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# Studies on Heterosis for Yield and Yield Attributes in Sesame (*Sesamum indicum* L.)

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## ABSTRACT

An experiment was conducted to estimate the heterosis for yield and yield component traits in sesame. In the present investigation, Line x tester analysis involving 7 lines and 3 testers were used to identify standard heterosis and heterobeltiosis in association with yield and its component characters in sesame. The trail was conducted at plant breeding farm, Faculty of Agriculture, Annamalai University during 2018-2019. For seed yield per plant, the cross-combination GT 10 × TMV 7 was identified as the best performing hybrid since it had possessed significant and positive heterobeltiosis 29.62 per cent and standard heterosis 29.49 per cent for all the traits. The hybrid GT 10 × TMV7 and ORM 17 x TMV5 recorded the maximum significant and negative heterobeltiosis -15.10 per cent and 11.02 for days to 50 per cent flowering. The hybrid GT 10 × TMV5 recorded maximum significant and negative standard heterosis -16.56 per cent for days to 50 per cent flowering. The next best hybrid identified was ACM 14-007 SI-2 × TMV5, since it possessed desirable standard heterosis for almost all the traits except the days to 50 per cent flowering. Among the 21 hybrids, GT 10 × TMV 7, GT 10 × TMV5 and ACM 14-007 SI-2 × TMV 5 were identified as superior hybrids as they recorded high magnitude of standard heterosis for number of branches per plant, number of capsules per plant, number of seeds per capsules ,1000 seed weight and seed yield per plant. These heterosis will be exploited through selection of superior and trait specific genotypes in the segregating generation for the evolution of high yielding varieties.

***Key words*:** Sesame, Line × Tester, Heterosis, Heterobeltiosis, Standard heterosis, Hybrids, Yield

Sesame (*Sesamum indicum* L.) is normally called sim sim, til and benniseed belongs to the family pedaliaceae one of the most important oil seed crop in India. In India, it is grown in an area of 1.8mha with production of 0.75mt. It is cultivated in Asia from a period of over 5000 years [1]. This is evidenced by the presence of archaeological remnants of the crop dating back to 5500BC in the Harappa valley in the Indian subcontinent [2]. Sesame seeds are rich in oil and protein and two unique substances namely sesamin and sesamolin known to have a cholesterol lowering effect in human and to prevent high blood pressure [3]. Also, it is rich in micronutrients such as minerals, liganans, tocopherol and phytosterol [4]. Sesame seed cake is a by-product of traditional oil processing [5]. Sesame seed oil was found to be rich in tocopherols [6]. Sesame had more preference from farmers because of low input required and high price of produce [7]. In spite of all these, it has not contributed enormously to the total oil seed production in India, mainly because of low productivity (417.2 kg/ha) [8]. For breaking the present yield barrier and evolving varieties with high yield potential, it is desirable to combine the genes from genetically diverse parents [9]. The use of the seeds for decoration on the surface of breads and cookies is most familiar to the Americans [10]. As much as 20% of sesame produced is used for direct domestic consumption [11]. During recent years developing hybrid varieties through heterosis breeding are being attempted [12]. In the present investigation an attempt was made to study the magnitude of heterosis for seed yield and its component characters in sesame for 21 crosses.

