**Genetic Analysis and Combining Ability for Yield and its Component Traits in Sesame (*Sesamum indicum* L.)**

**ABSTRACT**

Sesame (*Sesamum indicum* L.), known as the "Queen of Oilseeds," is an ancient oilseed crop of significant economic importance in tropical and subtropical regions. Despite its rich genetic diversity and nutritional value, its yield potential remains underexploited in India. The present investigation was undertaken to assess the genetic architecture and combining ability of yield and its attributes using a diallel mating design involving six genetically diverse sesame genotypes. Thirty-six crosses, including reciprocals, were generated during *Kharif* 2024 and evaluated during summer 2025 at ICAR-IIOR, Hyderabad. Significant genetic variability was observed for agronomic and yield-attributing traits, with hybrids outperforming parents in several traits, indicating the presence of heterosis and non-additive gene action. General combining ability (GCA) analysis revealed that TBS-6 and TTT-1 were superior combiners for traits like seed yield per plant, seed weight/capsule, Test weight and oil content. Specific combining ability (SCA) analysis identified TBS-6 x TTT-1, TBS-6 x Longkong-1, as promising hybrid combinations for improving yield; Lawkuti x Longkong-1, GT-10 x TBS-11, Longkong x TBS-6, as promising hybrid combinations for oil content, whereas GT-10 x TTT-1, as promising hybrid combinations for both improving yield and oil content. The study emphasises the utility of combining ability analysis for identifying genetically superior parents and hybrids, thereby facilitating targeted breeding strategies to enhance sesame productivity and seed quality under diverse agro-climatic conditions.

**Keywords:** Sesame, Diallel analysis, Combining ability, genotypes

**INTRODUCTION**

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oilseed crops in Asia, and it holds significant importance in the agricultural and economic landscape, particularly in tropical and subtropical regions. It belongs to the family *Pedaliaceae* and the order *Tubiflorae*, sesame has a chromosome number of 2n = 2x = 26. Sesamum is commonly referred to as “Til”, “Ellu”, “Sim-sim”, “Benni seed”, and “Nuvvulu” across different parts of India and is famously known as the “Queen of Oilseeds” due to the superior quality of oil and meal it produces (Sikarwar *et al.,*2021). Its oil is highly valued for its stability, owing to the presence of natural antioxidants like sesamol, which offers resistance to oxidative rancidity (Ashri, 1998). Originating from Africa and India, sesame remains a vital crop in tropical and subtropical regions across Asia and Africa, where it thrives under marginal conditions where other crops may fail (Yadav *et al.,*2022).

In India, sesame is cultivated on approximately 15.33 lakh hectares, yielding around 8.29 lakh tonnes, with an average productivity of 541 kg ha-1 (*upag.gov.in* 2024-25). In Telangana, it is grown across 0.14 lakh hectares, producing 0.10 lakh tonnes, with a productivity of 756 kg ha-1 (upag.gov.in, 2024-25). Despite its wide adaptability, the productivity of sesame in India remains low, i.e. compared to other major producers such as China and Japan, primarily due to traditional farming practices, susceptibility to biotic and abiotic stresses, and limited exploitation of modern breeding technologies (Madhuri and Karuna Sagar, 2018). Developing Sesamum varieties with high yield, oil content and seed weight suitable for various agro-climatic zones and conditions is the main breeding objective for sesame breeders.

To develop sesame varieties, understanding the genetic architecture of key agronomic traits, combining ability and gene action among the parents and breeding material for yield traits is essential. Combining ability analysis provides precise estimates of the nature and extent of gene action governing the inheritance of quantitative traits. This enables the identification of parental lines with desirable combining ability effects (GCA), as well as cross combinations exhibiting strong specific combining ability (SCA) effects. Diallel analysis of crosses is one most informative techniques to understand the combining ability and offers insights into the additive and non-additive gene actions governing yield and its components (Ramya *et al*., 2021). This knowledge aids in identifying superior general combiners and specific combiners for use in crossing and selection strategies (Ravindran and Raghinam, 1996; Saravanan and Nadarajan, 2003; Banerjee and Kole, 2009; Pandey *et al*., 2020). To understand the genetic architecture and gene action of yield and yield-attributing traits in sesame, the study was conducted.

