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COMBINING ABILITY FOR QUANTITATIVE TRAITS IN SESAME THROUGH LINE X TESTER ANALYSIS

MAINI BHATTACHARJEE[1], SABYASACHI KUNDAGRAMI[1] AND TAPASH DASGUPTA[2]
[1] Department of Genetics and Plant Breeding, Institute of Agricultural Science,
University of Calcutta, Kolkata - 700 019, INDIA
[2] School of Agriculture and Rural Development,
Ramakrishna Mission Vivekananda Educational and Research Institute,Narendrapur, Kolkata - 700 103, INDIA
e-mail: mainibhattacharjee02@gmail.com

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***Corresponding author**

ABSTRACT

Analysis of combining ability and genetic architecture were evaluated for twelve morphological quantitative characters in sesame using Line x Tester mating designs. The analysis of variance revealed that significant differences between lines and testers were observed for all the characters. Suprava and GT 10 found as a good general combiner for seed yield/plant and some yield component traits with early maturity. The top high yielding cross combinations *viz* RT 351 X TKG 22, Suprava X AT 238, Suprava X TKG 22, HT 2 X AT238, Savitri X CUHY 57 showed high, significant and positive SCA effects for yield and involved either good x good, good x poor or poor x poor combining parents. Heterosis for seed yield per plant ranged from -16.40 to 78.59, -21.98 to 18.59 and -21.35 to 33.51and -18.58 to 38.20 percent over mid parent, better parent and two standard varieties respectively. Among the hybrids Suprava X AT 238 and RT 351 X CUHY 57 were identified as the best performing hybrid. Hence the present study suggesting that these crosses could be utilized for the improvement of sesame yield and also in future breeding program for commercial exploitation.

INTRODUCTION

Sesame is a major predominantly self-pollinated oilseed crop and it is grown in tropical and subtropical areas (Ashri 1998). It is a good source of oil (44 - 58%), protein (18 - 25%), and carbohydrates (13.5%) (Bedigian *et al.*,1985). Sesame seed contains 83 - 90% unsaturated fatty acids such as oleic acid (18: 1) (39.6%) and linoleic acid (18:2) (46.0%) and natural antioxidants such as sesamin, sesamol, sesamolin which helps for greater stability of the oil and also has desirable physiological effects in blood pressure and serum lipid lowering potential (Yermanos *et al.,* 1972; Tripathi *et al.,* 2013). Due to the presence of its high quantity oil content and the excellent qualities of the seed oil and meal, it is termed as the "Queen of oilseeds" (Vijayarajan *et al.,* 2007; Bhattacharjee *et al,*. 2019). Though sesame is predominantly self-pollinated crop but considerable cross pollination has been recorded (Lal *et al.,* 2020). For breaking the present yield barrier and evolving new varieties with high yield potential, it is desirable to combine the genes from genetically diverse parents (Saxena and Bisen, 2017). In selection of parents for any hybridization program, it is seemed important to study the performance of the genotypes along with the genetic architecture of some important quantitative traits and estimating each of combining ability should always be considered. Evaluation of genotypes for combining ability and genetic architecture, Line x Tester analysis is more suitable mating designs extensively used for large number of genotypes as parents and crosses (Kempthorne, 1957). Combining ability analysis gives precise estimates of the nature and magnitude of gene actions involved in the expression of quantitative characters like yield and its components for obtaining better recombination (Hassan and Rehab, 2015). Since phenotypically superior genotypes may yield inferior hybrids or poor recombinants in the segregating generation therefore it is essential that parents are selected on the basis of their genetic worth (Banerjee and kole, 2009). Gene action is estimated through components of combining ability variances and effects which includes 'Additive' and 'Non additive' types. In sesame to exploit commercially viable Heterosis identification of parents with best combination which show good heterosis on crossing and production of hybrids with low cost is very important to achieve the goal (Lal *et al.,* 2020). The new crosses has been compared over the standard commercial check variety and also mid or better parent based on yield and yield components in sesame, so that the crosses with high heterotic potential could be identified (Jatothu *et al.,* 2013). So, in sesame breeding, hybridization is one of the feasible breeding approaches for development of elite cultivars in order to broaden the genetic base. Therefore, the present experiment was carried out to study combining ability, gene action and effects of heterosis for yield and its component traits through line × tester analysis in sesame.

MATERIALS AND METHODS

The present investigation was carried out in Calcutta University Experimental Farm, Baruipur, South 24-Paraganas during *pre-*

kharif season of 2018. The experimental material consisted of genetically diverse eleven sesame genotypes which used in a line X tester mating design where five (5) genotypes were selected as Lines (females) and six (6) were chosen as testers (males). All F1 hybrid seeds along with eleven parents (5 lines and 6 testers) were evaluated in layout of randomized complete block with three replications in *pre kharif* of 2019 to observe F1 generation and to obtain seeds for F2 generation. Each cross combination was planted in between the two parents' specific to a particular cross for easy comparison. The spacing of 45 cm between rows and 30 cm between plants was implemented for the crossing programme. Each and every plant was harvested separately from each cross combination.