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## MATERIALS AND METHODS

The present investigation on heterosis and heterobeltiosis in sesame (*sesamum indicum* L.) through line × tester analysis was carried out at the Plant Breeding Farm, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India during 2018. The experimental material consists of ten parents out of these seven lines viz, $L_1$-GT 10, $L_2$- SVPR 1, $L_3$-ACM 14-007 SI-2, $L_4$-ACM 14-010 SI-9, $L_5$-ORM 14, $L_6$-ORM 17 and $L_7$-Paiyur 1 and three testers viz., $T_1$-TMV 5, $T_2$-TMV6 and $T_3$-TMV7 were crossed in Line × Tester design and produced 21 hybrids during March - May, 2018. Hand emasculation was followed in the crossing block. The flower bud which is expected to open in the next day morning is selected in the previous day evening between 3 P.M. to 6 P.M. During the next day morning, between 7 A.M. and 9 A.M., pollen from the desired male parents were dusted gently on the surface of the stigmas of the emasculated flower buds. The crossed seeds are harvested separately after reaching physiological maturation and shade dried until the capsules shed seeds. The resulted 21 hybrids and 10 parents were sown in randomized block design with three replications during October - December, 2018. For this study, the observations were recorded on ten randomly selected plants for both in parents and hybrids in each replication for the following traits viz., days to 50 % flowering, plant height, number of branches per plant, number of capsules per plant, capsule length, number of seeds per capsule, 1000 seed weight and seed yield per plant.

## RESULTS AND DISCUSSION

The analysis of variance for the eight traits were studied and presented in (Table 1). All the twenty-one hybrids and ten parents showed significance for all the characters, the interaction effect (Line × Tester) indicating the existence of substantial amount of vigour in hybrids. As a result, highly significant at 1% level variation was observed among the hybrids which offering the scope for selection and further improvement by adopting suitable breeding procedure... Heterosis was estimated for eight characters in twenty-one cross combinations and expressed as percentage over Mid Parent (di-Relative heterosis), Better Parent (dii-Heterobeltiosis) and Standard Parent (diii-Standard heterosis).

Table 1 ANOVA for analysis of variance for eight characters in sesame

| Source | DF | Days to 50% flowering | Plant height (cm) | No. of branches plant$^{-1}$ | No. of capsules plant$^{-1}$ | Capsule length | No. of seeds capsule$^{-1}$ | 1000 seed weight | Seed yield per plant$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 3.4810 | 1.2745 | 0.0174 | 1.4704 | 0.0021 | 3.0220 | 0.0180 | 0.2627 |
| Hybrids | 20 | 47.0165** | 460.8541** | 3.1858** | 635.1918** | 0.0536** | 76.7020** | 1.16103** | 12.6800** |
| Lines | 60 | 38.9549** | 582.6426** | 2.9678** | 795.2892** | 0.0594** | 85.9221** | 1.5616** | 15.2405** |
| Testers | 2 | 125.7636** | 940.9732** | 10.4112** | 2170.2710** | 0.0879** | 114.3639** | 2.1099** | 48.3752** |
| Lines × tester | 12 | 37.9228** | 319.940** | 2.0906** | 299.2965** | 0.0449** | 65.81** | 0.8014** | 5.4506** |
| Error | 60 | 1.1202 | 24.0814 | 0.0192 | 19.2075 | 0.0038 | 7.1424 | 0.044 | 0.1154 |

*Days to 50 per cent flowering*

Among the hybrids, $L_1 \times T_3$ and $L_4 \times T_3$ showed the maximum significant and negative relative heterosis (-8.33 per cent and -8.14 percent respectively). Relative heterosis has limited importance because, it is only the deviation of $F_1$ hybrid from Mid parent value [13] and the hybrids $L_1 \times T_3$ and $L_6 \times T_1$ exhibited the maximum significant and negative heterobeltiosis (-15.10 per cent and -11.02 per cent respectively). The cross $L_1 \times T_1$ (-16.56 per cent) recorded the maximum negative standard heterosis.

Table 2 Percentage of heterosis for days to 50 per cent flowering and plant height