**MATERIAL AND METHODS**

The present investigation was carried out during late *Kharif* 2024 (August 1st week) and Summer 2025 (January 2nd week) at ICAR- Indian Institute of Oilseeds Research (IIOR), Rajendranagar farm and Narkhoda farm, respectively. The farm is nestled on the deccan plateau and geographical coordinates are approximately 17° 151 1611 N latitude and 78° 181 3011 E longitude with an altitude 536 meters and 17° 151 1611 N latitude and 78° 181 3011 E longitude, with an altitude of 542 meters above sea level in ICAR- Indian Institute of Oilseeds Research (IIOR), Rajendranagar farm and Narkhoda farm respectively.

The experimental material used in the present investigation comprised six Sesame genotypes as listed in the table below.

List 1: The experimental material used in the present investigation comprised six Sesame genotypes

|  |  |  |
| --- | --- | --- |
| **Parents** | **Description** | **Characteristics** |
| **GT-10** | Black seeded variety was released by Junagadh Agricultural University in 2003. | Popular variety and national check, high branching, high capsule number/plant |
| **Longkong-1** | Germplasm/local landrace collected from North East hill region | Small seed genotype (1.8 g/1000 seed) |
| **Lawkuti** | Germplasm/local landrace collected from North East hill region | Small seed genotype (1.6 g/1000 seed) |
| **TTT-1** | Variety released by ICAR-IIOR in 202 | New variety, basal branching, high number of capsules |
| **TBS-6** | Mutant line from BARC, Mumbai | Bold seed genotype (4.2 g/1000 seed) |
| **TBS-11** | Mutant line from BARC, Mumbai | Bold seed genotype (4.6 g/1000 seed) |

These parents were crossed in a Griffing`s diallel model I (F1s and reciprocals) during late *Kharif* 2024 (August to November 2024) to generate 30 crosses following the crossing method developed by Sirisha *et al*., 2021. All the 36 entries, including 15 F1s, 15 reciprocals, along with six parents, were evaluated during summer 2025 (January to April 2025) in a Randomized complete block design in three replications. Every entry was sown in two rows of 4 m each with a spacing of 45x10 cm. All the recommended package of practices were followed to raise a good crop. Quantitative data of nine yield-attributing traits were collected on 5 randomly selected plants from each entry in three replications. The oil content of seeds harvested from these crosses was assessed at the Biochemistry laboratory of Indian Institute of Oilseeds Research (IIOR), Hyderabad, by a non-destructive method using nuclear magnetic resonance (NMR)—Oxford- MQC-5 analyser (London, UK). The data collected was analysed by AGD-R (Analysis of Genetic Designs in R). Version 5.1 (2022-08-03) software was developed by CIMMYT.

**RESULTS AND DISCUSSION**

The analysis of variancefor grain yield and related traits in sesame presented in Table 1 indicated substantial genetic variation among diallel progenies, i.e., parents, hybrids, and their reciprocals, for key traits such as capsules per plant, plant height, seed yield, and oil content. This shows the requirement for the estimation and further analysis of combining ability effects and variances for yield and its attributing traits in the experimental material. These findings highlight the presence of diversity among the parents and their cross combinations and underscore the potential for identifying superior genotypes. The significant differences among the parents and hybrids indicate the possibility of heterosis for traits under consideration; whereas significant differences among crosses and its reciprocals indicate the presence of maternal effects and call for estimation of reciprocal effects for the traits among the experimental material. Relatively low error variance confirms the experimental precision, ensuring that the observed variability in the material under study is largely genetic. Analysis of variance for combining ability indicated in Table 2 showed that variance for diallel progenies can be partitioned into three components, i.e., variance due to GCA, variance due to *sca* and variance due to reciprocal effects. These variances were found significant for all the quantitative traits, indicating that both additive and non-additive variances are important in controlling the nine quantitative traits considered in the study. This further led to the computation of *GCA* and SCAeffects for each parent and cross were estimated respectively for all the traits.