The observations of following twelve morphological quantitative characters namely days to maturity, days to 50% flowering, plant height, number of primary branches/ plant, number of secondary branches/ plant, inter node length, number of capsules/ plant, capsule length (cm), capsule diameter (cm), number of seeds/ capsule, 1000 seed weight (g) and seed yield/ plant (g) were recorded. Data obtained from the F1 hybrid populations of thirty cross combinations and parents were analyzed to test the combining ability and to identify the gene action in control of twelve characters under study. The analysis of variance for the line x tester mating design as proposed by Kempthorne (1957) was used for the analysis of gca and sca effects in combining ability analysis from F1 generation of crosses. Heterosis of cross combinations over mid-parent and better parent and over two standard commercial check varieties were also estimated for the characters as described by Jadhav and Mohrir (2013). The variety *'GT 10'* used as standard check variety 1 and *'TKG 22'* used as standard check variety 2 for estimating standard heterosis. All analysis were done using SPAR 2 statistical package.

RESULTS AND DISCUSSION

The analysis of variance revealed that significant differences between lines and among testers were observed for all the characters (table 1) but capsule diameter showed no significant differences in lines. The results indicated that mean sum of squares of L x T interaction effect was significant for all traits indicates higher estimates of specific combining ability variance effects. Similar results were reported by Kumar and Kannan, (2010); Hassan and Rehab (2015). Days to maturity, plant height, number of primary branches per plant, number of capsule per plant, capsule length, number of seeds per capsule, 1000 seed weight and seed yield per plant revealed presence of significance in parents' vs crosses which afford proficiency for comparing the heterotic expression for seed yield and its component traits. The findings are in confirmation with Saxena and Bisen (2017).

The estimates of GCA and SCA variances revealed that the SCA variances had greater magnitude than GCA variance for all the characters studied, indicating the preponderance of non-additive gene action (table 3). Manivannan and Ganesan (2001); Krishnaiah *et al*. (2002); Vidhyavathi *et al*. (2005) and Bharathi and Vivekanandan, (2009) also reported the role of non-additive gene action for the traits studied especially for

Table 1: Analysis of Variance of yield and yield attributing traits for parents and hybrids

Mean sum of square	DF	Days to maturity	50% Flowering	Plant height	Primary Branch Per Plant	Secondary Branch Per Plant	Inter node Length	Capsules Per Plant	Capsule Length	Capsule Diameter	Seeds Per Capsule	1000 Seed Weight	Seed Yield Per Plant
Replication	2	1.38	0.39	83.19*	0.42	0.59	9.53	592.88**	0.03	0.09**	2.86	0.006	0.81
Treatment	41	34.57**	14.42**	244.95**	2.06**	1.52**	7.72*	1204.29**	0.49**	0.06**	37.63**	0.41**	9.22**
Parents (P)	10	25.43**	12.06**	216.38**	1.49**	0.60*	0.7	692.33**	0.11**	0.03**	24.46**	0.39**	6.79**
P vs. C	1	14.12**	0.01	440.61**	1.17*	0.41	0.01	914.32**	1.80**	0.002	22.56*	0.72**	33.61**
Crosses (C)	29	38.43**	15.75**	248.05**	2.33**	1.83**	10.40**	1390.82**	0.57**	0.07**	42.69**	0.41**	9.22**
Lines (L)	4	35.26**	9.23**	60.76**	1.06*	0.86*	11.91*	1350.37**	0.19**	0.001	25.57**	0.20**	6.02**
Testers (T)	5	46.91**	9.97**	132.30**	2.02**	1.14**	12.82*	2927.77**	0.92**	0.02**	33.75**	0.21**	7.60**
LxT	20	36.94**	18.50**	314.45**	2.66**	2.20**	9.49**	1014.67**	0.56**	0.01**	48.36**	0.50**	10.26**
Errors	80	1.49	0.77	21.02	0.4	0.34	4.28	64.52	0.02	0.001	4.03	0.02	0.57

* significant at 0.05 level of probability ,** significant at 0.01 level of probability

Table 2: Proportional contributions of lines, testers and line X tester

Parameters	Days to maturity	50% Flowering	Plant height	Primary Branch Per Plant	Secondary Branch Per Plant	Inter node Length	Capsules Per Plant	Capsule Length	Capsule Diameter	Seeds Per Capsule	1000 Seed Weight	Seed Yield Per Plant
Lines (L)	21.05	10.91	9.2	14.99	10.75	21.25	36.29	27.53	39.76	13.63	8.97	14.22
Testers (T)	12.66	8.08	3.38	6.31	6.46	15.8	13.39	4.57	2.56	8.26	6.65	9.01
LxT	66.3	81	87.48	78.7	82.79	62.95	50.31	67.9	57.67	78.11	84.38	76.77

Table 3: Estimation of genetic variance of yield and yield attributing traits in sesame.