| Hybrids | Heterosis for days to 50 per cent flowering | | | Heterosis for plant height | | |
|---|---|---|---|---|---|---|
| | (di) (%) | (dii) (%) | (diii) (%) | (di) (%) | (dii) (%) | (diii) (%) |
| $L_1 \times T_1$ | -2.91 | -3.69 | -16.56** | -0.65 | -1.70 | 10.21* |
| $L_1 \times T_2$ | 3.40 | -2.44 | -6.24** | 0.56 | -9.23* | 1.76 |
| $L_1 \times T_3$ | -8.33** | -15.10** | -15.10** | 13.19** | 7.07 | 20.04** |
| $L_2 \times T_1$ | -4.16* | -6.51** | -14.82** | 16.12** | 6.02 | 16.34** |
| $L_2 \times T_2$ | 12.08** | 9.17** | 4.92* | -6.90 | -7.09 | -15.79** |
| $L_2 \times T_3$ | 13.47** | 8.43** | 8.43** | -1.41 | -6.02 | -6.02 |
| $L_3 \times T_1$ | -2.66 | -8.21** | -10.23** | 5.14 | 3.29 | 17.47** |
| $L_3 \times T_2$ | -6.25** | -7.06** | -9.10** | -3.33 | -13.30* | -1.40 |
| $L_3 \times T_3$ | 10.76** | 9.54** | 9.54** | -8.14 | -13.69** | -1.84 |
| $L_4 \times T_1$ | 11.39** | 6.05** | 1.62 | 7.72 | -5.52 | 3.67 |
| $L_4 \times T_2$ | 11.62** | 11.45** | 7.11** | -18.01** | -21.43** | -29.07** |
| $L_4 \times T_3$ | -8.14** | -10.06** | -10.06** | 0.32 | -8.33 | -8.33 |
| $L_5 \times T_1$ | 1.82 | -7.83** | -1.47 | -18.72** | -22.88** | -15.38** |
| $L_5 \times T_2$ | -1.69 | -6.65** | -0.21 | 17.23** | 12.34** | 10.65* |
| $L_5 \times T_3$ | -0.85 | -4.05* | 2.57 | -6.64 | -7.34 | -7.34 |
| $L_6 \times T_1$ | -2.71 | -11.02** | -7.03** | 0.93 | -16.29** | -8.15 |
| $L_6 \times T_2$ | 8.64** | 4.29* | 8.96** | -7.32 | -16.55** | -24.67** |
| $L_6 \times T_3$ | -3.84* | -5.90** | -1.69 | 7.14 | -7.71 | -7.71 |
| $L_7 \times T_1$ | -0.04 | -0.25 | -13.58** | 1.93 | 0.03 | 9.77* |
| $L_7 \times T_2$ | 9.50** | 3.90 | -0.15 | -6.69 | -13.48** | -8.59 |
| $L_7 \times T_3$ | 15.25** | 7.34** | 7.34** | 9.78** | 6.85 | 12.89** |

*Significant at 5 percent level, **Significant at 1 percent level

*Plant height*

Among the hybrids, $L_5 \times T_2$ showed the maximum significant and positive relative heterosis and heterobeltiosis values (17.23 per cent and 12.34 per cent respectively). The highest significant and positive standard heterosis value was recorded by $L_1 \times T_3$ (20.04%) followed by $L_3 \times T_1$ (17.47%).

*Number of branches per plant*

Among the hybrids evaluated, $L_1 \times T_3$ recorded the maximum significant and positive heterobeltiosis value of 17.23 per cent followed by $L_5 \times T_1$ (12.98 per cent) and $L_3 \times T_1$ (11.39 per cent). The hybrid $L_3 \times T_1$ showed the maximum significant and positive standard heterosis value (39.01 per cent) followed by $L_5 \times T_1$ (35.88 per cent).

*Number of capsules per plant*

The cross $L_7 \times T_1$ recorded maximum significant positive relative heterosis (27.93 per cent) followed by $L_6 \times T_3$ (16.57 per cent) and $L_2 \times T_3$ (14.96 per cent). Among the hybrids studied, $L_7 \times T_1$ recorded the maximum significant and positive heterobeltiosis of 13.75 per cent followed by $L_1 \times T_3$ (12.82 per cent). The highest significant and positive standard heterosis value of 16.05 per cent was exhibited by the hybrid $L_3 \times T_1$ followed by $L_1 \times T_3$ (13.06 per cent).

