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Heterosis studies over the environments in sesame (*Sesamum indicum* L.)

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Abstract
An experiment was laid out on diallel analysis to study the extent of heterosis in sesame over the environments in Marathwada region of Maharashtra (India) for seed yield and component traits. The analysis of variance showed highly significant differences among genotypes. The interaction between parents vs hybrids recorded highly significant differences for all the traits except 1000 seed weight and oil content in all the four environments and days to 50 percent flowering in E_3, E_4, days to maturity in E_1, E_4, plant height in E_2, number of branches in E_1, E_2 and length of capsule in E_1, E_2 and E_3 indicating heterosis could be exploited for improvement of these traits. The best and three top ranking crosses were identified in each environment *viz*., TBS-105 x R-09, TBS-105 x V-29 and TBS-7 x V-29 in E_1, R-09 x V-29, TBS-7 x V-29 and TBS-105 x V-29 in E_2, TBS-10 x V-29, TBS-105 x V-29 and TBS-7 x TBS-12 in E_3 and TBS-10 x V-29, TBS-7 x TBS-12 and TBS-105 x V-29 in E_4 having high *per se* performance along with significant mid parent, better parent and standard heterosis for seed yield per plant. The significant desired standard heterosis was ranged from 20.69 to 152.66 percent over the check AKT-101 and heterobeltiosis from 15.78 to 148.42 percent for seed yield per plant.

Keywords: Sesame, heterosis, heterobeltiosis, diallel analysis

Introduction
Sesame (*Sesamum indicum* L.) is a very ancient and oldest oil crop known as "Queen of oilseeds" cultivated for its edible protein-rich seed and high-quality oil (Bhat *et al*., 1999) [4]. Besides, it has various minor nutrients such as vitamins, minerals and a large number of characteristic lignans (sesamin, sesamol and sesamolin) and tocopherols (Fukuda, *et al*., 1985) [7]. The sesame seeds have high amounts of nutritional components which are consumed as a traditional health food for their specific antihypertensive effect, anticarcinogenic, anti-inflammatory and antioxidative activity (Yokota, *et al*., 2007) [35].

In India, the productivity of sesame seems to be very low as compared to other sesame growing countries and almost stagnant during the last few years. However, the yield plateau and poor productivity can be overcome by the commercial exploitation of heterosis. The nature and magnitude of heterosis is one of the important aspects for the selection of the right parents for crosses and also help in the identification of superior cross combinations that may produce desirable transgressive segregants in advanced generations. Epipetalous flower structure of sesame enables easy emasculation and pollination, a high number of seeds (40-50) produced per flower, low seed rate (2.0-2.5 kg/ha) and high seed multiplication ratio (1: 50) for manual seed production increases the scope for heterosis breeding in sesame (Chaudhari, *et al.,* 2018) [5]. Heterosis of a small amount for an individual yield contributing characters may have an additive or synergistic effect on the end product (Sasikumar and Sardana, 1990) [27].

The development of commercial hybrids by heterosis breeding could improve the production level in sesame. High level of heterosis has been reported in sesame by Sarvanan and Nadarajan, 2002 [26] (151.46%), Uzun, *et al*., 2004 [33] (500.8%), Mubashir *et al*., 2009 [17] (255.12%) and Imran, *et al*., 2017 [11] (294.14%). Therefore, the present investigation was designed to study the magnitude of heterosis in hybrids over mid parent (MP), better parent (BP) and standard heterosis (SH) under different environments for seed yield and component traits in sesame.

Materials and Methods
The experimental material consists of eight diverse parents collected from different parts of the country. The 56 F_1 crosses were made at Oilseed Research Station, Latur during *kharif* 2019 by using an 8 x 8 diallel mating design including reciprocals.

The 56 F_1's with three checks *viz*., AKT-101, JLT-408 and GT-2 were grown in randomized block design with two replications in four environments. The experiment was conducted during summer 2020 at two locations *viz*., Parbhani (E_1), Ambajogai (E_2) and k*harif* 2020 at two locations *viz*., Parbhani (E_3) and Ambajogai (E_4) each at Department of Agricultural Botany, College of Agriculture, VNMKV, Parbhani and Oilseed Research Substation, Ambajogai, respectively. Each genotype was planted in a two-row plot of 3 m length following spacing of 45 cm between rows and 15 cm between plants within a row. Recommended cultural and plant protection practices were followed to raise good and healthy crops. Five competitive plants were selected randomly to record observations on days to 50 percent flowering, days to maturity, plant height, number of branches per plant, number of capsules per plant, length of capsule, number of seeds per capsule, 1000-seed weight, seed yield per plant and oil content. The magnitude of heterosis was calculated as per the standard method suggested by Fonseca and Patterson (1968) [6].