The general combining ability (*GCA*) effects for the studied traits are presented in Table 3. TTT-1 exhibited favourable *GCA* effects for no of primary branches (0.64\*\*), seeds/capsule (6.04\*\*), seed yield per plant (4.02\*\*), Seed weight/capsule (0.04\*\*), test weight (0.32\*\*) and oil content (2.5\*\*). Another parent, TBS-6, recorded significant positive *GCA* effects for number of capsules per plant (24.3\*\*), seed yield per plant (4.03\*\*), Seed weight/capsule (0.01\*\*), test weight (0.42\*\*) and oil content (1.6\*\*). TBS-11 showed significant positive *GCA* effects for seed yield per plant (2.15\*\*), Seed weight/capsule (0.01\*\*), test weight (0.55\*\*) and oil content (0.87\*\*). The above four parents among the six studied parents showed significant positive *GCA* effects for yield and its attributing traits, indicating the additive nature of gene action. The parent Lawkuti recorded significant positive *GCA* effects for traits such as number of capsules per plant (24.98\*\*), plant height (43.54\*\*), and seed per capsule (4.24\*\*). In contrast, GT-10 and Longkong showed significant negative *GCA* effects for important traits like seed yield, oil content, and number of capsules per plant. Results indicated that TTT-1, TBS-6 and TBS-11 have desirable *GCA* effects for seed yield and oil content, suggesting their utility in developing high-yielding genotypes with improved seed quality. These genotypes can be promising parents that could contribute favourable alleles in sesame improvement programs targeting yield and quality traits.

The analysis of specific combining ability (*sca*) effects among 30 cross combinations generated among six sesame parents revealed significant variability across traits studied, underscoring the potential for selecting superior cross combinations (Table 4). Positive and significant *SCA* indicates the role of non-additive gene action for the expression of a particular trait in the material. For seed yield per plant, significant positive *SCA* effects were exhibited were eleven hybrids involving GT-10, TTT-1 and TBS-6. 13 crosses showing negative *SCA* effects were registered as poor specific combinations. The hybrids TBS-6 x TTT-1 (9.425\*\*) was the best specific combination followed by TBS-6 x Longkong (8.35\*\*), GT-10 x TTT-1 (6.27\*\*), GT-10 x Lawkuti (6.19\*\*). Four crosses showed a positive significant *SCA* for no of primary branches, whereas fourteen crosses showed a positive significant *SCA* for no of capsules per plant and eleven crosses showed a positive significant *SCA* for seeds per capsule. Most of the best crosses for seed yield/plant with positive significant sca also have positive *SCA* effect for no of capsules per plant. The cross combinations indicate that high *SCA* effect can be raised not only from crosses involving parents with high positive *gca* effects but also from involving parents negative *gca* effects. So, the parents which are low general combiners for seed yield/parent can generate cross combinations with high SCA effects.

Seven cross combinations viz., GT-10 x TTT-1 (4.55\*\*) and Lawkuti x Longkong (3.28\*\*) showed positive sca effects for oil content. Test weight among the crosses studied indicated that five one one-cross combinations showed positive *SCA* effect for test weight especially GT-10 x TBS-6 (0.39\*\*). Two crosses were found to have negative *SCA* effect on days to flowering and days to flower cessation. Eleven crosses were found to show negative significant *SCA* effect for plant height, which can be exploited further to select the sesame genotypes with less plant height and early flowering.

Notably, the hybrid TBS-6 x Longkong-1 exhibited significantly positive *SCA* effects for the number of capsules per plant (NC/P), and plant seed yield per plant, suggesting strong hybrid vigour and possible dominance or epistatic gene action for these traits. Conversely, GT-10 x TBS-11 showed markedly negative *SCA* values for NC/P and PH, indicating limited combining potential for yield components in this combination. Moreover, crosses like TBS-6 × Longkong-1 and TBS-6 x TTT-1 recorded significantly positive *SCA* effects for traits such as seed yield per plant (SY/P), highlighting their suitability for enhancing productivity in breeding programs. Significant reciprocal effects for traits like seed yield, seed protein content, oil content, and test weight point toward maternal or cytoplasmic inheritance influences, which emphasises the importance of considering both directions of crosses in breeding strategies. The *SCA* effects of reciprocal crosses showed that parents like GT-10, Longkong-1 and TBS-6 performed better as female parents rather than as pollen parents in the cross combinations.

**Conclusion**

Overall, the results indicate that significant variation was observed in the experimental material for the nine quantitative traits studied. The presence of both additive and non-additive variance was recorded for traits, along with maternal effects influencing the expression of traits in the crosses. Based on the direction and magnitude of *GCA* effects computed parents like TTT-1, TBS-6 and TBS-11 are considered as best general combiners for seed yield, oil content and test weight. *SCA* effects indicated that the hybrids TBS-6 x TTT-1, followed by TBS-6 x Longkong and GT-10 x TTT-1, were found to best specific cross combinations. The results also indicated that parents like GT-10, Longkong-1 and TBS-6 performed better as female parents rather than deployed as pollen parents in the cross combinations, as understood from the reciprocal effects. The presence of both additive and non-additive variance was recorded for traits, along with maternal effects, indicates that careful selection of parents and cross combinations for improvement of any trait in sesame should be done in breeding programs aimed at improving complex traits like yield and oil content.