Source of variation	Days to maturity	50% Flow ering	Plant height	Primary Branch Per Plant	Secon dary Branch Per Plant	Inter node Length	Capsules Per Plant	Capsule Length	Capsule Diameter	Seeds Per Capsule	1000 Seed Weight	Seed Yield Per Plant
μ^2 L	0.66	-0.57	-12.14	-0.04	-0.07	0.22	127.54	0.02	0.01	-0.97	-0.02	-0.18
μ^2 T	-0.09	-0.52	-14.09	-0.09	-0.07	0.13	18.65	-0.02	0	-1.27	-0.02	-0.24
μ^2 gca	0.25	-0.54	13.21	-0.07	-0.07	0.17	68.15	0	0.001	1.13	0.02	0.21
μ^2 sca	11.82	5.91	97.81	0.75	0.62	1.74	316.72	0.18	0.012	14.78	0.16	3.23
μ^2 gca /μ^2sca	0.02	-0.09	-0.14	-0.09	-0.12	0.1	0.22	0	0.11	-0.08	-0.11	-0.06
μ^2A	0.5	-1.08	26.41	-0.14	-0.15	0.35	136.29	0	0	2.27	0.04	0.42
μ^2D	11.82	5.91	97.81	0.75	0.62	1.74	316.72	0.18	0.01	14.78	0.16	3.23
μ^2A/ μ^2D	0.04	-0.18	-0.27	-0.18	-0.23	0.2	0.43	-0.01	0.22	-0.15	-0.22	-0.13
μ^2A (μ^2A + μ^2D	0.04	-0.22	-0.37	-0.22	-0.31	0.17	0.3	-0.01	0.18	-0.18	-0.29	-0.15

Table 4. Estimates of general combining ability (GCA/gi) effects of parents

Parents lines	Days to maturity	50% Flowering	Plant height	Primary Branch Per Plant	Secondary Branch Per Plant	Inter node Length	Capsules Per Plant	Capsule Length	Capsule Diameter	Seeds Per Capsule	1000 Seed Weight	Seed Yield Per Plant
RT 351	0.95**	0.80**	-1.18	-0.40**	-0.06	-0.44	-8.87**	0.08*	0.01	-0.37	-0.03	-0.44*
SUPRAVA	-1.38**	-0.22	-0.18	0.04	0.33**	-0.42	-5.42**	-0.09**	0.01	0.66	0.01	0.94**
GT 10	-1.49**	-1.07**	-1.68	0.04	0	1.44**	13.69**	-0.03	0.01	-1.58**	0.18**	0.19
HT 2	1.65**	0.47*	3.04**	0.27	-0.28**	-0.16	1.8	-0.10**	-0.02	-0.3	-0.07*	-0.35
SAVITRI	0.27	0.01	-0.01	0.04	0	-0.42	-1.2	0.13**	-0.01	1.59**	-0.09*	-0.35
SE	0.288	0.2081	1.0806	0.1502	0.1381	0.488	1.893	0.0341	0.007	0.4737	0.035	0.1794
SE (gi-gj)	0.407	0.294	1.528	0.212	0.195	0.689	2.677	0.048	0.01	0.669	0.049	0.253
TESTERS												
AT 238	-0.98**	-1.40**	-5.52**	0.53**	-0.33*	-0.18	-0.56	-0.01	0.07**	1.30**	0	0.11
ATGHARA	0.47	0.67**	1.34	-0.27	0.2	-0.37	-24.76**	-0.11**	-0.01	1.77**	-0.09*	-0.04
CUHY 57	0.71*	-0.07	1.74	0.40*	-0.27	-0.5	10.31**	-0.28**	-0.01	0.43	0.04	-0.31
EC103	2.25**	0.73**	-0.92	0.40*	0	-0.65	13.11**	0.38**	0.01	-0.5	0.21**	0.88**
TKG 22	-2.98**	-0.4	2.74*	0.2	0.40**	1.85**	7.38**	0.20**	-0.03**	-0.63	-0.04	0.51**
EC90	0.53	0.47*	0.61	-0.2	0	-0.15	-5.49**	-0.18**	-0.02**	-2.37**	-0.12**	-1.15**
SE	0.316	0.228	1.1838	0.1645	0.1513	0.534	2.0741	0.0381	0.008	0.5189	0.0388	0.1965
SE (gi-gj)	0.447	0.3224	1.6741	0.2327	0.214	0.7431	2.9332	0.0539	0.0156	0.7338	0.0549	0.278

* significant at 0.05 level of probability , ** significant at 0.01 level of probability

seed yield.

The proportional contribution of lines, testers and their interaction for all the traits to the total variance square showed that lines played an important role towards yield and yield attributing characters by giving greater contribution towards the trait indicating predominant influence of lines for these traits (table 2). Testers were also important for traits inter node length, capsules per plant and days to maturity. The greater contributions of lines x testers *i.e* maternal and paternal interaction for all the characters indicates higher estimates of specific combining ability variance effects. These results are in conformity with the findings of Rashid *et al.* (2007).

General combining ability (*gca*) effects

In the present investigation, Suprava proved as desirable performers for high seed yield and also for early maturity. GT 10 showed early flowering and early maturity as they showed negative significant gca effects and it also showed highly positive significant GCA effects for capsules per plant, inter node length and 1000 seed weight (table 4). On the other hand among testers, TKG 22 was found as effective for yield and yield contributing characters like plant height, branches per plant, inter node length, capsules per plant and capsules length and also early maturing. AT 238 were observed as average performer for yield per plant, early maturity, short heighted with high primary branches, capsules diameter and seeds per capsule. Although significant GCA was observed in all the traits but no parent was found having significant GCA in all the traits studied. Similar trend was observed by Banerjee and Kole (2009).