Table 3 Percentage of heterosis for number of branches per plant and number of capsules per plant

| Hybrids | Heterosis for number of branches per plant | | | Heterosis for number of capsules per plant | | |
|---|---|---|---|---|---|---|
| | (di) (%) | (dii) (%) | (diii) (%) | (di) (%) | (dii) (%) | (diii) (%) |
| $L_1 \times T_1$ | 7.65** | 3.66* | 24.67** | 14.93** | 11.95** | 12.19** |
| $L_1 \times T_2$ | -7.90** | -16.60** | -7.14** | -1.61 | -12.45** | -12.26** |
| $L_1 \times T_3$ | 23.52** | 17.23** | 30.53** | 12.94** | 12.82** | 13.06** |
| $L_2 \times T_1$ | -2.42 | -13.46** | 4.08 | -6.43 | -9.50* | -14.01** |
| $L_2 \times T_2$ | -17.53** | -18.77** | -24.41** | -13.32** | -18.52** | -27.66** |
| $L_2 \times T_3$ | 14.69** | 10.71** | 10.71** | 14.96** | 8.52* | 8.52* |
| $L_3 \times T_1$ | 13.45** | 11.39** | 39.01** | 12.71** | 4.63 | 16.05** |
| $L_3 \times T_2$ | -4.24* | -17.47** | 3.00 | 0.67 | -14.21** | -4.84 |
| $L_3 \times T_3$ | 17.83** | 6.13** | 32.44** | -18.25** | -22.28** | -13.79** |
| $L_4 \times T_1$ | -4.29* | -10.65** | 7.46** | -13.12** | -20.72** | -24.67** |
| $L_4 \times T_2$ | 23.75** | 15.46** | 20.40** | -7.84 | -7.99 | -27.87** |
| $L_4 \times T_3$ | -15.94** | -17.67** | -14.15** | 0.33 | -10.52** | -10.52** |
| $L_5 \times T_1$ | 13.25** | 12.98** | 35.88** | 2.77 | 1.76 | -3.31 |
| $L_5 \times T_2$ | -7.50** | -18.85** | -2.87 | -2.91 | -10.74 | -16.85** |
| $L_5 \times T_3$ | -25.91** | -32.00** | -18.61** | 12.74** | 8.88** | 8.88* |
| $L_6 \times T_1$ | 9.48** | -8.16** | 10.45** | 9.10 | -16.47** | -20.63** |
| $L_6 \times T_2$ | -9.94** | -14.33** | -22.63** | -1.70 | -19.10** | -36.79** |
| $L_6 \times T_3$ | 1.05 | -8.29** | -8.29** | 16.57** | -12.30** | -12.30** |
| $L_7 \times T_1$ | 4.59** | -3.92* | 15.55** | 27.93** | 13.75** | 8.08* |
| $L_7 \times T_2$ | -13.85** | -18.29** | -17.72** | -9.98* | -12.39* | -31.55** |
| $L_7 \times T_3$ | 7.65** | 7.28** | 8.03** | -1.42 | -14.26** | -14.26** |

*Significant at 5 percent level, **Significant at 1 percent level

Table 4 Percentage of heterosis for capsule length and number of seeds per capsule

