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Heterosis for seed yield and its components in sesame (*Sesamum indicum* L.)

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Abstract
Heterosis for seed yield and its components was studied in a set of line × tester crosses of nine lines and five testers. Analysis of variance revealed significant differences among the genotypes for all the characters, indicating the presence of sufficient variability in the experimental material for all the characters studied. Differences among parents were also found highly significant for days to 50 % flowering, number of capsules per leaf axil, number of seeds per capsule and seed yield per plant. The differences among hybrids were also found significant for all the characters suggesting the presence of sufficient diversity among hybrid themselves for all the characters. While, differences among the parents *vs* hybrids were also found significant for seven characters *viz.*, days to 50 % flowering, days to maturity, plant height, height to first capsule, number of capsules per leaf axil, number of capsules per plant and 1000-seed weight. Heterosis was worked out over mid-parent, better parent and standard check variety, GT-6. The standard heterosis for seed yield per plant ranged from -60.61 to 42.60 %. The crosses AT-471 × GT-2, AT-472 × GT-3 and AT-483 × GT-3 were good heterotic combinations for seed yield per plant, which recorded 42.60, 33.06 and 17.96 % standard heterosis, respectively. The heterosis for seed yield per plant was associated with the heterosis expressed by its component characters.

Keywords: Sesame, relative heterosis, heterobeltiosis, standard heterosis

Introduction
Sesame (*Sesamum indicum* L.) is a member of the order Tubiflorae and family Pedaliaceae with chromosome number 2n=26. It is probably the most ancient oilseed known and used by man and its domestication is lost in the mists of antiquity. Although originated in Africa, it spread early through West Asia to India, China and Japan which themselves became secondary distribution centres (Weiss, 1983) [19]. Among the oilseed crops, sesame has been cultivated for centuries, particularly in Asia and Africa for its high content of edible oil and protein. Sesame is also known as gingelly, gergelin, senniseed, simsim, etc. Sesame contains about 50-60% seed oil (Uzun *et al*., 2002) [16], which is of superior quality. It is called as the "Queen of oil seeds" because of its excellent qualities of the seed, oil and meal. Its oil contains an antioxidant called "Sesamol", which imparts a high degree of resistance against oxidative rancidity and has a reducing effect on the plasma cholesterol and in conjunction with blood presser-lowering medicine, it also lowers the blood pressure (Shankar *et al.*, 2005) [13]. Sesame seed is rich in fat, protein, carbohydrates, fiber and some minerals. The oil is renowned for its stability because it strongly resists oxidative rancidity even after long exposure to air and sesame seeds are also known as the "seeds of immortality" (Bedigian and Harlan, 1986) [2]. Despite its importance as an oilseed crop, research on sesame has been scarce (Bedigian, 2003) [3].

Most of the high yielding varieties in sesame were developed through hybridization followed by selection. Although these varieties, gave higher yields, the potentiality of these varieties could not be improved significantly. Some of F_1 hybrids excel the improved variety by 50% or more. Hence, hybrid breeding appears to be promising in achieving the yield breakthrough required. Before going for a hybrid breeding programme, heterosis should be assessed for yield and yield contributing traits. Being an autogamous crop, sesame has not so far been amenable for heterosis breeding due to lack of economic method for large scale seed production. For commercial exploitation of heterosis, the basic requirements are identification of parents which show good heterosis and development of male sterility system to reduce the cost of hybrid seed. However, stable male sterile lines have not yet been developed in India (Ranganatha *et al*., 2012) [11].

Nevertheless, manual emasculation and pollination for the production of hybrids in sesame is the preferred route. This is possible because of epipetalous flower, easy emasculation and pollination, high number of seeds produced per flower, low seed rate and high multiplication ratio for manual seed production (Jadhav and Mohir, 2013) [9]. Heterosis of small amount for individual yield contributing characters may have an additive or synergistic effect on the end product (Sasikumar and Sardana, 1990) [12]. Therefore, the present study was undertaken to study the extent of heterosis for quantitative traits in sesame.

Materials and Methods

The experiment was conducted at Cotton Research Station, Junagadh Agricultural University, Junagadh, Gujarat. Nine diverse lines *viz*., AT-409, AT-464, AT-468, AT-470, AT-471, AT-472, AT-480, AT-482, AT-483 and five testers *viz*., GT-2, GT-3, GT-4, GT-5 and GT-6 were crossed in a line × tester mating design during summer 2019 to produce 45 hybrids. The resulting 45 hybrids along with 14 parents and a check variety, GT-6 were evaluated during *Kharif* 2019 in a Randomized Block Design with three replications. Each entry was accommodated in a single row plot of 2 meters length with row to row and plant to plant distances of 45 cm and 10 cm, respectively. All need based agronomic practices were followed during the crop growth period to raise a good crop. Observations were recorded on randomly selected five plants in each entry for 12 quantitative traits *viz*., days to 50 % flowering, days to maturity, plant height (cm), height to first capsule (cm), number of branches per plant, length of capsule (cm), number of capsules per leaf axil, number of capsules per plant, number of seeds per capsule, 1000-seed weight (g), seed yield per plant (g) and oil content (%) for each replication. The mean values were used for the analysis of variance for experimental design. The days to 50 % flowering and days to maturity were recorded on plot basis. The oil content was analysed by using Nuclear Resonance Spectrophotometer as suggested by Tiwari *et al*. (1974) [15]. The analysis of variance was performed to test the significance of difference among the genotypes for all the characters based on the following fixed effect statistical model as suggested by Panse and Sukhatme (1985) [10]. The estimation of heterosis over mid-parent, better parent and standard check was carried-out as per the standard procedure.

