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Genetic analysis for seed yield and its traits in summer sesame (*Sesamum indicum* L.) over environments

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Abstract

A study was undertaken to evaluate the magnitude of combining ability variance and effects of four females as testers and ten males as lines and forty crosses in sesame for seed yield and component traits over environments. The F_1s along with parents were evaluated in RBD with three replications at the Agricultural Research Station, J.A.U., Amreli and Deptt. Seed Science and Technology, Sagadividi Farm, J.A.U., Junagadh, Gujarat. The analysis of variance for combining ability revealed that the variances due to lines, testers and lines x testers were significant for all the characters over environments (except variance due to lines for days to flowering, 1000-seed weigh and seed yield per plant which indicated the importance of both additive and non-additive types of gene action. Parents AT-285, G.Til-1, RT-54, AT-265, AT-306, AT-341 and G.Til-10 offered the best possibilities for exploitation in the development of improved lines with enhanced yielding ability. It is suggested that population involving these parents in a multiple crossing programme may be developed for isolating desirable recombinants. The hybrids Khadkala-S x G.Til-1, AT-307 x AT-285, AT-322 x AT-285, AT-319 x G.Til-10 and AT-341 x G.Til-10 were high yielding and heterotic along with desirable sca effect for seed yield per plant over environments. These could profitably be exploited through heterosis breeding for general cultivation in order to increase the yield potentiality in sesame.

Keywords: Sesame, combining ability, gca, sca and seed yield

Introduction

Sesame *(Sesamum indicum* L.) is most important oil seed crop, not only in India, but across the world. This crop is feasibly the most ancient oil seed known and used by man. Area wise it is known as Til, Tilli, Gingelly, Ellu, Sim-sim, Benni Seed, and sesame in different parts of India. It is often called as the epithet "the queen of oilseeds by virtue of quality of oil it produces. Sesame seed contains oil (57-63%), protein (22-24%), carbo- hydrates (10-12%), and crude fiber (4-7). It is rich in unsaturated fatty acids, methionine, and tryptophan. Also, it is rich in micronutrients such as minerals, lignans, tocopherol, and phytosterol (Hassan *et al*., 2018) [5]. The sesame is a self-pollinated crop and the genus *sesamum* belongs to Pedaliaceae family. The genus *Sesamum* consists of many species but, only *Sesamum indicum* L. has been recognized as a cultivated species (Ashri, 1998) [2]. According to Kobayashi *et al.* (1990) [9], 36 species have been identified of which 22 species have been found in Africa, five in Asia, seven in both Africa and Asia and one species each in Crete and Brazil. There are three cytogenetic groups of which 2n=26 consist of the cultivated *S. indicum* along with *S. alatum, S. capense, S. schenckii, S. malabaricum*; 2n=32 consist of *S. prostratum, S. laciniatum, S. angolense, S. angustifolium;* while *S. radiatum, S. occidentale, S. schinzianum* belong to 2n=64. Mainly due to the differences in chromosomal numbers across the three cytotaxonomic groups, there is limited cross compatibility among the species. It is one of the important oilseed crops grown next to groundnut and mustard in India. The oilseed crops play an important role in agriculture and industrial economy of our country. India occupies a very prominent place in the oilseed map of the world as it produces a large variety of oilseed crops and ranks first in respect of area and production. Sesame can grow well in many ecological regions of tropical and sub-tropical climates, although its cultivation reaches from 40° N to 40° S latitude.

In India, during 2015-16, sesame is cultivated in an area of 17.46 lakh ha with a production of 9.11 lakh tones annually and productivity of 474 kg/ha (Anon., 2016) [1]. Being the fourth important oilseed crop in Indian agriculture after groundnut, rape seed and mustard, it is widely cultivated in the states of Uttar Pradesh, Rajasthan, Orissa, Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, West Bengal, Bihar and Assam. In Gujarat, during 2015-16, sesame is cultivated in an area of 2.56 lakh ha with a production of 1.52 lakh tones and productivity of

530 kg/ha (Anon., 2016) [1]. The average productivity is very low as compare to other growing countries China, Japan and Korea. Hence, there is an urgent need to increase the productivity by breaking the present yield barrier and developing hybrids with high yield potential.

The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and Tatum (1942) [20]. The resulting total genetic variance is partitioned into the variance due to general combining ability and specific combining ability. The general combining ability is an average performance of a line in hybrid combinations and can be recognized as a measure of additive gene action and specific combining ability is the deviation from expectation on the basis of average performance of lines involved and can be regarded as a measure of non-additive gene action. The line x tester analysis proposed by Kempthorne (1957) [8] is powerful tool to discriminate good as well as poor combiners and choose appropriate parental material in breeding programme. Therefore, combining ability analysis was carried-out in the present study with a view to obtain useful information for selection of better parents and crosses for their further use in breeding programme. The information regarding nature and magnitude of gene action could also be obtained, which is useful in deciding breeding methodology aiming at exploitable fixable (additive) and non-fixable (non-additive) genetic variances. An estimate of combining ability is known to be greatly influenced by the environment. The results of combining ability analysis based on single environment do not take into account genotype by environment interaction and so results obtained might be highly biased. Therefore, the results based on several environments would be more realistic, which take into account the stability of gene action. Increasing the number of environments reduces the contribution of both the pooled error and the additive by environment interaction to the phenotypic variances, whereas increasing replications only reduces the pooled error. Therefore, the present study was undertaken to study the combining ability estimates, combining ability x environment interaction and nature and extent of gene action in sesame.

Selection of the parents for hybridization programme is most important aspect in the crop improvement programme and the performance of varieties in a varietal trial may give an idea of their relative superiority. Therefore, in any robust breeding programme, the proper choice of parents based on their combining ability is a pre-requisite. As such studies intended to determine the combining ability provide not only necessary information regarding the choice of parents but also illustrate the nature and magnitude of gene action involved. Accordingly, the present investigation was undertaken on combining ability for yield and yield components in sesame with a view to identify good combiners which may be used to create a population with favourable genes for yield and contributing characters in sesame. An estimate of combining ability is known to be greatly influenced by the environments. The results of combining ability analysis based on single environment do not take into account genotype by environment interaction and so results obtained might be highly biased. Therefore, the results based on several environments would be more realistic, which take into account the stability of gene action. Increasing the number of environments reduces the contribution of both pooled error and additive environment interaction to the phenotypic variances, whereas increasing replications only reduces the pooled error. Therefore, the present study was undertaken to study the combining ability estimates, combining ability x environment interaction and nature and extent of gene action in sesame.