Specific combining ability (*sca*) effects

Estimates of specific combining ability (SCA) effects to the crosses revealed that no cross combinations exhibited significant and desirable SCA effects for all the Parameters (table 5). There were a good number of crosses with significant SCA effects in desirable direction for yield and yield contributing characters. The top yielding cross combinations *viz* RT 351 X TKG 22, Suprava X AT 238, Suprava X TKG 22, HT 2 X AT238, Savitri X CUHY 57 showed high, significant and positive sca effects for seed yield per plant and involved either good x good, good x poor or poor x poor combining parents. These cross combinations also depicted significant and positive sca effects for various yield contributing traits. Similar findings were observed by Vavdiya *et al.* (2014). Crosses between good x poor and poor x poor could be attributed for better complementation between favourable alleles of parents involved. These findings are in agreement with the earlier findings of Sakhare *et al.* (2000); Arulmozhi *et al.* (2001) and Mothilal and Manoharan (2004). The best specific combination was observed in cross Suprava X AT 238, Suprava X TKG which involved good x good combining parents for seed yield per plant and also, desirable SCA effects were obtained for most studied traits. This could be lead to put these best crosses into further evaluation and would be considered as promising desirable segregants. Present study

Table 5: Estimates of specific combining ability (SCA/gj) effects of parents for yield and its attributing traits

Hybrids	Days to maturity	50% Flowering	Plant height	Primary Branch Per Plant	Secon dary Branch Per Plant	Inter node Length	Capsules Per Plant	Capsule Length	Capsule Diameter	Seeds Per Capsule	1000 Seed Weight	Seed Yield Per Plant
RT 351 X AT 238	-0.11	-1.01*	-1.76	-1.80**	-1.61**	0.33	5.67	0.18*	0.05**	-3.34**	0.14	-1.76**
RT 351 X Atghara	-1.56*	-0.58	-9.09**	0.42	0.67*	-0.52	27.56**	0.27**	0	1.85	-0.32**	-9.09**
RT 351 X CUHY 57	-1.44*	1.44**	7.08**	0.42	0.67*	0.89	4.44	-0.15	0	-1.36	-0.43**	7.08**
RT 351 X EC 103	3.97**	-0.58	-6.98**	0.2	-0.06	1.11	3.36	0.09	-0.02	-4.97**	0.17*	-6.98**
RT 351 X TKG 22	-0.86	0.73	10.74**	0.76*	0.33	-0.03	-1.67	-0.38**	-0.02	7.81**	-0.09	10.74**
RT 351 X EC 90	-1.6	-3.18**	-8.96**	-0.4	-0.14	-0.65	-12.4**	-0.27	0.03	1.97	-0.15	-8.96**
Suprava X AT 238	-2.24**	-3.79**	8.71**	1.16**	0.2	-0.07	15.64**	0.09	0.07**	2.94*	0.56**	17.64**
Suprava X Atghara	-1.16	-1.07*	-4.79	0.84*	0.13	-0.57	5.09	0.09	0.06	-2.16	-0.03	-4.79**
Suprava X CUHY 57	4.03**	2.79**	13.49**	0.6	0.08	0.13	19.53**	0.16	0.01	2.57*	0.19*	8.48**
Suprava X EC 103	-1.03	-2.33**	-8.46**	-0.51	0.13	1.16	-27.8**	0.11	-0.05*	-5.32**	-0.01	-8.46**
Suprava X TKG 22	-3.73**	-3.47**	-8.02**	0.93*	0.32	-0.69	5.47	-0.31**	-0.03	-0.69	0.59**	13.49**
Suprava X EC 90	7.83**	4.55**	3.31	-0.51	0.27	0.65	-10.31*	0.07	0.08**	1.06	-0.79**	-8.02**
GT 10 X AT 238	-4.76**	-2.80**	8.48**	-1.51**	-1.07**	-1.4	-8.42	-0.01	-0.06**	-0.16	-0.22*	3.31**
GT 10 X Atghara	-2.42**	0.99	-7.91**	0.27	0.88*	0.76	15.53**	0.33**	0.02	1.9	0.1	-7.91**
GT 10 X CUHY 57	1.96**	0.73	4.15	0.82*	-0.4	0.68	28.80**	-0.09	-0.01	0.01	-0.13	4.15**
GT 10 XEC 103	-1.28	-2.12**	0.64	-0.73*	0.06	1.34	-11.33*	-0.49	-0.02	-2.43*	-0.29**	0.64
GT 10 X TKG 22	-1.69*	-1.34**	-8.36**	0.49	-1.00**	0.22	-18.4**	-0.62**	0.02	-4.13**	-0.38**	-8.36**
GT 10 X EC 90	3.57**	1.53**	-9.19**	0.49	0.33	-1.91	6.78	-0.07	0.02	4.11**	-0.07	-9.19**
HT 2 X AT238	-1.73*	-2.60**	13.42**	-0.73*	-0.39	-0.15	15.67**	0.17*	-0.03	4.83**	0.39**	13.42**
HT 2 X Atghara	-1.12	1.07*	3.48	0.49	1	0.51	7.33	1.01**	0.01	-2.39*	0.35**	3.48**
HT 2 X CUHY 57	0.51	2.08**	17.64**	0.67	0.66**	-1.43	14.40**	0.84**	-0.05**	3.04**	0.59**	8.71**
HT 2 X EC 103	-1.15	0.86	-9.02**	-0.11	1.27*	-1.05	-16.0**	0.27**	-0.01	-2.66*	-0.27**	-9.02**
HT 2 X TKG 22	4.63**	1.86**	-4.19	0.22	0.27**	5.99	-9.49*	-0.02	-0.01	-3.09**	-0.1	-4.19**
HT 2 X EC 90	-2.52**	-1.94**	-2.91	-0.33	-0.79	-1.31	10.73*	-0.47**	0.07**	-1.7	-0.02	-2.91**
Savitri X AT238	-1.46*	0.6	-1.52	-0.44	-1.40*	-2.19	0.4	-0.62**	0.01	4.41**	-0.19*	-1.52**
Savitri X Atghara	-4.2**	-0.32	0.44	1.33**	0.72**	1.1	1.73	0.07	0.01	1.44	-0.36**	0.44
Savitri X CUHY 57	3.10**	1.33**	14.44**	0.56	-1.00*	0.78	12.16**	0.09	-0.02	3.07**	0.49**	14.44**
Savitri X EC 103	0.41	-1.87**	2.61	-0.78*	-0.33**	-1.21	-8.96	0.16	-0.02	2.64*	-0.48**	-9.11**
Savitri X TKG 22	-2.49**	1.66**	-9.11**	0	0.28	-0.55	5.6	-0.27**	-0.04*	-2.63*	0.27**	2.61**
Savitri X EC 90	3.13**	-0.8	-8.39**	-1.11**	0.33	-0.12	-7.07	-0.04	0.07**	-4.52**	0.07	-8.39**
SE	0.706	0.509	2.647	0.368	0.338	1.662	4.638	0.085	0.018	1.16	0.087	0.439
SE (Sij –Sk1)	0.999	0.721	3.743	0.52	0.478	2.349	6.559	0.12	0.035	1.641	0.123	0.621