| Hybrids | Heterosis for capsule length | | | Heterosis for number of seeds per capsule | | |
|---|---|---|---|---|---|---|
| | (di) (%) | (dii) (%) | (diii) (%) | (di) (%) | (dii) (%) | (diii) (%) |
| $L_1 \times T_1$ | -0.62 | -1.24 | 9.75** | -6.24* | 11.37** | -6.02 |
| $L_1 \times T_2$ | -5.96** | -8.28** | 1.92 | -5.85* | 6.61* | 0.64 |
| $L_1 \times T_3$ | 7.22** | 1.85 | 13.19** | 5.85* | 2.84 | 9.04** |
| $L_2 \times T_1$ | 0.00 | -4.26* | 5.08* | -4.62 | 10.57** | -3.51 |
| $L_2 \times T_2$ | -5.33** | -7.67** | -2.47 | 5.78* | 5.72 | 14.06** |
| $L_2 \times T_3$ | 0.07 | -0.14 | 0.27 | -1.86 | 5.45 | 2.01 |
| $L_3 \times T_1$ | 1.99 | 1.11 | 12.91** | 18.16** | 17.81** | 11.90** |
| $L_3 \times T_2$ | -7.08** | -9.59** | 0.96 | -8.93** | 14.33** | -7.68* |
| $L_3 \times T_3$ | -4.35* | -9.35** | 1.24 | 9.63** | 6.88* | 6.88* |
| $L_4 \times T_1$ | -0.33 | -5.76** | 3.43 | 1.75 | 0.23 | -5.78 |
| $L_4 \times T_2$ | 7.63** | 3.64 | 9.48** | 7.67** | 0.82 | 6.88* |
| $L_4 \times T_3$ | 0.28 | -0.82 | -0.82 | 0.63 | 4.01 | -4.01 |
| $L_5 \times T_1$ | 0.94 | -5.88** | 3.30 | 0.71 | 5.95 | -11.19** |
| $L_5 \times T_2$ | 6.03** | 0.65 | 6.32** | -0.81 | 12.70** | -5.92 |
| $L_5 \times T_3$ | -0.35 | -2.88 | -2.88 | 3.59 | 5.77 | -5.77 |
| $L_6 \times T_1$ | -0.33 | -6.26** | 2.88 | -3.14 | 6.54 | -11.74** |
| $L_6 \times T_2$ | -4.68** | -8.71** | -3.57 | 0.88 | 8.46** | -1.35 |
| $L_6 \times T_3$ | -2.37 | -3.98 | -3.98 | 0.35 | 5.77 | -5.77 |
| $L_7 \times T_1$ | 1.79 | -0.50 | 9.20** | -5.10 | 8.86** | -6.52* |
| $L_7 \times T_2$ | -6.14** | -6.50** | -1.24 | -3.72 | 6.04* | 1.26 |
| $L_7 \times T_3$ | 7.65** | 7.28** | 8.03** | -1.42 | -14.26** | -14.26** |

*Significant at 5 percent level, **Significant at 1 percent level

*Capsule length*

The cross $L_7 \times T_3$ recorded maximum significant positive relative heterosis (8.52 per cent) followed by $L_4 \times T_2$ (7.63 per cent). Among the hybrids evaluated, $L_7 \times T_3$ produced the maximum significant and positive heterobeltiosis value of 6.03 per cent. The maximum significant and positive standard heterosis value (13.19 per cent) was recorded by $L_1 \times T_3$ followed by $L_3 \times T_1$ (12.91 per cent).

*Number of seeds per capsule*

The cross $L_3 \times T_1$ recorded maximum significant positive relative heterosis (18.16 per cent) followed by $L_3 \times T_3$ (9.63 per cent) and $L_4 \times T_2$ (7.67 per cent). Among the hybrids estimated, $L_3 \times T_1$ produced the maximum significant and positive heterobeltiosis value 17.81 per cent followed by $L_3 \times T_2$ (14.33 per cent). The highest significant and positive standard heterosis value (14.06 per cent) was expressed by the hybrid $L_2 \times T_2$ followed by $L_3 \times T_1$ (11.90 per cent).

*1000 seed weight*

Among the crosses, $L_1 \times T_1$ recorded maximum significant positive relative heterosis (61.76 per cent) followed by $L_3 \times T_1$ (42.70 per cent) and $L_5 \times T_3$ (38.94 per cent). Among the hybrids estimated, $L_4 \times T_2$ produced the maximum significant and positive heterobeltiosis of 23.78 per cent. The highest significant and positive standard heterosis value (20.48 per cent) was recorded by $L_1 \times T_3$ followed by $L_7 \times T_3$ (20.10 per cent).