Materials and Methods

The experimental material for the present investigation consisted of 14 parents (4 females as testers and 10 males as lines) and their forty crosses along with Gujarat Til-2 and Gujarat Til-3 as checks. The forty crosses was generated in line x tester mating design during summer 2015 at Agricultural Research Station, J.A.U., Amreli and it was evaluated in randomized block design with three replications over four environments (timely and late sowing) during summer 2016 at the Agricultural Research Station, J.A.U. Amreli and Dept. of Seed Science and Technology, COA, Sagadividi Farm, J.A.U., Junagadh. Four environments were created through different time and location for sowing during summer 2016 i.e. E_1= Timely sowing 3rd week of February at Amreli (20th February), E_2= Timely sowing 3rd week of February at Junagadh (20th February), E_3= Late sowing 2nd week of March at Amreli (10th March), and E_4= Late sowing 2nd week of March at Junagadh (10th March). The parents and F_1's with checks were sown in single row (plot) of 2.25 m length with spacing 45 cm x 15 cm. All the agronomical practices and plant protection measures were followed as and when required to raise a good crop of sesame. The observations were recorded on five randomly selected plants from parents and crosses for all characters *viz.*, days to flowering, days to maturity, plant height (cm), height to first capsule (cm), number of branches per plant, number of internodes per plant, length of capsule (cm), width of capsule (cm), number of capsules per plant, number of capsules per leaf axil, number of seeds per capsule, 100-seed weight (g) and seed yield per plant (g). Agricultural Research Station, J.A.U., Amreli is located in North Saurashtra Agro-climatic zone-VI of Gujarat state. Geographically, Amreli is situated at 21.35 N latitude and 71.12 E longitudes with an elevation of 130 meters above the mean sea level. The soil of the experimental site was medium black with pH is 7.5 to 8.3.

Deptt. Seed Science and Technology, Sagadividi Farm, J.A.U. Junagadh is located in South Saurashtra Agro Climatic Zone-III of Gujarat state. Geographically, Junagadh is situated at 21.50 N latitude and 70.50 E longitudes with an elevation of 82.92 meters above the mean sea level. The soil of the experimental site was medium black with pH 7.8. Standard procedures for analysis of variance were followed. Data were first subjected to the analysis followed for randomized block design as per Panse and Sukhatme (1967). Line x tester analysis method developed by Kempthorne (1957) [8] was utilized in the present investigation to develop forty experimental hybrids of sesame from ten males as lines and four testers females as testers, which were evaluated under four different locations for seed yield and component characters.

Results and Discussion

Seed yield is the ultimate result of most of the yield component characters and having almost economic importance in sesame cultivation. In present study, the analysis of variance for combining ability revealed that the variances due to lines, testers and lines x testers were significant for all the characters under all the environments as well as in pooled analysis over environments (except variance due to lines for days to flowering, 1000-seed weigh and seed yield per plant which indicated the importance of both additive and non-additive types of gene action in the expression of seed yield and its component traits. Interaction effects of environments with lines, testers and lines x testers were also found significant for all the characters indicating the influence of environments in the expression of different lines, testers and hybrids for various traits.

In pooled over environment, analysis of variance for combining ability revealed that mean squares due to lines and testers were significant for all the suggesting that both lines and testers had considerable general combining ability (gca) and contributed towards additive genetic variance. Highly significant mean squares due to lines x testers were manifested by all the characters reflecting its significant contribution in favor of specific combining ability (sca) and towards non-additive genetic variance. The estimated variances due to testers (σ^2t) were higher than the corresponding variances due to lines (σ^2l) for all the characters except length of capsule, width of capsule and number of capsules per leaf axils. This indicated that testers contributed more than lines towards $\hat{\sigma}^2$gca. Hybrids showed sensitivity to environments with estimated high value as in plant height, height to first capsule, length of capsule, number of capsules per plant, number of seeds per capsule, 1000-seed weight and seed yield per plant. In estimated value for males and female indicated that $\hat{\sigma}^2$gca due to males and female was less sensitive to changing environments for remaining traits.

The estimates of σ^2gca were higher than the corresponding σ^2sca for days to flowering, days to maturity, plant height, height to first capsule, number of branches per plant, number of internodes per plant, width of capsule, number of capsules per plant, number of capsules per leaf axil, number of seeds per capsule and seed yield per plant. While, in case of remaining characters *viz*., length of capsule and 1000-seed weight, the magnitude of σ^2sca was higher than σ^2gca.The ratio of σ^2gca/σ^2sca was less than unity for length of capsule and 1000-seed weight which indicated that non-additive gene action, while for remaining character it was more than unity which indicated that additive gene action (Table 1.).

The estimates of additive component due to lines (σ^2l x e), testers (σ^2t x e) and non-additive components due to hybrids (σ^2lt x e) under pooled analysis indicated that all these sources significantly interacted varied with environments. However, comparing its magnitude, non-additive component due to hybrids (σ^2lt x e) was more sensitive to fluctuating environments as compared to additive component due to lines (σ^2l x e) and testers (σ^2t x e), which indicated that the study of estimation of components of genetic variance for these characters is necessary in large number of environments to arrive at a correct decision regarding their relative importance. The results also suggested that the hybrids were more sensitive to fluctuating environments as compared to lines and testers. Similar results have been reported by Chaudhari *et al.* (2015) [4] for days to flowering, days to maturity, plant height, number of branch per plant, number of capsule per plant, capsule length, number of seeds per capsule, 1000-seed weight and seed yield per plant (Table 1.).

