | 11.67 | 0.33 | 10.17 | 0.08 | 1.37 | 0.21 | 0.85 | 10.92 |
|  | CD at 5 % | 1.57 | 1.51 | 8.09 | 1.508 | 4.97 | 0.226 | 2.674 | 1.096 | 1.059 | 4.189 |
|  | CD at 1 % | 2.1 | 0.97 | 17.77 | 2.013 | 6.52 | 0.301 | 3.56 | 1.462 | 1.358 | 5.59 |

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

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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References

* Andarkhor, S. A., Rameeh, V., & Alitabar, R. A. (2013). Estimation of genetic parameters for yield components and seed yield in sunflower using line × tester analysis. *African Journal of Biotechnology*, 10(25), 5027–5030.
* Binodh, A. K., Manivannan, N., & Vindhya Varman, P. (2008). Character association and path analysis in sunflower. *Madras Agricultural Journal*, 95(7–12), 425–428.
* Chandra, B.S., Ranganatha, A. R. G. & Kumar, S. S. (2013). Heterosis Studies for Seed Yield and its Components in Sunflower Hybrids Over Locations. *Madras Agricultural Journal*. 100 (1-3), 23-29. <https://pdfs.semanticscholar.org/1bc0/3a4a02646979a1fd1fdc1cb7346b49d79487.pdf>
* Choudhary, A. K. (2018). Heterosis, combining ability and stability analysis studies in sunflower (*Master’s thesis*). Vasantrao Naik Marathwada Krushi Vidyapeeth, Parbhani.
* Dhanalakshmi, R., Manivannan, N., Viswanathan, P. L., Sasikala, R., Rajendran, L. & Senthivelu, M. (2022). Combining ability analysis in sunflower (Helianthus annuus L.). Electronic Journal of Plant Breeding. 13(3), 1036-1041. [https://ejplantbreeding.org/index.php/EJPB/article/view/4409Doke, S. R., Patil, R. M., & Borde, V. M. (2024). Specific combining ability analysis for seed yield and oil content in sunflower. *Journal of Agricultural Research and Technology*, 49(1), 33–40.](https://ejplantbreeding.org/index.php/EJPB/article/view/4409Doke%2C%20S.%20R.%2C%20Patil%2C%20R.%20M.%2C%20%26%20Borde%2C%20V.%20M.%20%282024%29.%20Specific%20combining%20ability%20analysis%20for%20seed%20yield%20and%20oil%20content%20in%20sunflower.%20Journal%20of%20Agricultural%20Research%20and%20Technology%2C%2049%281%29%2C%2033%E2%80%9340.)
* Farrokhi, E., Alizadeh, B. & Ghaffari, M. (2008). General combining ability analysis in sunflower maintainer lines using Line x Tester Crosses. Proc. 17th International Sunflower Conference, Córdoba, Spain. 571-574.
* Ghodekar, V. G., Ghodke, M. K., Sargar, P. R. & Dhakne, V. R. (2021). Gene action and combining ability studies using Line x Tester analysis in sunflower (Helianthus annuus L.). Madras Agricultural Journal. 108(1), 1-5. <https://www.researchgate.net/publication/372882448_Gene_Action_and_Combining_Ability_Studies_Using_Line_x_Tester_Analysis_in_Sunflower_Helianthus_annuus_L.>
* Gomez, K. A., & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research* (2nd ed.). New York: John Wiley & Sons.
* IIOR (Indian Institute of Oilseeds Research). (2024). *Annual Report 2023–24*. Hyderabad: ICAR-IIOR.
* Ingle, A. U., Nichal, S. S., Gare, S. G. & Gaikwad, A. R. (2016). Combining ability for seed yield, its components and oil content in sunflower (Helianthus annuus L.). International Journal of Tropical Agriculture. 34(3), 2387-2395. <https://www.cabidigitallibrary.org/doi/full/10.5555/20173079202>
* Jondhale, A. S., Goud, I. S. & Praveenkumar, B. (2012). Combining ability and gene action studies in diverse CMS sources in sunflower (Helianthus annuus L.). International journal of Science & Research. 3(12), 2183-2187. <https://www.ijsr.net/articlerating.php?paperid=SUB141018>.
* Kale, M. M., Salunke, D. K., & Ingle, A. A. (2018). Performance of sunflower hybrids under different agro-climatic conditions. *Journal of Oilseeds Research*, 35(1), 67–72.
* Kamptorne, O. (1957). *An Introduction to Genetic Statistics*. New York: John Wiley & Sons.
* Kaya, Y., & Atakisi, I. (2004). Combining ability analysis of some yield characters of sunflower (Helianthus annuus L.). *Helia*, 27(40), 75–84.
* Kulkarni, V.V. & Supriya, S.M. (2017). Heterosis and combining ability studies for yield and yield component traits in sunflower (Helianthus annuus L.). International Journal of Current Microbiology & Applied Science. 6(9), 3346-3357. <https://www.ijcmas.com/6-92017/Vikas%20V.%20Kulkarni%20and%20S.M.%20Supriya.pdf>