* significant at 0.05 level of probability ,** significant at 0.01 level of probability

indicates that both GCA and SCA effects should be considered in choosing the parental lines in breeding programs of sesame. These results are in conformity with the findings of Jhajharia *et al.* (2013).

Heterosis effects

Heterosis for the 30 F1s has been emphasized along with the heterotic vigor, over mid-parent (relative heterosis) as well as better parent (heterobeltiosis) and over two standard varieties (SV) (standard heterosis) value (table 6). For days to maturity, relative heterosis ranged -6.46 to 2.69 percent and better-parent heterosis was -9.62 to 1.22 percent, standard Heterosis 1 ranged -3.19 to 9.43 and standard Heterosis 2 disposed from -6.87 to 5.27. Negative heterosis is desirable for days to maturity for breeding. Similar results over mid parent are being reported by Mishra and Sikarwar, (2001); Nijagun *et al.* (2003) and over better parent by Raghunaiah, (2005).

Results revealed that RT 351 X AT 238, Suprava X AT 238, CUMS 17 X Atghara, Suprava X CUHY 57, GT 10 X AT 238, Savitri X AT238 crosses showed positive and significant heterosis over both mid and better parents and also over two standard checks for plant height.

Heterosis analysis for primary branches per plant showed that only Suprava X AT 238 had positive and significant heterosis over mid, better and two standard check parents. For secondary branches per plant, only Suprava X TKG 22 recorded significantly positive heterosis over both mid and better parents and also over two standard check varieties. The extent of heterosis over mid-parent for inter node lengtht was -14.38 to 32 percent and that of better parent was -33.76 to 14.78 percent and both standard heterosis ranged -33.10 to 4.14. For capsules per plant, significantly positive three types heterosis were shown only in three F1 hybrid RT 351 X EC 103, Suprava X AT 238, HT 2 X AT238. Significant positive heterosis over standard check is in agreement with the findings of Mothilal and Manoharan, (2004).

With regards to 1000 seed weight, over mid parent, better parent and standard check significant positive heterosis observed in six hybrids namely RT 351 X AT 238, RT 351 X CUHY 57, GT 10 X CUHY 57, GT 10 X TKG 22, HT 2 X Atghara, Savitri X CUHY 57. Significant positive heterosis over better parent is being reported by Ray and Sen, (1992). The heterotic effects over the standard check were also reported by Kannan *et al.* (2001) and Raghunaiah *et al.* (2008).

In the present investigation, heterosis for seed yield per plant ranged from -16.40 to 78.59, -21.98 to 18.59 and -21.35 to 33.51and -18.58 to 38.20 percent over mid parent, better parent and two standard variety respectively. Significant positive heterosis was observed in 8 crosses over mid parent and over better parent and 13 crosses over two standard checks. The crosses RT 351 X AT 238, Suprava X AT 238, Suprava X EC 103, CUMS 17 X EC 90, GT 10 X AT 238 and GT 10 X TKG 22, Savitri X CUHY 57 recorded considerable heterosis over mid parent, better parent and standard check. Positive significant heterosis for seed yield in sesame were also reported by Mishra and Sikarwar, (2001); Nijagun *et al.*

Table 6: Relative Heterosis (Ht), Heterobeltiosis (Htb) and Standard Heterosis estimates (%) in sesame crosses