AT-285 female was found good general combiner for days to flowering among the males, AT-265 was found as good general combiners. Total 14 crosses displayed significant and negative sca effect for days to flowering in pooled analysis. The top five important crosses namely Khadkala-S x AT-285 (-2.28), Bhuva-2 x AT-285 (-1.56), AT-306 x G.Til-1 (-1.55), IS-209 x G.Til-1 (-1.52), and AT-253 x G.Til-10 (-1.36). Among the 40 crosses, two crosses *viz.*, Khadkala-S x AT-285 and IS-209 x G.Til-1, were identified as good specific combiners for days to flowering.

The females, AT-285 was identified as good general combiner as it exhibited significant desirable (negative) gca effect for days to maturity. Two males *viz.*, AT-265 and AT-341 showed significant and negative gca they were considered as good general combiners for days to maturity. Significant and desirable (negative) sca effect for days to maturity of primary was displayed by 9 cross..Best five specific combiners identified for days to maturity were AT-306 x AT-285 (-2.51), AT-253 x G.Til-10 (-2.37), AT-265 x G.Til-10 (-1.95), AT-322 x RT-54 (-1.60) and Bhuva-2 x AT-285 (-1.56). Out of 40 hybrids, only one cross AT-265 x G.Til-10 was identified as good specific combiners for days to maturity.

G.Til-10 female were identified as good general combiners as they had significant and positive gca effect for plant height. In case of males, AT-341 and AT-306 recorded significant and positive gca effect in desirable direction for plant height. Thus, these parents were identified as good general combiners for this character.14 crosses were identified as good specific combiners for this character. The maximum desirable sca effect was recorded by the cross AT-265 x RT-54 (15.76) followed by IS-209 x G.Til-10 (11.01), Bhuva-2 x AT-285 (7.53), AT-253 x G.Til-1 (6.44), AT-341 x AT-285 (5.81), Bhuva-2 x G.Til-10 (5.70), AT-306 x RT-54 (5.65), AT-319 x AT-285 (5.58) and Khadkala-S x RT-54 (4.81). In all, five crosses *viz.,* AT-265 x RT-54, IS-209 x G.Til-10, AT-307 x RT-54, AT-341 x AT-285 and Bhuva-2 x G.Til-10 were identified as good specific combiners for plant height.

Among the females, G.Til-1 and AT-285 were identified as good general combiner as it exhibited significant and negative (desirable) gca effect for height to first capsule. The two males *viz.,* AT-253 and AT-322 showed significant and negative gca effect in pooled analysis and hence, they were considered as good general combiners for height to first capsule. Three male *viz.*, AT-253, AT-322 and AT-319 were good general combiners simultaneously for pooled analysis. Fourteen cross combinations exhibited significant and negative (desirable) sca effect for this trait in pooled environments, the most important crosses included AT-265 x AT-285 (-6.89), Bhuva-2 x RT-54 (-6.41), IS-209 x RT-54 (-5.91), AT-307 x G.Til-10 (-5.75) and AT-265 x G.Til-10 (-4.20) as they expressed negative and significant sca effect for height to first capsule. Five cross displayed significant and desirable (negative) sca effect.

The females, G.Til-10 were identified as good general combiners as they had significant and positive GCA effect for number of branches per plant. In case of males, AT-319, Bhuva-2 and AT-253 recorded significant and positive gca effect in desirable direction. Thus, these parents were identified as good general combiners for this character. The significant cross combinations identified for number of branches per plant were 17. Twelve crosses were identified as good specific combiners for traits. The best ones among them were AT-253 x G.Til-10 (1.47), AT-319 x G.Til-10 (0.78), AT-306 x G.Til-10 (0.71), AT-307 x AT-285 (0.62), Khadkala-S x G.Til-1 (0.48), AT-341 x G.Til-1 (0.42) and AT-341 x RT-54 (0.36). Five crosses *viz.*, AT-253 x G.Til-10, AT-319 x G.Til-10, AT-306 x G.Til-10, AT-307 x AT-285 and AT-341 x G.Til-1 were identified as good specific combiners.

Out of four females, G.Til-10 was found good general combiners for number of internodes per plant. Two males *viz.*, AT-306 and AT-322 were identified as good general combiners. None of male's parents was consistent in pooled analysis. Significant and positive sca effect for 11 crosses. Across environment, ten crosses displayed significant and desirable sca effect for number of internodes per plant, among them the best five specific combiners were Bhuva-2 x AT-285 (4.37), AT-265 x RT-54 (3.90), AT-319 x G.Til-1 (2.93), AT-322 x G.Til-1 (2.75) and Khadkala-S x RT-54 (2.62). The crosses namely AT-265 x RT-54 and Bhuva-2 x AT-285 were adjusted as good specific combiners for number of internodes per plant.

The perusal of results revealed that among female parents only G.Til-1 (0.08) was found to be good general combiner for length of capsule by exhibiting highly significant and positive gca effects. Three males exhibited highly significant and positive gca categorized as good general combiners. The three males, AT-253 (0.18), AT-265 (0.15) and IS-209 (0.18) expressed significant and positive gca effects. Eleven crosses were isolated as best specific combiners. With maximum desirable sca effect included Bhuva-2 x G.Til-10 (0.31), AT-319 x AT-285 (0.30), AT-265 x G.Til-1(0.27), AT-253 x RT-54 (0.27), Khadkala-S x G.Til-1 (0.25), IS-209 x AT-285 (0.18) and AT-306 x AT-285 (0.17). Four cross combinations displayed significant and desirable (positive) sca effect.

The female, G.Til-1 had highly significant and positive gca effects and hence considered as good general combiners for width of capsule. The males, AT-253, AT-265, AT-306 and IS-209 recorded highly significant and positive GCA effect. Nineteen crosses were considered as good specific combiners for this character. The maximum top five sca effect was recorded by the cross AT-307 x AT-285 (0.08) followed by AT-319 x G.Til-1 (0.06), AT-319 x RT-54 (0.06), AT-341 x G.Til-1 (0.04) and IS-209 x G.Til-10 (0.03). Three crosses i.e., AT-307 x AT-285, AT-319 x G.Til-1 and AT-319 x RT-54 were identified as good specific combiner for width of capsule.