* Lakshman, S. S., Ghodke, M. K., & Meena, H. P. (2021). Evaluation of combining ability and heterosis for achene yield and related traits in sunflower through line × tester analysis. *European Journal of Experimental Biology*, 11(4), 134–142.
* Manivannan, N. (2014). *TNAUSTAT – Statistical Analysis Software*. Tamil Nadu Agricultural University, Coimbatore.
* Nehru, S. D., Budihal, A. T., Farooq, M. U., Shadakshari, Y. G., Uma, M. S., Ramesh, S. & Bhat, D. (2021). Identification of inbred lines with good combining ability and hybrids surpassing the best checks in sunflower (Helianthus annuus L.). The Pharma Innovation Journal. 10(4), 259-265. <https://www.thepharmajournal.com/archives/?year=2021&vol=10&issue=4&ArticleId=593>
* Patil, R., Goud, I.S., Kulkarni, V. & Banakar, C. (2012). Combining ability and gene action studies for seed yield and its components in sunflower (Helianthus annuus L.). Electronic Journal of Plant Breeding. 3(3), 861-867.
* Ramaraju, D., Rajguru, A.B., Rajput, H.J. & Nimbalkar, R.D. (2019). Heterosis studies in sunflower (Helianthus annuus L.). International Journal Current Microbiology & Applied Science. 8(9), 2155-2161. [https://www.ijcmas.com/8-9-2019/D.%20Ramaraju,%20et%20al.pdf](https://www.ijcmas.com/8-9-2019/D.%20Ramaraju%2C%20et%20al.pdf)
* Rambilash, M. & Majumder, K. (2023), Integrated nutrient management in sunflower. *Indian Journal of Agricultural Research* 57(1): 47–51.
* Rukminidevi, K., Ranganadha, A.R.G. & Ganesh, M. (2006) Analysis of diverse hybrids for stability to seed yield and yield components in sunflower. Ann. Agric. Res. New Series. 27(2), 167-178. <https://epubs.icar.org.in/index.php/AAR/article/view/42320>
* Salem, A. H., & Ali, M. A. (2012). Combining ability for sunflower yield contributing characters and oil content over different water supply environments. Journal of American Science. 8(9), 227-233.
* Salke, P.S., Singh R.J., Toprope, V.N., Ingle, N.P. & Fesate, C.G., (2018). Studies on combining ability, heterosis and gene action in restorer lines of sunflower (Helianthus annuus L.). International Journal of Current Microbialogy & Applied Science. (6), 1267-1274. [https://www.ijcmas.com/special/6/P.%20S.%20Salke,%20et%20al.pdf](https://www.ijcmas.com/special/6/P.%20S.%20Salke%2C%20et%20al.pdf)
* Sharma, M., & Shadakshari, Y. (2021). Combining ability and nature of gene effects controlling seed yield and its component traits in alien cytoplasm-based hybrids in sunflower (Helianthus Annuus L.). Research Square. 1-19. <https://doi.org/10.21203/rs.3.rs-693842/v1>
* Shinde S.R., Sapkale, R.B. & Pawar, R.M., (2016). Combining ability analysis for yield and its components in sunflower (Helianthus annuus L.). International Journal of Agricultural Sciences. 12(1), 51-55. <https://www.researchgate.net/profile/Ranveer-Pawar2/publication/298331281_Combining_ability_analysis_for_yield_and_its_components_in_sunflower_Helianthus_annuus_L/links/64c3ff4dcda2775c03ccce65/Combining-ability-analysis-for-yield-and-its-components-in-sunflower-Helianthus-annuus-L.pdf>
* Sreedhar, S., Sahib, K.H. & Reddy, A.V. (2010). Heterosis in three-way cross hybrids of sunflower, (Helianthus annuus L.). Journal of Oilseeds Research. 27(1), 57-59. <https://www.cabidigitallibrary.org/doi/full/10.5555/20113149839>
* Sujatha, M. & Reddy, A.V. (2009). Heterosis and combining ability for seed yield and other yield contributing characters in sunflower (Helianthus annuus L.). Journal of Oilseeds Restarch. 26(1), 21-31. <https://www.cabidigitallibrary.org/doi/full/10.5555/20113278318>
* Vairam, N., Gyanamalar, R. P. (2016). Combining ability studies in sunflower (Helianthus annuus L.). *Journal of Oilseeds Research*, 33(1), 139–056.
* Varalakshmi, K., & Neelima, S. (2019). General combining ability of parents and specific combining ability of crosses for yield and oil related traits in sunflower (Helianthus annuus L.). The Indian Society of Oilseeds Research. 36(3),141-149. <https://www.researchgate.net/publication/378311616_General_combining_ability_of_parents_and_specific_combining_ability_of_crosses_for_yield_and_oil_related_traits_in_sunflower_Helianthus_annuus_L_GCA_OF_PARENTS_AND_SCA_OF_CROSSES_FOR_YIELD_AND_OIL_REL>