Hybrids	Days to maturity				50% Flowering				Plant height			
	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2
RT 351 X AT 238	-6.46**	-6.62**	-2.81	-6.50**	-9.35**	-0.34	-7.91**	0	10.76**	10.61**	3.73**	9.45**
RT 351 X Atghara	0.65	0.29	4.03**	0.07	-9.24**	-10.74**	2.53	11.34**	5.81*	-0.93	6.47**	12.34**
RT 351 X CUHY 57	-3.18*	-4.09**	-0.51	-4.29**	-11.31**	-5.77*	-6.96**	1.03	2.88	1.55**	-2.24**	3.15**
RT 351 X EC 103	-1.79	-5.15**	5.61**	1.6	8.10**	8.10**	20.08**	30.39**	0.84	-7.89**	4.48**	10.24**
RT 351 X TKG 22	-1.98*	-2.08	1.79	-2.08	-9.35**	-0.34	-7.91**	0	5.01	4.46**	-1	4.46**
RT 351 X EC 90	0.2	-3.96**	8.65**	4.52**	1.73	8.20*	21.22**	31.63**	-1.19	-1.58**	-6.97**	-1.84**
Suprava X AT 238	-1.96	-4.78**	-0.89	-4.66**	0.67	-1.64	-5.06*	3.09	10.62**	2.39**	8.71**	3.67**
Suprava X Atghara	-1.04	-3.39*	-0.51	-4.29**	-9.24**	-10.74**	2.53	11.34**	13.67**	3.94**	11.69**	17.85**
Suprava X CUHY 57	0.45	-1.37	0.39	-3.43**	-5.88**	0	-1.26	7.22*	10.07**	5.94**	1.99**	7.61**
Suprava X EC 103	-1.34	-7.22**	3.32*	-0.61	3.35	-3.42	7.28**	16.49**	13.02**	0.88	14.43**	20.73**
Suprava X TKG 22	1.13	-1.72	2.17	-1.72	2.68	0.32	-3.16	5.15*	3.65	0.52	-4.73**	0.52
Suprava X EC 90	1.81	-4.96**	7.53**	3.44*	7.69**	7.54*	20.48**	30.82**	6.50*	3.42**	-2.24**	3.15**
GT 10 X AT 238	-1.37	-3.31*	0.64	-3.19*	1.81	-2.21	-2.21	6.19*	5.66*	2.24**	2.24**	7.87**
GT 10 X Atghara	2.17*	0.7	3.70*	-0.25	4.26*	-2.49	12.02**	21.64**	-2.64	-6.02**	1	6.56**
GT 10 X CUHY 57	0.84	-0.04	1.74	-2.13	0.32	0.96	-0.31	8.25**	1.9	0	0	5.51**
GT 10 XEC 103	-1.87*	-6.87**	3.70*	-0.25	1.65	-3.42	7.28**	16.49**	4.2	-1.97**	11.19**	17.32**
GT 10 X TKG 22	-4.69**	-6.50**	-2.81*	-6.50**	-0.16	-4.11	-4.11*	4.12	3.96	1.24*	1.24*	6.82**
GT 10 X EC 90	2.69*	-3.27*	9.43**	5.27**	6.97**	8.48**	21.53**	31.97**	-1.28	-3.98**	-3.98**	1.31*
HT 2 X AT238	1.35	1.22	5.61**	1.6	15.70**	19.53**	14.24**	24.05**	1.07	0.8	-5.72**	-0.52
HT 2 X Atghara	0.41	-0.25	4.08**	0.12	1.72	-2.49	12.02**	21.64**	3.97	-3.01**	4.23**	9.97**
HT 2 X CUHY 57	-2.35*	-9.62**	0.64	-3.19*	-6.98**	-3.85	-5.06*	3.09	3.81	2.07**	-1.74**	3.67**
HT 2 X EC 103	-1.72	-4.81**	5.99**	1.96	-1.75	-4.27	6.33*	15.46**	9.64**	-0.22	13.18**	19.42**
HT 2 X TKG 22	-5.21**	-5.03**	-1.28	-5.03**	-4.81*	-1.66	-6.01*	2.06	2.52	1.57**	-3.73**	1.57**
HT 2 X EC 90	-2.52*	-6.31**	5.99**	1.96	0.4	4.24	16.78**	26.80**	1.59	0.79	-4.73**	0.52
Savitri X AT238	-5.24**	-5.88	-2.04	-5.77**	-3.44	-2	-6.96*	1.03	6.55**	1.20*	5.22**	11.02**
Savitri X Atghara	-5.85**	-5.99**	-3.19*	-6.87**	-9.25**	-14.8**	-2.21	-6.19*	4	2.31**	9.95**	16.01**
Savitri X CUHY 57	-1.93*	-1.5	0.26	-3.56*	-4.76*	-3.85	-5.06*	3.09	2.11	-1.67**	2.24**	7.87**
Savitri X EC 103	-4.17**	-7.90**	2.55*	-1.35	-0.44	-5.13*	5.38*	14.43**	2.97	-1.32**	11.94**	18.11**
Savitri X TKG 22	-5.82**	-5.77**	-2.04	-5.77**	-0.49	1	-4.11*	4.12	3.13	-9.65**	2.49**	8.14**
Savitri X EC 90	-1.55	-5.97**	6.38**	2.33*	0	1.69	13.93**	23.71**	-2.26	-14.47**	-2.99**	2.36**

*Significant at 5% level of significance and **Significant at 1% level of significance; Relative Heterosis = Ht, Heterobeltiosis = Htb, Standard Heterosis1 = SHt 1 and Standard Heterosis 2 = SHt 2