**Table 1. Analysis of variance for grain yield and its component traits of sesame (*Sesamum indicum L*.)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Source of variance** | ***df*** | **MSS** | | | | | | | | | | | |
| **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| Replication | 2 | 43.595\*\* | 68.53\*\* | 74.70 \*\* | 1.361 | 1204.398\*\* | 774.597\*\* | 3.592 | 11.940 | 9.042 | 0 .00 | 0.047 | 3.631 |
| Diallel progenies | 35 | 13.34\*\* | 28.52\*\* | 41.62\*\* | 15.40\*\* | 9536.6\*\* | 14659.79\*\* | 58.100\*\* | 299.08\*\* | 207.64\*\* | 0.01\*\* | 1.58\*\* | 39.78\*\* |
| Parents | 5 | 17.60\*\* | 33.60\*\* | 15.20 | 18.30\*\* | 2549.70\*\* | 264.90 | 91.500\*\* | 258.20\*\* | 96.70\*\* | 0.003\*\* | 0.24\*\* | 14.80 |
| Hybrids | 29 | 13.10\*\* | 28.70\*\* | 46.40\*\* | 12.00\*\* | 10767.30\*\* | 17612.50\*\* | 54.300\*\* | 244.70\*\* | 232.40\*\* | 0.005\*\* | 1.74\*\* | 43.70\*\* |
| Parent *vs* Hybrids | 1 | 0.470 | 0.400 | 35.80\* | 98.80\*\* | 8778.90\*\* | 1006.90\*\* | 1.100 | 2078.70\*\* | 42.60\* | 0.002\* | 1.74\*\* | 46.40\* |
| F1s | 14 | 13.40\*\* | 30.80\*\* | 84.20\*\* | 11.30\*\* | 10635.00\*\* | 34749.30\*\* | 48.600\*\* | 137.30\*\* | 222.40\*\* | 0.002\*\* | 0.59\*\* | 32.10\*\* |
| Reciprocals | 14 | 13.60\*\* | 28.20\*\* | 3.50 | 13.40\*\* | 10603.90\*\* | 855.40\*\* | 61.200\*\* | 306.10\*\* | 151.30\*\* | 0.005\*\* | 1.41\*\* | 10.90 |
| F1s *vs* Reciprocal | 1 | 0.40 | 4.00 | 117.90\*\* | 1.30 | 14907.30\*\* | 12294.40\*\* | 36.100\*\* | 889.80\*\* | 1510.40\*\* | 0.04\*\* | 22.40\*\* | 663.80\*\* |
| Error | 70 | 5.29 | 7.48 | 8.13 | 2.12 | 224.42 | 134.93 | 3.3 | 19.06 | 7.83 | 0.0004 | 0.07 | 7.07 |

**Note:** \*-Significant at 5% level and \*\*-Significant at 1% level of probability.

DFI: Days to flower initiation DFF: Days to 50 per cent flowering DFC: Days to flower cessation NPB: Number of primary branches

NC/P: Number of capsules per plant PH: Plant height (cm) DM: Days to maturity (cm) SPC: Seeds per capsule

SY/P: Seed yield per plant (gm) SW/C: Seed weight per capsule (gm) TW(gm): Test weight (gm) Oil (%): Oil content

**Table 2. Analysis of variance for combining ability of different crosses and their parents for seed yield and its component traits in sesame (*Sesamum indicum* L.)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Source of variance** | **DF** | **MSS** | | | | | | | | | | | |
| **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| ***gca* effects** | 5 | 18.685\*\* | 31.889\*\* | 113.941\*\* | 74.844\*\* | 18,998.00\*\* | 18,635.06\*\* | 55.341\*\* | 753.046\*\* | 699.916\*\* | 0.024\*\* | 8.661\*\* | 177.334\*\* |
| ***sca* effects** | 15 | 12.036\*\* | 32.653\*\* | 22.788\*\* | 7.313\*\* | 9,007.47\*\* | 9,100.85\*\* | 61.251\*\* | 210.23\*\* | 141.58\*\* | 0.001\*\* | 0.509\*\* | 12.002 |
| **Reciprocal effects** | 15 | 12.867\*\* | 23.267\*\* | 36.333\*\* | 3.667 | 6,911.89\*\* | 18,893.64\*\* | 55.878\*\* | 236.608\*\* | 109.615\*\* | 0.002\*\* | 0.166\*\* | 21.379\* |
| **Error** | 70 | 5.29 | 7.48 | 8.132 | 2.123 | 224.421 | 134.934 | 3.297 | 19.057 | 7.825 | 0 | 0.074 | 7.068 |