Among the females, G.Til-10 was identified as good general combiners as they had significant and positive gca effect for number of capsules per plant. In case of males, AT-341, recorded positive significant gca effect in desirable direction. Thus, these parents were identified as good general combiners for this character. Five best crosses *viz.*, AT-306 x G.Til-10 (12.99), Khadkala-S x G.Til-1 (10.74), AT-307 x RT-54 (9.63), AT-319 x AT-285 (8.56) and AT-307 x AT-285 (8.20) expressed positive and significant sca. Five crosses *viz.*, AT-306 x G.Til-10, Khadkala-S x G.Til-1, AT-307 x AT-285, Bhuva-2 x G.Til-1 and AT-253 x RT-54 displayed significant and positive sca effect for number of capsules per plant.

Female parent, G.Til-1 showed desirable gca effect for number of capsules per leaf axil and was identified as good general combiners as it exhibited significant and positive gca effect. Whereas, two males only, Khadkala-S and AT-265 in displayed significant and positive (desirable) gca effect. Hence, they were considered as good general combiners for traits. A total eleven crosses displayed significant and positive sca effect number of capsules per leaf axil in pooled analysis. The top five important crosses were IS-209 x RT-54 (0.38), AT-307 x RT-54 (0.30), AT-265 x G.Til-1 (0.27), AT-322 x G.Til-1 (0.22) and Bhuva-2 x G.Til-1 (0.21). Among the 40 crosses, three crosses *viz.*, IS-209 x RT-54, AT-307 x RT-54 and AT-306 x AT-285 were identified as good specific combiners.

Among the females, only G.Til-10 was identified as good general combiner as it exhibited significant and positive gca effect for number of seeds per capsule. Whereas, two males *viz.*, AT-319 and AT-253 showed significant and positive gca effect in pooled analysis and hence, they were considered as good general combiners for traits. Across environments, six crosses displayed significant and desirable sca effect for traits, among them the best specific combiners were AT-306 x AT-285 (5.73), AT-253 x G.Til-10 (5.24), AT-319 x G.Til-10 (4.28), Khadkala-S x G.Til-1 (3.91), AT-253 x RT-54 (2.97) and Bhuva-2 x RT-54 (2.19). One cross i.e., AT-306 x AT-285 was adjusted as good specific combiner.

The perusal of results revealed that among female parents, only G.Til-1 was found to be good general combiner for 1000-seed weight by exhibiting significant and positive gca effects. Out of 10 males, two male parents AT-265 and AT-319 showed their consistent performance by recording significant gca effects in desirable direction for characters. The male, AT-265 (0.14) and AT-319 (0.08) expressed maximum positive gca effects. Pooled analysis displayed nineteen crosses with significant and positive SCA effects, out of which five best crosses were AT-341 x G.Til-10 (0.42), IS-209 x G.Til-1 (0.42), AT-322 x AT-285 (0.38), AT-322 x G.Til-10 (0.32) and AT-306 x G.Til-1 (0.32). Eight crosses namely AT-341 x G.Til-10, IS-209 x G.Til-1, AT-322 x AT-285, AT-322 x G.Til-10, AT-306 x G.Til-1, AT-253 x RT-54, Bhuva-2 x G.Til-10 and AT-253 x AT-285 displayed significant and positive sca effect for 1000-seed weight (g)..

G.Til-10 was found to be good general combiner for seed yield per plant by exhibiting highly significant and positive gca effects. AT-341 exhibited significant and positive gca effect categorized as good general combiner. However, none of male parents showed their consistent performance. The males, AT-341 and AT-253 expressed significant and positive gca effects. In pooled analysis, twelve crosses were considered as good specific combiners for seed yield per plant. The top five sca effect was recorded by the cross Khadkala-S x G.Til-1 (2.35) followed by AT-307 x RT-54 (1.58), AT-307 x AT-285 (1.54), AT-322 x AT-285 (1.44) and AT-322 x G.Til-10 (1.42). Four crosses were adjusted as good specific combiners for seed yield per plant *viz.*, AT-319 x AT-285, AT-306 x G.Til-10, AT-341 x G.Til-10 and IS-209 x G.Til-1 (Table 2 & 3.).

In the present study, the gca effects of parent were more or less associated with their *per se* performance for all the characters. For instance, male AT-341 which exhibited highly significant and positive gca effect for seed yield per plant, days to flowering, days to maturity, plant height and number of capsules per plant also expressed high *per se* performance for the respective characters. G.Til-10 exhibited highly significant and positive gca effect for seed yield per plant, plant height, number of branch per plant, number of internodes per plant, number of capsules per plant, number of seeds per capsule also expressed high *per se* performance for the respective characters. Similarly, AT-253, AT-265, AT-306, AT-307, AT-319, Bhuva-2, Khadkala-S, AT-285 and G.Til-1 parents showing significant gca effect in desired direction for different traits also showed good *per se* performance for the respective characters. Thus, the association between *per se* performance of parents and their gca effect suggested that while selecting the parents for hybridization programme, *per se* performance of the parents should be given due consideration. Thus, if a character is uni-directionally controlled by a set of alleles and additive effect are important, the choice of parents on the basis of the *per se* performance may be more effective. Vavdiya *et al.* (2014) [23], Chaudhari *et al.* (2015) [4], Vaithiyalingan (2015) [22], Pawar and Monpara (2016) [13], Priya *et al.* (2016) [15], Tripathy *et al.* (2016b) [21], Mungala *et al.* (2017) [11], Saxena and Bisen

(2017) [18], Ram *et al.* (2018) [17] and Virani *et al.* (2018) [24] have also suggested that parental selection can be done on the basis of *per se* performance, which supported the present findings.