Relative heterosis

It was calculated as the deviation of F_1 from the mid parent (Fonesca and Patterson, 1968) [8] and was expressed as per cent basis by the following formula:

$$\text{Relative heterosis (\%)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Heterobeltiosis

It was calculated as the deviation of F_1 from the better parent (Fonesca and Patterson, 1968) [8] and was expressed as per cent basis by the following formula:

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Standard heterosis

It was calculated as the deviation of F_1 from the standard check (GT-6) and expressed as per cent basis by the following formula:

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Results and Discussion

Analysis of variance showed highly significant differences among the genotypes for all the characters, indicating the presence of sufficient variability in the experimental material for all the characters under investigation (Table 1). Differences among hybrids and parents were also found highly significant for days to 50 % flowering, number of capsules per leaf axil, number of seeds per capsule and seed yield per plant. Differences due to parents *vs* hybrids were also found highly significant for days to 50 % flowering, days to maturity, plant height, height to first capsule, number of capsules per leaf axil, number of capsules per plant and 1000-seed weight. This indicated that performance of parents was different than that of hybrids as well as with exception of few traits heterosis could be exploited for most of the traits. Similar results were reported by Virani *et al.* (2017), Chauhan *et al.* (2019) and Chemeda *et al.* (2019) [18, 5, 6].

The details on range of relative heterosis, heterobeltiosis and standard heterosis as well as number of hybrids having significant heterosis are presented in Table 2. The extent of heterosis for days to 50 % flowering varied from -26.28 to 8.33 %, where 42 crosses exceeded the standard heterosis in desirable direction. Eighteen crosses surpassed the standard parent for days to maturity in which heterosis ranged from -12.96 to 3.33 %. These findings are in consonance with Chaudhari *et al.* (2017) [4], Vekariya and Dhaduk (2018) [17] and Chauhan *et al.* (2019) [5]. The crosses AT-409 × GT-4 and AT-409 × GT-3 could be exploited for this trait.

The characters contributing towards vegetative growth such as plant height and number of branches per plant exhibited heterosis upto 24.90 and 32.20 %, respectively. The results are in concurrence with the findings of Virani *et al*. (2017) and Vekariya and Dhaduk (2018) [18, 17]. A desirable degree of vegetative growth is essential for realizing high yield as total dry matter production is one of the components deciding high seed yield in crop plants. Out of 45 crosses, seven and five crosses showed significant positive standard heterosis for the length of capsule and number of capsules per leaf axil, in which heterosis ranged from -21.47 to 20.70 % and -64.29 to 33.33 %, respectively. Similar results have been reported by Virani *et al*. (2017) [18]. A total of one hybrid for number of capsules per plant, 18 hybrids for number of seeds per capsule and 10 hybrids for 1000-seed weight hybrids showed significant positive standard heterosis. Similar results have been reported for these characters by Vekariya and Dhaduk (2018) [17] and Dela and Sharma (2019) [7].

The hybrid vigour for seed yield per plant varied from -60.61 to 42.60 %. A total of three hybrids registered significant standard heterosis for seed yield per plant. The highest value for heterosis was displayed by the cross AT-471 × GT-2. Heterosis for seed yield has been reported by Vekariya and Dhaduk (2018) [17], Chauhan *et al.* (2019) [5], Chemeda *et al.* (2019) [6] and Dela and Sharma (2019) [7]. Heterosis in case of oil content varied from -66 to 21 %. Two crosses registered positive standard heterosis out of 45 hybrids. Vekariya and Dhaduk (2018) [17] also reported significant positive heterosis for this trait.

The crosses which showed high heterosis for seed yield per plant also had high heterosis for days to 50 % flowering, days to maturity, number of branches per plant, number of capsules per plant, number of seeds per capsule and 1000-seed weight. The results thus, revealed that the heterosis for seed yield per plant was associated with the heterosis expressed by its component characters (Table 3). Such a situation of combinational heterosis has been reported in sesame by Thiyagu *et al*. (2007) and Banerjee and Kole, (2010) [14, 1]. The cross AT-471× GT-2 showed desirable heterosis for days to maturity, number of seeds per capsule, 1000-seed weight and oil content, cross AT-472 × GT-3 showed significant and desirable standard heterosis for other component traits like days to 50 % flowering, days to maturity, number of branches per plant, number of seeds per capsule and 1000-seed weight along with seed yield per plant. Likewise, cross AT-483 × GT-3 exhibited significant desirable standard heterosis for various component traits *viz*., days to 50 % flowering, days to maturity, number of seeds per capsule and 1000-seed weight. Therefore, these cross combinations may be tested in large scale trial to confirm the superiority for heterosis.