Table 6: Continued

Hybrids	Primary Branch Per Plant				Secondary Branch Per Plant				Inter node Length			
	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2
RT 351 X AT 238	73.33**	30.00*	7.77	27.36*	100.0**	14.29	3.88	3.88	16.84	0.48	-13.38	-13.38
RT 351 X Atghara	33.33	5	-23.08*	-9.09	-33.33	-62.5**	-62.5**	-62.5**	11.11	-4	-17.24	-17.24
RT 351 X CUHY 57	52.38**	0.5	23.08*	45.45**	77.78**	0	0	0	0	-8.05	-5.52	-5.52
RT 351 X EC 103	70.00**	13.33	30.77**	54.55**	25	-28.57	-37.50*	-37.50*	2.67	1.44	-12.55	-12.55
RT 351 X TKG 22	37.50*	0.36	-15.38	0	55.56**	-12.5	-12.5	-12.5	4.44	-2.76	-2.76	-2.76
RT 351 X EC 90	52.38**	0.88	23.08*	45.45**	25	-28.57	-37.5**	-37.50*	2.86	-13.6	-25.52	-25.52
Suprava X AT 238	39.13**	23.08*	23.08*	45.45**	0	-11.11	0	0	5.26	0	-31.03	-31.03
Suprava X Atghara	13.04	0.85	0	18.18	-41**	-44.44**	-37.50*	-37.50*	0.96	-2.78	-27.59	-27.59
Suprava X CUHY 57	10.34	6.31	23.08*	45.45**	17.65	11.11	25	25	-6.02	-21.48	-19.31	-19.31
Suprava X EC 103	0	-6.67	7.69	27.27*	25	11.11	25	25	19.82	9.02	-8.28	-8.28
Suprava X TKG 22	8.33	0.85	0	18.18	52.94**	44.44**	62.50**	62.50**	18.37	0	0	0
Suprava X EC 90	-3.45	7.69	7.69	27.27*	12.5	0	12.5	12.5	4.86	-3	-33.1	-33.1
GT 10 X AT 238	13.04	0.85	0	18.18	-33.3*	-37.50*	-37.50*	-37.50*	23.4	0	0	0
GT 10 X Atghara	4.35	-7.69	-7.69	9.09	-50.00**	-50.00**	-50.00**	-50.00**	-12.25	-23.45	-23.45	-23.45
GT 10 X CUHY 57	10.34	0.69	23.08*	45.45**	12.5	12.5	12.5	12.5	1.36	0	2.76	2.76
GT 10 XEC 103	7.14	6.6	15.38	36.36*	-33.3*	-37.50*	-37.50*	-37.50*	4.87	-3.45	-3.45	-3.45
GT 10 X TKG 22	-8.33	-15.38	-15.38	0	-25	-25	-25	-25	-6.21	-6.21	-6.21	-6.21
GT 10 X EC 90	-3.45	7.69	7.69	27.27*	-6.67	-12.5	-12.5	-12.5	-6.09	-31.21	-25.52	-25.52
HT 2 X AT238	-13.04	-23.08*	-23.08*	-9.09	33.33	14.29	0	0	-8.5	-28.03	-22.07	-22.07
HT 2 X Atghara	-4.35	-15.38	-15.38	0	7.69	-12.5	-12.5	-12.5	-5.66	-20.38	-13.79	-13.79
HT 2 X CUHY 57	-3.45	-12.5	7.69	27.27*	53.85**	25	25	25	-14.38	-16.56	-9.66	-9.66
HT 2 X EC 103	14.29	6.67	23.08*	45.45**	66.67**	42.86*	25	25	6.09	-5.73	2.07	2.07
HT 2 X TKG 22	16.67	7.69	7.69	27.27*	23.08	0	0	0	-2.65	-6.37	1.38	1.38
HT 2 X EC 90	10.34	23.08*	23.08*	45.45**	33.33	14.29	0	0	-14.05	-33.76	-28.28	-28.28
Savitri X AT238	16.67	4.57	7.69	27.27*	14.29	14.29	0	0	21.95	8.7	-13.79	-13.79
Savitri X Atghara	-16.67	-28.62*	-23.08*	-9.09	-6.67	-12.5	-12.5	-12.5	4.93	1.74	-19.31	-19.31
Savitri X CUHY 57	6.67	0.69	23.08*	45.45**	6.67	2	0	0	14.39	1.34	4.14	4.14
Savitri X EC 103	-10.34	-13.33	0	18.18	-14.29	-14.29	-25	-25	18.14	14.75	-3.45	-3.45
Savitri X TKG 22	4	-7.21	0	18.18	-6.67	-12.5	-12.5	-12.5	10	-1.38	-1.38	-1.38
Savitri X EC 90	-26.67**	-21.48	-15.38	0	-14.29	-14.29	-25	-25	32	14.78	-8.97	-8.97

*Significant at 5% level of significance and **Significant at 1% level of significance,