\*-Significant at 5% level and \*\*-Significant at 1% level of probability

DFI: Days to flower initiation DFF: Days to 50 per cent flowering DFC: Days to flower cessation NPB: Number of primary branches

NC/P: Number of capsules per plant PH: Plant height (cm) DM: Days to maturity (cm) SPC: Seeds per capsule

SY/P: Seed yield per plant (gm) SW/C: Seed weight per capsule (gm) TW(gm): Test weight (gm) Oil (%): Oil content

**Table 3. Estimates of general combing ability effects of parents for seed yield and its component traits in sesame (*Sesamum indicum* L.)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parent** | **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| **GT-10** | -1.074\* | -1.472\*\* | -0.657 | -0.222 | -11.540\*\* | 4.878\* | -0.130 | -2.148\* | -0.553 | -0.016\*\* | -0.239\*\* | -2.486\*\* |
| **Longkong-1** | 0.231 | 1.361\* | -0.019 | -1.417\*\* | -35.026\*\* | -6.964\*\* | 1.454\*\* | 1.194 | -7.412\*\* | -0.025\*\* | -0.476\*\* | -2.940\*\* |
| **Lawkuti** | 0.648 | 0.333 | 3.370\*\* | 2.583\*\* | 24.977\*\* | 43.542\*\* | 1.009\*\* | 4.238\*\* | -2.231\*\* | -0.024\*\* | -0.577\*\* | 0.446 |
| **TTT-1** | 0.676 | 0.306 | 0.065 | 0.639\* | 3.921 | -17.511\*\* | -1.352\*\* | 6.035\*\* | 4.016\*\* | 0.039\*\* | 0.320\*\* | 2.499\*\* |
| **TBS-6** | 0.204 | -0.083 | -1.713\*\* | -0.750\*\* | 24.380\*\* | -8.317\*\* | 0.565 | -4.045\*\* | 4.031\*\* | 0.014\*\* | 0.418\*\* | 1.616\*\* |
| **TBS-11** | -0.685 | -0.444 | -1.046 | -0.833\*\* | -6.712\* | -15.628\*\* | -1.546\*\* | -5.273\*\* | 2.149\*\* | 0.012\*\* | 0.555\*\* | 0.865 |
| **Standard Error** | | | | | | | | | | | | |
| **G(i)** | 0.35 | 0.416 | 0.434 | 0.222 | 2,279 | 1.767 | 0.276 | 0.664 | 0.426 | 0.003 | 0.041 | 0.404 |
| **G (i)- G(J)** | 0.939 | 1.117 | 1.164 | 0.595 | 6.116 | 4.742 | 0.741 | 1.782 | 1.142 | 0.008 | 0.111 | 1.085 |