It can be concluded from present investigation that AT-471 × GT-2, AT-472 × GT-3 and AT-483× GT-3 were found to be the more heterotic cross combinations for seed yield and yield contributing traits on the basis of *per se performance* and heterosis over standard check. Therefore, these crosses may be advanced and exploited in future breeding programmes for improving yield and its components in sesame.

Table 1: Analysis of variance (mean square) for line × tester design for seed yield and its contributing characters in sesame

Sources	df	Mean square for					
		Days to 50% flowering	Days to maturity	Plant height (cm)	Height to first capsule (cm)	Number of branches per plant	Length of capsule (cm)
Replications	2	7.73	27.81	1218.00**	401.68**	0.08	0.06
Genotypes	58	38.76**	57.12**	243.68**	198.57**	0.17**	0.11**
a) Parents	13	33.07**	10.05	135.43	40.62	0.20	0.03
b) Hybrids	44	39.59**	61.35**	237.02**	158.75**	0.16*	0.14**
c) Parents vs. Hybrids	1	76.46**	482.62**	1943.66**	4004.07**	0.23	0.01
Error	116	2.84	9.08	81.04	38.28	0.10	0.03
Sources	**df**	**Mean square for**					
		Number of capsules per leaf axil	**Number of capsules per plant**	**Number of seeds per capsule**	**1000-seed weight (g)**	**Seed yield per plant (g)**	**Oil content (%)**
Replications	2	0.09	49.07	3.42	0.15	0.02	47.31
Genotypes	58	1.16**	372.04**	100.08**	0.16**	20.75**	132.19**
a) Parents	13	1.22**	106.77	53.91**	0.03	4.81**	30.83
b) Hybrids	44	1.15**	448.74**	115.93**	0.19**	25.91**	163.69**
c) Parents vs. Hybrids	1	1.12**	445.74**	3.14	0.58**	0.71	64.29
Error	116	0.06	64.83	20.47	0.07	1.84	22.65

* and ** significant at 5 % and 1 % levels of probability, respectively

Table 2: Range of heterosis and number of crosses with response to heterotic effects for various traits in sesame

S. N.	Characters	Range of Heterosis (%)			No. of crosses with significant heterosis					
		H_1	H_2	H_3	H_1		H_2		H_3	
					+Ve	-Ve	+Ve	-Ve	+Ve	-Ve
1	Days to 50 % flowering	-18.75 to 26.12	-13.67 to 29.01	-26.28 to 8.33	04	23	07	10	01	42
2	Days to maturity	-12.80 to 4.12	-12.64 to 6.51	-12.96 to 3.33	00	20	02	18	00	18
3	Plant height (cm)	-12.63 to 42.32	-19.38 to 38.71	-18.67 to 24.90	15	00	06	01	04	00
4	Height to first capsule (cm)	-11.01to 70.36	-8.66 to 83.78	-9.96 to 61.41	30	00	30	00	22	00
5	Number of branches per plant	-26.17 to 32.17	-27.63 to 30.00	-8.47 to 32.20	05	04	02	06	05	00
6	Length of capsule (cm)	-25.15 to 14.50	-26.07 to 20.98	-21.47 to 20.70	05	06	02	07	07	02
7	Number of capsules per leaf axil	-63.86 to 65.62	-66.67 to 29.27	-64.29 to 33.33	16	13	04	28	05	21
8	Number of capsules per plant	-35.62 to 31.72	-38.76 to 23.86	-40.31 to 13.11	08	18	08	16	01	26
9	Number of seeds per capsule	-33.33 to 26.77	-34.02 to 15.68	-21.92 to 29.23	11	06	05	10	19	03
10	1000-seed weight (g)	-9.55 to 24.08	-10.43 to 21.27	-11.07 to 19.80	10	00	07	01	10	01
11	Seed yield per plant (g)	-55.75 to 79.77	-57.78 to 64.83	-60.61 to 42.60	10	15	06	15	03	21
12	Oil content (%)	-65.40 to 25.85	-66.96 to 24.41	-66.00 to 21.00	05	02	01	02	01	02

Table 3: The best performing hybrids for seed yield per plant along with relative heterosis, heterobeltiosis, standard heterosis and standard heterosis for component characters in sesame

Sr. No.	Hybrids	Seed yield per plant (g)	Relative heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)	Significant desirable standard heterosis for component traits
1	AT-471 × GT-2	18.19	79.77**	64.83**	42.60**	DM, NSPC, TW, OC
2	AT-472 × GT-3	16.97	68.77**	44.30**	33.06**	DFF, DM, NBPP,NSPC, TW
3	AT-483 × GT-3	15.04	68.58**	58.41**	17.96*	DFF, DM, NSPC, TW
4	AT-464 × GT-4	14.63	25.21**	23.00**	14.74	DFF, DM, NCPP, NSPC,TW, OC

* and ** significant at 5 % and 1 % levels of probability, respectively

DM: Days to maturity
DFF: Days to 50% flowering
NSPC: Number of seeds per capsule
NBPP: Number of branches per plant
OC: Oil content
NCPP: Number of capsules per plant
TW: 1000-seed weight

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