Table 6 : Continued

Hybrids		Capsules Per Plant				Capsule Length				Capsule Diameter		
	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2	Ht	Htb	SHt 1	SHt 2
RT 351 X AT 238	17.70**	-1.27	-15.07**	59.43**	-8.85**	-16.34**	-3.98	-13.42**	-1.81	-8.21*	0	26.67**
RT 351 X Atghara	24.86**	14.72**	-1.31	85.25**	-9.63**	-16.83**	-4.55	-13.93**	-15.97**	-27.54**	-21.05**	0
RT 351 X CUHY 57	-2.83	-5.73	-13.7**	61.89**	-4.61	-8.81*	4.66	-5.64	-14.36**	-17.87**	-10.53*	13.33*
RT 351 X EC 103	31.56**	31.39**	13.32**	112.7**	-10.3**	-14.6**	-1.7	-11.7**	-14.44**	-22.71**	-15.79**	6.67
RT 351 X TKG 22	20.38**	-2.54	-16.16**	57.38**	-6.95*	-8.51*	5	-5.33	-4.76	-17.87**	-10.53*	13.33*
RT 351 X EC 90	-9.02*	-12.44*	-18.56**	52.87**	-6.59	-17.23**	-5	-14.34**	-1.91	-13.04**	-5.26	20.00**
Suprava X AT 238	37.31**	7.66*	10.48*	107.3**	11.41**	3.34	15.91**	4.51	-2.7	-5.26	-5.26	20.00**
Suprava X Atghara	24.25**	5.74	8.52*	103.6**	16.56**	8.41*	21.59**	9.63**	-5.88	-15.79**	-15.79**	6.67
Suprava X CUHY 57	4.16	-1.49	1.09	89.75**	45.70**	40.83**	57.95**	42.42**	-10.53**	-10.53*	-10.53*	13.33*
Suprava X EC 103	2.66	-5.53	-3.06	81.97**	33.19**	28.67**	44.32**	30.12**	-15.97**	-21.05**	-21.05**	0
Suprava X TKG 22	1.68	-22.77**	-20.7**	48.77**	6.98*	6.38	19.32**	7.58*	-5.88	-15.79**	-15.79**	6.67
Suprava X EC 90	-1.79	-6.38	-3.93	80.33**	11.15**	-0.51	11.59**	0.61	-8.57*	-15.79**	-15.79**	6.67
GT 10 X AT 238	28.28**	1.53	1.53	90.57**	43.56**	-6.25	-6.25	-15.47**	-2.7	-5.26	-5.26	20.00**
GT 10 X Atghara	7.87	-7.21	-7.21	74.18**	-1.68	-3.41	-3.41	-12.9**	-5.88	-15.79**	-15.79**	6.67
GT 10 X CUHY 57	-18.5**	-22.5**	-22.5**	46.31**	2.72	0.43	5.11	-5.23	-10.53**	-10.53*	-10.53*	13.33*
GT 10 XEC 103	-4.1	-10.70*	-10.70*	67.62**	-2.22	-4.35	0	-9.84**	-10.36**	-15.79**	-15.79**	6.67
GT 10 X TKG 22	14.81**	-12.01**	-12.01**	65.16**	-0.86	-5.74	4.55	-5.74	-5.88	-15.79**	-15.79**	6.67
GT 10 X EC 90	-7.01	-10.26*	-10.26*	68.44**	-7.23	-12.50**	-12.50**	-21.1**	-14.29**	-21.05**	-21.05**	0
HT 2 X AT238	28.17**	20.93**	-20.52**	49.18**	2.59	-2.15	3.41	-6.76	-0.55	-1.1	-5.26	20.00**
HT 2 X Atghara	6.91	17.27**	-15.50**	58.61**	1.18	-3.23	2.27	-7.79*	2.41	-6.59	-10.53*	13.33*
HT 2 X CUHY 57	26.94**	9.07*	-0.22	87.30**	-6	-6.45	-1.14	-10.86**	-3.23	-5.26	-5.26	20.00**
HT 2 X EC 103	31.90**	16.20**	0.22	88.11**	-8.11**	-8.60*	-3.41	-12.91**	-8.31*	-12.09**	-15.79**	6.67
HT 2 X TKG 22	33.94**	21.26**	-20.31**	49.59**	-2.41	-4.71	5.68	-4.71	2.41	-6.59	-10.53*	13.33*
HT 2 X EC 90	-2.06	-16.4**	-22.27**	45.9**	-6.43	-13.9**	-9.09*	-18.3**	-6.43	-12.09**	-15.79**	6.67
Savitri X AT238	29.91**	8.86	-6.11	76.23**	-6.1	-6.98	-9.09*	-18.03**	-5.56	-5.56	-10.53*	13.33*
Savitri X Atghara	15.59**	6.08	-8.52	71.72**	-7.31*	-7.91	-10.00*	-18.85**	-3.03	-11.11*	-15.79**	6.67
Savitri X CUHY 57	17.20**	13.84**	4.15	95.49**	1.07	-2.28	2.27	-7.79*	-2.7	-5.26	-5.26	20.00**
Savitri X EC 103	17.47**	17.47**	1.31	90.16**	-4.49	-7.61	-3.41	-12.91**	-13.54**	-16.67**	-21.05**	0
Savitri X TKG 22	17.68**	-4.81	-17.9**	54.10**	1.31	-4.71	5.68	-4.71	9.09*	0	-5.26	20.00**
Savitri X EC 90	14.74**	10.56*	2.84	93.03**	-7.32	-11.63**	-13.64**	-22.13**	-5.88	-11.11*	-15.79**	6.67

*Significant at 5% level of significance and **Significant at 1% level of significance

(2003); Mothilal and Manoharan, (2004); Lal *et al.* (2020).

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