High general combining ability effect of parents mostly contributes additive gene effect and additive x additive interaction effect and represents fixable portion of genetic variation. In view of this, parents AT-285, G.Til-1, RT-54, AT-265, AT-306, AT-341 and G.Til-10 offered the best possibilities for exploitation in the development of improved lines with enhanced yielding ability. It is suggested that population involving these parents in a multiple crossing programme may be developed for isolating desirable recombinants. Further, the varieties or lines showing good general combining ability for particular component may be utilized in component breeding for effective improvement in particular component ultimately seeking improvement in seed yield itself (Table 4).

The estimate of SCA effects revealed that none of the crosses was superior simultaneously for all the characters. However, the best hybrids on the basis of significant and positive sca effect for seed yield per plant were Khadkala-S x G.Til-1, AT-307 x RT-54, AT-307 x AT-285, AT-322 x AT-285 and AT-319 x G.Til-10 (Table 4). All of these hybrids recorded significant and desirable sca effect for one or more component traits of seed yield. In general, results revealed that as component traits of seed yield with significant and desirable effect increased, the value of sca effect of hybrids for seed yield also increased, e.g., the top ranking hybrid Khadkala-S x G.Til-1 recorded significant and desirable sca effect for number of branch per plant, length of capsule, number of capsules per plant and number of seeds per capsule; second ranking hybrid AT-307 x RT-54 recorded significant and desirable sca effect for number of capsules per leaf axil; third ranking hybrid AT-307 x AT-285 recorded significant and desirable sca effect for width of capsule and number of capsules per plant; fourth ranking hybrid AT-322 x AT-285 only 1000-seed weight; and fifth ranking hybrid AT-319 x G.Til-10 number of branch per plant and number of seeds per capsule. In general, the hybrids with significant and desirable sca effect for seed yield also recorded significant and desirable sca effect for one or more of its component traits. Similar findings, as observed in present study, were also reported by Senthil and Kannan (2010) [19], Prajapati *et al.* (2010b) [14], Rajaram and Kumar (2011) [16], Vavdiya *et al.* (2014) [23], Chaudhari *et al.* (2015) [4], Hassan and Rehab (2015) [6], Joshi *et al.* (2015) [7], Meena kumari *et al.* (2015) [10], Pawar and Monpara (2016) [13], Priya *et al.* (2016) [16], Tripathy *et al.* (2016b) [21], Mungala *et al.* (2017) [11], Saxena and Bisen (2017) [18], Ram *et al.* (2018) [17] and Virani *et al.* (2018) [24].

Table 1: Analysis of variance (mean squares) for pooled over environments

Source	d.f.	Days to flowering	Days to maturity	Plant height	Height to first capsule	No. branches /plant	No. internodes/ plant	Length capsule	Width capsule	No.of capsule/ plant	No. of capsules/ leaf axil	No. seeds /capsule	1000-seed weight	Seed yield/ plant
Lines (L)	9	2.64**	9.20**	186.50**	101.79**	0.73**	13.32**	0.31**	0.02**	149.70**	0.42**	50.59**	0.08**	4.61*
Testers (T)	3	58.69**	140.94**	1129.70**	345.00**	19.09**	227.68**	0.18**	0.02**	1979.00**	0.28**	296.43**	0.12**	81.33**
L x T	27	3.53**	4.62**	106.20**	45.82**	0.67**	12.20**	0.08**	0.00**	110.40**	0.08**	20.00**	0.18**	4.74**
Environments (E)	3	203.82**	705.72**	1814.9**	1607.89**	0.13	448.41**	0.06**	0.00**	1710.00**	0.20**	272.90**	0.46**	82.33**
L x E	27	4.56**	16.86**	231.60**	113.98**	0.66**	37.96**	0.25	0.01**	254.60**	0.37**	110.75**	0.08**	7.68**
T x E	9	43.85**	100.35**	793.90**	306.32**	13.32**	168.30**	0.17	0.02**	1684.70**	0.24**	272.62**	0.10**	79.92**
(L x T) x E	81	5.17**	8.33**	138.60**	64.05**	0.72**	17.22**	0.09	0.00**	373.00**	0.11**	50.72**	0.16**	8.08**
Error	106	0.98	2.20	24.94	13.23	0.092	4.75	0.01	0.00	50.59	0.02	15.51	0.013	1.90
Variance components														
Lines ($\hat{\sigma}^2$l)		-0.06	0.29	5.02	3.50	0.00	0.07	0.01	0.00	2.45	0.02	1.91	-0.01	-0.01
Testers ($\hat{\sigma}^2$t)		1.38	3.41	25.59	7.48	0.46	5.39	0.00	0.00	46.71	0.01	6.91	-0.00	1.91
$\hat{\sigma}^2$l x e		0.25	1.12	18.70	9.16	0.05	2.90	0.02	0.00	17.74	0.03	8.73	0.01	0.61
$\hat{\sigma}^2$t x e		1.42	3.29	25.01	9.54	0.44	5.45	0.00	0.00	56.78	0.01	8.59	0.00	2.58
$\hat{\sigma}^2$lt x e		1.20	1.65	43.81	20.01	0.23	4.68	0.03	0.00	75.69	0.03	14.91	0.05	2.59
$\hat{\sigma}^2_{GCA}$		1.94	5.03	39.42	12.68	0.66	7.74	0.01	0.00	68.14	0.02	10.96	-0.01	2.73
$\hat{\sigma}^2_{SCA}$		0.63	0.61	20.31	8.15	0.14	1.86	0.02	0.00	13.04	0.02	0.88	0.04	0.65
$\hat{\sigma}^2_{GCA}/\hat{\sigma}^2_{SCA}$		3.05	8.31	1.94	1.56	4.57	4.16	0.78	1.08	5.23	1.21	12.45	-0.13	4.22

Table 2: General combining ability effect for lines and testers under pooled over environments in sesame