**Note** \* - Significant at 5 % and \*\*- Significant at 1 % level of probability

**Table 4. Estimates of specific combining ability effects of single cross hybrids for yield and its component traits in sesame (*Sesamum indicum* L.)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cross** | **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| GT-10 x Longkong-1 | -0.833 | -0.833 | 2.500\*\* | 0.000 | -9.400\*\* | -3.717 | 2.167\*\* | 3.333\*\* | -1.180\* | -0.007 | -0.202\*\* | -3.590\*\* |
| GT-10 x Lawkuti | 1.167\* | 2.000\*\* | 6.000\*\* | 1.500\*\* | 34.933\*\* | 160.883\*\* | -3.167\*\* | 4.267\*\* | 6.185\*\* | 0.015\*\* | 0.117\* | 0.130 |
| GT-10 x TTT-1 | 0.000 | 0.833 | 2.000\*\* | 0.500 | 41.383\*\* | 13.083\*\* | -5.333\*\* | 14.450\*\* | 6.265\*\* | 0.025\*\* | -0.223\*\* | 4.550\*\* |
| GT-10 x TBS-6 | -1.167\* | -0.833 | 0.000 | -0.167 | 15.000\*\* | 9.450\*\* | -0.167 | -8.900\*\* | -0.423 | -0.003 | 0.318\*\* | 1.107\* |
| GT-10 x TBS-11 | 0.833 | 3.500\*\* | 0.500 | 0.000 | -65.217\*\* | -6.000\* | 6.000\*\* | -8.567\*\* | -4.705\*\* | -0.035\*\* | -0.153\* | 2.443\*\* |
| Longkong-1 x GT-10 | -0.509 | -2.250\* | -1.426 | 0.889 | -37.130\*\* | -36.342\*\* | 1.185 | -6.974\*\* | -3.132\*\* | -0.011 | 0.200\* | -2.584\* |
| Longkong-1 x Lawkuti | -0.667 | 1.361\*\* | 3.667\*\* | 1.500\*\* | 6.233\* | 138.500\*\* | -0.333 | 4.450\*\* | -3.438\*\* | 0.005 | -0.037 | 0.375 |
| Longkong-1 x TTT-1 | -0.333 | -0.167 | -2.667\*\* | 0.000 | 15.917\*\* | 13.333\*\* | 2.667\*\* | 1.750\* | 3.135\*\* | 0.017\*\* | 0.153\*\* | -0.488 |
| Longkong-1 x TBS-6 | 0.000 | -0.667 | 2.333\*\* | -0.167 | -25.500\*\* | -13.167\*\* | -3.833\*\* | -7.767\*\* | -9.570\*\* | -0.022\*\* | -0.063 | 2.403\*\* |
| Longkong-1 x TBS-11 | -1.000 | 0.833 | -2.667 | 0.000 | 16.167\*\* | 32.83 | -2.333\*\* | -3.167\*\* | 4.537\*\* | -0.002 | 0.098 | 1.550\*\* |
| Lawkuti x GT-10 | 3.074\*\* | 2.278\* | 3.352\*\* | -0.944 | 6.868 | 92.886\*\* | -2.704\*\* | -1.419 | 4.813\*\* | 0.004 | 0.180 | 0.799 |
| Lawkuti x Longkong-1 | -1.731\* | 1.389 | -0.287 | 0.583 | 20.087\*\* | 68.111\*\* | -1.120 | -2.377 | 2.405\* | -0.004 | 0.100 | 3.288\*\* |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cross** | **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| Lawkuti x TTT-1 | 2.167 | 2.500\*\* | -3.000\*\* | -1.500\*\* | 12.133 | -5.817\* | -0.167 | -1.283 | 0.617 | -0.023\*\* | -0.270\*\* | -0.240 |
| Lawkuti x TBS-6 | 2.333\*\* | 3.333\*\* | -1.000 | 0.667\* | -10.183\*\* | 10.067\*\* | 1.000\* | -0.100 | 3.325\*\* | -0.007 | -0.112\* | -0.258 |
| Lawkuti x TBS-11 | 0.333 | 1.167\* | -0.167 | 0.167 | 53.217\*\* | 1.850 | 2.000\*\* | -3.933\*\* | 5.160\*\* | 0.003 | 0.163\*\* | 1.282\* |
| TTT-1 x GT-10 | -1.454 | -1.861 | -1.676 | -0.333 | -4.860 | -12.894\*\* | -2.843\*\* | 4.168\*\* | -1.448\*\* | 0.014 | 0.156 | 0.340 |
| TTT-1 x Longkong-1 | 0.574 | 2.639\*\* | 3.352\*\* | -0.639\* | -13.341\* | -10.003\*\* | 1.907\*\* | -0.141 | -4.726\*\* | -0.009 | -0.060 | -0.290 |
| TTT-1 x Lawkuti | 0.991 | 1.333 | -0.704 | 1.194 | 8.473 | -24.892\*\* | 1.519\* | -0.952 | -1.844 | -0.010 | -0.079 | -0.499 |