Table 5 Percentage of heterosis for 1000 seed weight and seed yield per plant

| Hybrids | Heterosis for 1000seed weight | | | Heterosis for seed yield per plant | | |
|---|---|---|---|---|---|---|
| | (di) (%) | (dii) (%) | (diii) (%) | (di) (%) | (dii) (%) | (diii) (%) |
| $L_1 \times T_1$ | 61.76** | 22.70** | 18.96** | 32.09** | 28.20** | 27.94** |
| $L_1 \times T_2$ | 9.89 | 4.99 | 1.78 | -23.54** | -32.28** | -32.42** |
| $L_1 \times T_3$ | 22.35** | 20.48** | 20.48** | 29.62** | 29.49** | 29.49** |
| $L_2 \times T_1$ | -14.25 | -19.04 | -59.41** | 0.13 | -12.28** | -17.61** |
| $L_2 \times T_2$ | 8.05 | -18.73* | -28.24** | -17.75** | -21.13** | -39.30** |
| $L_2 \times T_3$ | 13.73 | -17.81** | -17.81** | 12.02** | -4.42 | -4.42 |
| $L_3 \times T_1$ | 42.70** | 3.81 | 14.38* | 14.32** | 6.29* | 16.16** |
| $L_3 \times T_2$ | -13.72* | -22.29** | -14.38* | -14.46** | -27.11** | -20.34** |
| $L_3 \times T_3$ | -17.19** | -21.02** | -12.98 | 20.31** | 15.20** | 25.90** |
| $L_4 \times T_1$ | 9.70 | -15.95* | -20.87** | 16.17** | 5.77 | -0.66 |
| $L_4 \times T_2$ | 27.75** | 23.78** | 16.54* | -14.93** | -15.00** | -34.46** |
| $L_4 \times T_3$ | -10.35 | -12.98 | -12.98 | -8.99** | -19.41** | -19.41** |
| $L_5 \times T_1$ | -11.85 | -23.41* | -47.96** | 21.32** | 15.26** | 8.25** |
| $L_5 \times T_2$ | 7.17 | -5.19 | -16.28* | 19.22** | 13.89** | -3.73 |
| $L_5 \times T_3$ | 38.94** | 16.67 | 16.67* | -3.48 | -10.95** | -10.95 |
| $L_6 \times T_1$ | -17.29 | -26.57* | -32.54** | 11.46** | -14.19** | -19.41** |
| $L_6 \times T_2$ | 14.48 | -0.86 | -12.47 | -1.05 | -17.95** | -36.84** |
| $L_6 \times T_3$ | 8.04 | -11.07 | -11.07 | 6.09* | -19.61** | -19.61** |
| $L_7 \times T_1$ | -0.47 | -28.00** | -19.21** | -10.11** | -12.76** | -18.06** |
| $L_7 \times T_2$ | -20.69** | -29.14** | -20.48** | -2.74 | -9.02** | -19.58** |
| $L_7 \times T_3$ | 13.19* | 7.03 | 20.10** | 16.28** | 9.53** | 9.53** |

*Significant at 5 percent level,
**Significant at 1 percent level

*Seed yield per plant*

The cross $L_1 \times T_1$ recorded highest significant positive relative heterosis (32.09 per cent) followed by $L_1 \times T_3$ (29.62 per cent), $L_1 \times T_3$ produced the maximum significant and positive heterobeltiosis of 29.49 per cent. The maximum significant and positive standard heterosis value (29.49 per cent) were exhibited by $L_1 \times T_3$ followed by $L_1 \times T_1$ (27.94 per cent).

Heterobeltiosis is a measure of hybrid vigour over the better parent [14]. Bobby and Nadrajan [15] and Devaraj and Nadarajan [16] indicated the need for computing standard heterosis for commercial exploitation of hybrid vigour.

## CONCLUSION

Evaluation of hybrids standard heterosis is to be given importance rather than the other two hybrids of heterosis, so the hybrids are evolved based on standard heterosis. Based on standard heterosis for most of the yield attributing characters the hybrids GT 10 × TMV 7, ACM 14-007 SI-2 × TMV 5 and GT 10 × TMV 5 were rated as the best since it possessed desirable performance for most of the yield attributing characters and the hybrid GT 10 × TMV 5 showed the maximum significant and negative standard heterosis and heterobeltiosis for days to 50% flowering hence, this hybrid can be used for earliness. So, these hybrids could be exploited for further crop improvement.