Parents	Days to flowering	Days to maturity	Plant height	Height to first capsule	No. branches /plant	No. internodes/ plant	Length capsule	Width of capsule	No. capsule/ plant	No. capsules/ leaf axil	No. seeds /capsule	1000-seed weight	Seed yield/ plant
Females (Testers)													
AT-285	-0.75**	-1.31**	-1.30	-1.92*	-0.46**	-0.37	-0.04	0.00	-0.68	-0.04	-1.08	0.02	-0.22
G.Til-1	-0.55*	-0.55	-4.43**	-1.82*	-0.50**	-1.45**	0.08**	0.03**	-3.28	0.10**	-0.96	0.07*	-0.61
G.Til-10	1.81**	2.78**	7.71**	4.31**	0.99**	3.48**	-0.07**	-0.03**	10.02**	-0.09*	4.02**	-0.04	2.05**
RT-54	-0.51*	-0.92*	-1.99	-0.56	-0.04	-1.65**	0.03	0.00	-6.06**	0.03	-1.99	-0.05	-1.22**
SEgi ±	0.16	0.25	0.74	0.57	0.05	0.35	0.02	0.004	1.12	0.02	0.65	0.02	0.22
Males (Lines)													
AT-253	0.20	0.35	-4.99**	-4.33**	0.24**	-0.61	0.18**	0.04**	2.59	-0.07	2.02*	0.02	0.61
AT-265	-0.86**	-1.13**	0.35	0.06	-0.02	0.03	0.15**	0.04**	-3.52*	0.15**	0.35	0.14**	-0.27
AT-306	-0.21	0.04	3.50**	4.00**	0.00	1.12*	-0.07*	0.03**	-1.67	-0.16**	1.83	-0.02	-0.20
AT-307	-0.05	-0.04	2.27	3.01**	-0.12	0.05	-0.12**	-0.04**	-0.38	-0.01	-0.13	-0.01	-0.13

AT-319	-0.26	-0.11	-3.83**	-1.46	0.34**	-2.02**	0.03	-0.02**	0.05	-0.17**	2.86**	0.08**	0.59
AT-322	0.39	-0.44	-4.01**	-2.54**	-0.23**	1.09*	-0.17**	0.00	2.78	-0.08*	-1.39	-0.05	0.32
AT-341	-0.26	-1.09**	5.27**	1.92*	-0.32**	-0.04	-0.06*	-0.05**	5.45**	-0.11**	0.07	-0.02	0.76*
Bhuva-2	0.33	0.33	1.21	-0.40	0.24**	0.28	-0.18**	-0.03**	1.43	0.07	-1.80	-0.13**	-0.28
Khadkala-S	0.29	0.79	1.20	0.56	-0.08	-0.46	0.05	0.00	-3.23	0.37**	-2.26*	-0.01	-0.75*
IS-209	0.43	1.29**	-0.98	-0.82	-0.05	0.56	0.18**	0.03**	-3.50	0.00	-1.56	0.00	-0.65
SEg_i ±	0.25	0.40	1.17	0.89	0.08	0.55	0.03	0.01	1.78	0.04	1.02	0.03	0.34

*,** Significant at 5 and 1 % levels, respectively.

Table 3: Specific combining ability effect of hybrids pooled over environments in sesame