| TTT-1 x TBS-6 | -3.333\*\* | -2.167\*\* | -0.500 | -0.167 | 63.167\*\* | 13.983\*\* | -3.333 | -9.117\*\* | 0.602 | -0.037\*\* | -0.063 | 0.617 |
| TTT-1 x TBS-11 | 1.333\*\* | 1.333\* | -0.500 | -0.500 | 34.167\*\* | 0.283 | 4.000\*\* | -1.883\* | 0.432 | -0.008\* | -0.053 | -1.392\* |
| TBS-6 x GT-10 | 0.185 | 0.861 | 0.102 | -0.611 | 30.198 | 3.544\*\* | 3.741\*\* | 5.365\*\* | -2.228\* | -0.003 | -0.208\* | 0.813 |
| TBS-6 x Longkong-1 | -1.620 | -4.139\*\* | -1.537 | -0.417 | 75.818\*\* | 7.069\*\* | -1.176 | 5.923\*\* | 8.355\*\* | 0.008 | -0.182 | 1.356 |
| TBS-6 x Lawkuti | -0.037 | 1.222 | -1.593 | 1.750\*\* | -15.402\*\* | -31.103\*\* | -2.231\*\* | -6.021\*\* | -6.687\*\* | -0.028 | -0.316\*\* | -2.158\* |
| TBS-6 x TTT-1 | 0.269 | 0.750 | 0.880 | -0.472 | 44.237\*\* | 19.233\*\* | -1.204 | -2.835 | 9.425\*\* | 0.002\*\* | 0.142 | 0.358 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cross** | **DFI** | **DFF** | **DFC** | **NPB** | **NC/P** | **PH (cm)** | **DM** | **SPC** | **SY/P** | **SW/C** | **Tw (gm)** | **Oil (%)** |
| TBS-6 x TBS-11 | -1.833\*\* | -2.333\*\* | 0.833 | 1.167 | -18.333\*\* | -9.733\*\* | -1.000 | 1.950\* | -0.632 | 0.000 | -0.168\*\* | -0.060 |
| TBS-11 x GT-10 | 0.741 | 3.222\*\* | 0.602 | 0.639 | -15.706\*\* | -13.961\*\* | -2.981\*\* | 1.826 | -3.254\*\* | 0.010 | 0.014 | -0.489 |
| TBS-11 x Longkong-1 | 1.269 | 3.056\*\* | 3.130\*\* | 0.833 | -13.291\* | 7.281\*\* | 0.435 | -0.749 | -2.473\* | -0.003 | -0.231\* | -0.876 |
| TBS-11 x Lawkauti | -1.148 | -1.917 | -1.759 | 0.333 | 36.657\*\* | -29.775\*\* | 8.213\*\* | 11.706\*\* | 1.857\*\* | 0.011 | -0.432\*\* | 0.030 |
| TBS-11 x TTT-1 | -0.176 | -1.389 | -1.120 | 0.944 | 15.329\*\* | 16.144\*\* | -1.093 | 3.759\* | 1.791 | 0.002 | -0.289\*\* | 0.754 |
| TBS-11 x TBS-6 | -0.870 | -0.667 | 0.324 | -0.333\*\* | -42.763\*\* | 15.967\*\* | 0.657 | 1.206 | -2.351\* | 0.015\* | 0.165 | 0.145 |
| **Standard Error** | | | | | | | | | | | | |
| **S (ij)** | 0.798 | 0.949 | 0.989 | 0.506 | 5.197 | 4.03 | 0.630 | 1.515 | 0.97 | 0.007 | 0.094 | 0.922 |
| **S (ij)-S (ik)** | 1.212 | 1.441 | 1.503 | 0.768 | 7.896 | 6.122 | 0.957 | 2.301 | 1.474 | 0.011 | 0.143 | 1.401 |
| **S(ij)-S(kl)** | 1.084 | 1.289 | 1.344 | 0.687 | 7.062 | 5.476 | 0.856 | 2.058 | 1.319 | 0.01 | 0.128 | 1.253 |

**Note:** \*-Significant at 5% level and \*\*-Significant at 1% level of probability.

DFI: Days to flower initiation DFF: Days to 50 per cent flowering DFC: Days to flower cessation NPB: Number of primary branches NC/P: Number of capsules per plant PH: Plant height (cm) DM: Days to maturity (cm) SPC: Seeds per capsule SY/P: Seed yield per plant (gm) SW/C: Seed weight per capsule (gm) Tw (gm): Test weight (gm) Oil (%): Oil content C.D; Critical difference SE(m) Standard error of mean

**Disclaimer (Artificial intelligence)**

**Option 1:**

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

**Option 2:**

**Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology**

**Details of the AI usage are given below:**

**1.**

**2.**

**3.**

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