## LITERATURE CITED

1. Troncoso-ponce MA, Kilaru A, Cao X, Durrett TP, Fan J, Jensen JK, Thrower NA, Pauly M, Wilkerson C, Ohlrogge JB, 2011. Comparative deep transcriptional profiling of four developing oilseeds. *The Plant Journal* 68(6): 1014-1027.

2. Ashri A, Singh RJ. 2007. Sesame (*Sesamum indicum* L.) genetics resources chromosome Engineering and crop improvement. *Oilseed Crop* 4: 231-289.
3. Anilakumar KR, Pal A, Khanum F, Bawa AS. 2010. Nutritional, medicinal and industrial uses of sesame (*Sesamum indicum* L.) seeds-an overview. *Agriculturae Conspectus Scientificus* 75(4): 159-168.
4. Hassan AB, Mahmoud NS, Elmamoun K, Adiamo OQ, Ahmed IAM. 2018. Effects of gamma radiation on the protein characteristics and functional properties of sesame (*Sesamum indicum* L.) seeds. *Radiation Physics and Chemistry* 144: 85-91.
5. Plaitho Y, Rattanasena P, Chaikham P, Prangthip P. 2017. Biochemical and antioxidative properties of unprocessed and sterilized white and black sesame by-product from northern Thailand. *Current Research in Nutritive and Food Science* 5(3): 196-205.
6. Gharby S, Harhar H, Bouzoubaa Z, Asdadi A, El Yadini A, Charrouf Z. 2017. Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. *Journal of the Saudi Society of Agricultural Sciences* 16(2): 105-111.
7. De PS, Bhale VM, Khadse VA. 2013. Quality and Economics of summer sesame (*Sesamum indicum* L.) as influenced by irrigation and nutrient levels. *International Journal of Bio-resource and Stress Management* 4(2): 369-371.
8. FAO. 2017. Food and Agriculture Organization, 2017, WWW.FAO.Otg. Area, production and productivity of sesame.
9. Wadikar PB, Dhare SL, Thorat GS. 2019. Line × Tester analysis for yield and yield contributing traits in sesame (*Sesamum indicum* L.). *Bulletin of Environment, Pharmacology and Life Sciences* 8(6): 88-91.
10. Shilpi S, Islam MN, Sutradhar GNC, Husna A, Akter F. 2012. Effect of nitrogen and sulfur on the growth and yield of sesame. *International Journal of Bio-resource and Stress Management* 3(2): 177-182.
11. Karthikeyan P, Eswaran R, Saravanan KR, Thangavel P. 2019. Combining ability studies through Line × Tester analysis in sesame (*Sesamum indicum* L.). *Journal of Pharmacognosy and Phytochemistry* 8(2): 311-314.
12. Duhoon SS. 2004. Exploitation of heterosis for raising productivity in sesame. *In*: New directions for a diverse planet: Proceedings of the 4th international crop science congress, Brisbane, Australia. Volume 26.
13. Grakh SS, Chaudhary MS. 1985. Heterosis for yearly maturity and high yield in *Gossypium arboretum Ind. Jr. Agric. Sciences* 55: 10-13.
14. Swaminathan MS, Siddiq EA, Sharma SD. 1972. Outlook for hybrid rice in India. *In*: Rice breeding. International Rice Research Institute, Manila, Philippines. pp 609-613.
15. Bobby TPM, Nadarajan N. 1994. Heterosis and Combining ability studies in rice hybrids involving CMS lines. *Oryza* 31: 5-8.
16. Devaraj M, Nadarajan N. 1995. Gene action for seven biometrical traits in rice. *Ann. Agric. Research* 16(3): 360-361.