.Sr. No.	Crosses	Days to flowering	Days to maturity	Plant height	Height to first capsule	No.branches /plant	No. internodes/ plant	Length of capsule	Width of capsule	No. capsule/ plant	No. capsules/ leaf axil	No. seeds /capsule	1000-seed weight	Seed yield/ plant
1	AT-253 x AT-285	0.94**	2.52**	-2.14	-1.89*	-0.33**	-1.43**	-0.10**	0.03**	-1.45	-0.12**	-4.94**	0.12**	-0.57
2	AT-253 x G.Til-1	1.12**	0.73	6.44**	3.16**	-0.73**	1.10*	-0.06*	0.01	-1.83	0.12**	-3.27**	0.01	-0.53
3	AT-253 x G.Til-10	-1.36**	-2.37**	2.73*	2.18*	1.47**	0.58	-0.11**	-0.01*	-0.87	0.18**	5.24**	-0.42**	-0.26
4	AT-253 x RT-54	-0.70**	-0.88*	-7.02**	-3.45**	-0.41**	-0.24	0.27**	-0.03**	4.15*	-0.17**	2.97**	0.29**	1.36**
5	AT-265 x AT-285	0.91**	0.83*	-5.78**	-6.89**	0.15	0.48	-0.30**	-0.01*	-5.55**	0.05	0.93	-0.13**	-1.13**
6	AT-265 x G.Til-1	-0.35	0.26	-0.63	1.28	0.22**	-0.73	0.27**	0.02**	1.22	0.27**	-0.80	0.08**	0.13
7	AT-265 x G.Til-10	-1.05**	-1.95**	-9.35**	-4.20**	-0.34**	-3.65**	0.13**	0.00	1.53	-0.14**	0.10	-0.06	0.48
8	AT-265 x RT-54	0.49	0.87*	15.76**	9.81**	-0.03	3.9**	-0.10**	0.00	2.80	-0.19**	-0.23	0.10**	0.53
9	AT-306 x AT-285	-0.06	-2.51**	-3.92**	-3.32**	-0.22**	1.48**	0.17**	0.03**	-2.55	0.15**	5.73**	0.15**	0.42
10	AT-306 x G.Til-1	-1.55**	1.37**	-5.42**	2.42**	-0.11	-2.56**	-0.17**	-0.05**	-4.58*	-0.19**	-0.26	0.32**	-0.29
11	AT-306 x G.Til-10	1.64**	1.38**	3.69**	-1.90*	0.71**	0.22	-0.08**	0.01	12.99**	0.05	-3.63**	-0.16**	1.14**
12	AT-306 x RT-54	-0.04	-0.24	5.65**	2.80**	-0.38**	0.85	0.08**	0.01*	-5.86**	-0.01	-1.84	-0.31**	-1.27**
13	AT-307 x AT-285	-0.06	1.27**	-0.40	2.44**	0.62**	-0.07	-0.06*	0.08**	8.20**	0.11**	0.37	0.01	1.54**
14	AT-307 x G.Til-1	0.68**	-1.07**	3.6**	0.04	0.25**	0.45	0.10**	-0.08**	-3.87*	-0.23**	1.66	0.17**	-0.01
15	AT-307 x G.Til-10	-1.47**	-0.62	-7.86**	-5.75**	-1.02**	0.13	-0.02	-0.03**	-13.96**	-0.18**	0.09	-0.36**	-3.11**
16	AT-307 x RT-54	0.85**	0.43	4.66**	3.27**	0.16*	-0.50	-0.01	0.03**	9.63**	0.30**	-2.12*	0.18**	1.58**
17	AT-319 x AT-285	1.33**	0.69	5.58**	6.73**	-0.19*	-2.35**	0.30**	-0.06**	8.56**	-0.06	-2.18*	0.23**	1.41**
18	AT-319 x G.Til-1	-0.82**	-0.55	1.21	-0.92	-0.20*	2.93**	0.05	0.06**	-4.96**	-0.11**	0.61	-0.42**	-1.62**
19	AT-319 x G.Til-10	-0.41	-0.42	-2.87*	-3.69**	0.78**	1.01	-0.21**	-0.07**	1.75	0.04	4.28**	0.09**	1.42**
20	AT-319 x RT-54	-0.09	0.29	-3.91**	-2.12*	-0.39**	-1.59**	-0.14**	0.06**	-5.34**	0.12**	-2.72**	0.10**	-1.21**
21	AT-322 x AT-285	-0.75**	0.35	-1.23	2.25*	0.10	-0.58	-0.02	0.01*	6.66**	-0.20**	-0.01	0.38**	1.44**
22	AT-322 x G.Til-1	1.43**	1.01*	1.72	-0.33	-0.16*	2.75**	0.03	0.02**	-5.73**	0.22**	-2.70**	-0.43**	-1.80**
23	AT-322 x G.Til-10	0.06	0.24	-1.99	-2.18*	-0.02	-2.79**	-0.01	0.03**	3.44	0.05	0.75	0.32**	1.41**
24	AT-322 x RT-54	-0.73**	-1.60**	1.51	0.26	0.08	0.61	0.00	-0.06**	-4.37*	-0.07	1.96	-0.28**	-1.04**
25	AT-341 x AT-285	1.44**	-0.12	5.81**	-0.11	-0.11	1.45**	0.08**	-0.03**	-1.82	0.05	1.86	-0.24**	-0.60
26	AT-341 x G.Til-1	-0.60*	-0.35	-4.52**	-0.49	0.42**	-2.58**	0.02	0.04**	-2.26	0.07	0.13	-0.13**	-0.48
27	AT-341 x G.Til-10	-0.53*	-0.79	0.23	0.33	-0.68**	1.58**	-0.07**	0.01	3.02	-0.03	-3.10**	0.42**	1.01**
28	AT-341 x RT-54	-0.31	1.26**	-1.52	0.27	0.36**	-0.45	-0.02	-0.02**	1.05	-0.09*	1.12	-0.05	0.08
29	Bhuva-2 x AT-285	-1.56**	-1.56**	7.53**	3.98**	-0.03	4.37**	-0.01	-0.02**	0.06	0.06	0.74	-0.01	0.10
30	Bhuva-2 x G.Til-1	1.62**	-1.02*	-1.69	-2.48**	0.04	-1.80**	-0.24**	-0.01*	7.33**	0.21**	-0.62	-0.11**	0.87*
31	Bhuva-2 x G.Til-10	1.03**	2.66**	5.70**	4.91**	-0.13	0.92	0.31**	0.01*	-3.68*	0.06	-2.31*	0.15**	-0.77*
32	Bhuva-2 x RT-54	-1.09**	-0.07	-11.53**	-6.41**	0.13	-3.49**	-0.06*	0.02**	-3.70*	-0.33**	2.19*	-0.04	-0.20
33	Khadkala-S x AT-285	-2.28**	-0.73	-5.91**	-2.15*	0.16*	-3.08**	-0.23**	-0.06**	-2.06	0.12**	0.55	-0.15**	-0.52
34	Khadkala-S x G.Til-1	0.01	-0.30	2.37*	-1.58	0.48**	0.30	0.25**	0.03**	10.74**	-0.16**	3.91**	0.08**	2.35**
35	Khadkala-S x G.Til-10	1.20**	0.16	-1.27	2.25*	-0.72**	0.15	0.03	0.02**	-8.05**	-0.01	-1.25	-0.05	-1.73**
36	Khadkala-S x RT-54	1.08**	0.87*	4.81**	1.49	0.08	2.62**	-0.05	0.01*	-0.63	0.05	-3.21**	0.13**	-0.09
37	IS-209 x AT-285	0.08	-0.73	0.46	-1.04	-0.14	-0.28	0.18**	0.02**	-10.06**	-0.15**	-3.06**	-0.36**	-2.08**
38	IS-209 x G.Til-1	-1.52**	-0.07	-3.06**	-1.10	-0.20*	0.14	-0.24**	-0.02**	3.93*	-0.20**	1.36	0.42**	1.39**
39	IS-209 x G.Til-10	0.89**	1.71**	11.0**	8.06**	-0.05	1.86**	0.03	0.03**	3.84*	-0.03	-0.17	0.06*	0.43
40	IS-209 x RT-54	0.55*	-0.91*	-8.4**	-5.91**	0.39**	-1.72**	0.03	-0.03**	2.28	0.38**	1.88	-0.11**	0.27
Min.		-2.28	-2.51	-11.53	-6.89	-1.02	-3.65	-0.30	-0.08	-13.96	-0.33	-4.94	-0.43	-3.11
Max.		1.64	2.66	15.76	9.81	1.47	4.37	0.31	0.08	12.99	0.38	5.73	0.42	2.35
S.E. (S_{ij})		0.51	0.80	2.34	1.80	0.16	1.10	0.05	0.012	3.56	0.07	2.04	0.06	0.69
Np. desirable sca effect		14	9	14	14	12	10	11	19	10	11	6	19	12

*,** Significant at 5% and 1% levels, respectively.

E_1, E_2, E_3 and E_4 = Environments (locations) *viz.*, Timely sowing Amreli, Timely sowing Junagadh, Late sowing Amreli and Late sowing Junagadh, respectively.

Table 4: Best five parents in *per se* and gca effect and crosses in *per se*, and sca effect over environments for various characters in sesame

Characters	Best performing parents	Good general combiners	Best specific combiners	Characters	Best performing parents	Good general combiners	Best specific combiners
Days to flowering	Khadkala-S	AT-265	Khadkala-S x AT-285	Length of capsule (cm)	AT-319	AT-253	Bhuva-2 x G.Til-10
	AT-319	AT-285	Bhuva-2 x AT-285		AT-265	IS-209	AT-319 x AT-285
	G.Til-1	G.Til-1	AT-306 x G.Til-1		G.Til-10	AT-265	AT-265 x G.Til-1
	Bhuva-2	RT-54	IS-209 x G.Til-1		Bhuva-2	G.Til-1	AT-253 x RT-54
	AT-341	AT-341	AT-307 x G.Til-10		AT-253	Khadkala-S	Khadkala-S x G.Til-1
Days to maturity	AT-285	AT-285	AT-306 x AT-285	Width of capsule (cm)	Bhuva-2	AT-253	AT-307 x AT-285
	IS-209	AT-265	AT-253 x G.Til-10		AT-285	AT-265	AT-319 x RT-54
	AT-307	AT-341	AT-265 x G.Til-10		G.Til-10	G.Til-1	AT-319 x G.Til-1
	AT-341	RT-54	AT-322 x RT-54		AT-319	AT-306	AT-341 x G.Til-1
	Khadkala-S	G.Til-1	Bhuva-2 x AT-285		AT-306	IS-209	IS-209 x G.Til-10
Plant height (cm)	G.Til-10	G.Til-10	AT-265 x RT-54	Number of capsules per plant	AT-341	G.Til-10	AT-306 x G.Til-10
	AT-341	AT-341	IS-209 x G.Til-10		G.Til-10	AT-341	Khadkala-S x G.Til-1
	Khadkala-S	AT-306	Bhuva-2 x AT-285		RT-54	AT-322	AT-307 x RT-54
	RT-54	AT-307	AT-253 x G.Til-1		Khadkala-S	AT-253	AT-319 x AT-285
	AT-285	Bhuva-2	AT-341 x AT-285		Bhuva-2	Bhuva-2	AT-307 x AT-285
Height to first capsule (cm)	IS-209	AT-253	AT-265 x AT-285	Number of capsules per leaf axil	Khadkala-S	Khadkala-S	IS-209 x RT-54
	AT-253	AT-322	Bhuva-2 x RT-54		AT-253	AT-265	AT-307 x RT-54
	AT-307	AT-285	IS-209 x RT-54		IS-209	G.Til-1	AT-265 x G.Til-1
	AT-306	G.Til-1	AT-307 x G.Til-10		RT-54	Bhuva-2	AT-322 x G.Til-1
	AT-265	AT-319	AT-265 x G.Til-10		G.Til-1	RT-54	Bhuva-2 x G.Til-1
Number of branch per plant	RT-54	G.Til-10	AT-253 x G.Til-10	Number of seeds per capsule	G.Til-10	G.Til-10	AT-306 x AT-285
	G.Til-10	AT-319	AT-319 x G.Til-10		AT-253	AT-319	AT-253 x G.Til-10
	Bhuva-2	Bhuva-2	AT-306 x G.Til-10		RT-54	AT-253	AT-319 x G.Til-10
	Khadkala-S	AT-253	Khadkala-S x G.Til-1		AT-319	AT-306	Khadkala-S x G.Til-1
	AT-253	AT-306	AT-341 x G.Til-1		IS-209	AT-265	AT-253 x RT-54
Number of internodes per plant	G.Til-10	G.Til-10	Bhuva-2 x AT-285	1000-seed weight (g)	AT-307	AT-265	AT-341 x G.Til-10
	RT-54	AT-306	AT-265 x RT-54		AT-319	AT-319	IS-209 x G.Til-1
	Khadkala-S	AT-322	AT-319 x G.Til-1		AT-341	G.Til-1	AT-322 x AT-285
	AT-341	IS-209	AT-322 x G.Til-1		AT-253	AT-285	AT-322 x G.Til-10
	AT-285	Bhuva-2	Khadkala-S x RT-54		AT-322	AT-253	AT-306 x G.Til-1
Seed yield per plant (g)	AT-341	G.Til-10	Khadkala-S x G.Til-1				
	G.Til-10	AT-341	AT-307 x RT-54				
	RT-54	AT-253	AT-307 x AT-285				
	G.Til-1	AT-319	AT-322 x AT-285				
	Bhuva-2	AT-322	AT-319 x G.Til-10				

Conclusion

Parents AT-285, G.Til-1, RT-54, AT-265, AT-306, AT-341 and G.Til-10 offered the best possibilities for exploitation in the development of improved lines with enhanced yielding ability. It suggested that population involving these parents in a multiple crossing programme may be developed for isolating desirable recombinants. Further, the varieties or lines showing good general combining ability for particular component may be utilized in component breeding for effective improvement in particular component ultimately seeking improvement in seed yield itself. The foregoing discussion and clearly indicated that the hybrids Khadkala-S x G.Til-1, AT-307 x AT-285, AT-322 x AT-285, AT-319 x G.Til-10 and AT-341 x G.Til-10 were high yielding and heterotic along with desirable sca effect for seed yield per plant over environments. These hybrids also had higher values for height to first capsule, number of branch per plant and number of capsule per plant and could profitably be exploited through heterosis breeding for general cultivation in order to increase the yield potentiality in sesame. Selection is rapid if gca effect of the parents and sca effect of crosses are in same direction. If the crosses showing high sca effect involve atleast one parent possessing good gca effect and high mean value, they could be exploited for practical breeding. However, Chaudhary *et al.* (1974) stated that high sca effect would not necessarily mean a high performance by the hybrid and the exploitation of sca effect seemed to be superfluous, as no additional information was obtained by doing so. Therefore, it is suggested that the selection of parents for further breeding programme should be based on gca effect and due consideration should be given to mean value of the cross combinations while selecting crosses for specific heterosis.

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