Results and Discussion

The analysis of variance was carried out and the mean square due to genotypes (Table 1). It showed significant differences for all the traits indicated the presence of significant amount of genetic variability for all the traits under study. The interaction between parents vs hybrids recorded highly significant differences for all the traits except 1000 seed weight and oil content in all the four environments and except days to 50 percent flowering in E_3, E_4, days to maturity in E_1, E_4, plant height in E_2, number of branches in E_1, E_2 and length of capsule in E_1, E_2 and E_3 indicating heterosis could be exploited for improvement of these traits.

The estimates of heterosis exhibited that none of the crosses were found significantly high heterosis over mid parent, better parent and standard check (AKT-101) for all the traits in all the environments. However, three best crosses were selected in each environment based on high *per se* performance in desirable direction along with their respective MP, BP and SH (AKT-101) (Table 2).

Earliness is desirable trait, hence the crosses possessing significant negative heterosis, heterobeltiosis and standard heterosis for days to 50 percent flowering were considered superior. The crosses R-20 x V-29 in E_3 and TBS-7 x V-29 in E_4 and TBS-10 x V-29 in E_4 showed significant negative heterosis. The cross R-20 x V-29 in E_3 and crosses TBS-7 x V-29, R-20 x V-29 and TBS-12 x R-09 in E_4 showed significant negative heterobeltiosis and crosses TBS-3 x V-29 and TBS-3 x R-20 in E_2 only displayed significant negative standard heterosis (Table 2). Significant negative heterosis (Thiyagu, *et al*., 2007a [32], Virani, *et al*., 2017 [34] and Nayak, *et al*., 2017 [18]) and heterobeltiosis for days to 50 percent flowering was also reported by Singh (2007) [30], Prajapati, *et al*., (2010) [21], Jatothu, *et al*., (2013) [12], Kumar, *et al*., (2015) [14] and Hassan and Sedeck (2015) [10].

Early maturity is most desirable trait in rainfed cultivation. One cross each in E_1 (TBS-3 x R-09) and E_3 (TBS-7 x V-29) and one in E_4 (TBS-7 x V-29) showed significant negative heterobeltiosis (Table 2). Similar results were also previously found by Sharmila and Ganesh (2008) [28] and Kumar, *et al*.,(2015) [14]. Hence, these crosses are considered desirable for earliness.

Heterosis for the trait plant height may be considered in both the directions positive as well as negative. In this study positive heterosis is considered. Among crosses 17 in E_1, seven in E_2, three in E_3 and E_4 exhibited significant positive heterosis. Seven crosses in E_1 and one in E_3 showed significant positive heterobeltiosis and 28 crosses in E_1, 17 in E_2 and 14 in E_4 showed significant positive standard heterosis for plant height. (Table 2). Environments E_1 followed by E_2 were the best for getting high number of crosses showing desirable heterosis, heterobeltiosis and standard heterosis for plant height. Mothilal and Ganesan (2005) [16], Thiyagu, *et al*., (2007a) [32], Sharmila and Ganesh (2008) [28], Mubashir, *et al*., (2009) [17], Hassan and Sedeck (2015) [10] and Reddy, *et al*., (2015) [25] reported similar results.

The more number of branches per plant is a desirable parameter; hence positive heterotic effects were expected. Eleven in E_1, four in E_2, seven in E_3 and three in E_4 crosses disclosed significant positive heterosis, whereas, six in E_1, two in E_2 and one in E_4 exhibited significant positive heterobeltiosis. (Table 2). Therefore environment E_1 and E_2 were the best environment for the exploitation of heterosis. The crosses, TBS-105 x R-20, TBS-105 x R-09 and TBS-7 x TBS-105 in E_1, R-09 x R-20, R-20 x V-29 and TBS-7 x TBS-105 in E_2, TBS-7 x R-20, TBS-105 x R-20 and TBS-105 x R-09 in E_3 and TBS-105 x R-20, TBS-10 x R-09 and TBS-7 x TBS-105 in E_4 revealed highly significant positive heterosis, standard heterosis except heterobeltiosis in E_2, E_3 and E_3 for number of branches per plant. Similar results were also achieved by Mubashir, *et al*., (2009) [17], Prajapati, *et al*., (2010) [21], Hassan and Sedeck (2015) [10], Patel, *et al*., (2016) [20], Rajput, *et al*., (2017) [23], Nayak, *et al*., (2017) [18] and Virani, *et al*., (2017) [34].

High number of capsules per plant is directly contributed in increasing yield per plant, which is reflected by the positive heterotic effects. Twenty four crosses in E_1, 8 in E_2, 10 in E_3 and 12 in E_4 showed significant positive heterosis, whereas, 23 in E_1, 15 in E_2, 7 in E_3 and 11 in E_4 exhibited significant positive heterobeltiosis and 28 crosses in E_1, 12 in E_2, 11 each in E_3 and E_4 displayed significant positive standard heterosis. Among the environment E_1 followed by E_2 having high number of desirable crosses showing high standard heterosis and heterobeltiosis for this trait. The crosses TBS-105 x R-20, TBS-105 x R-09 and TBS-7 x V-29 in E_1, TBS-10 x R-09, R-09 x V-29 and TBS-10 x TBS-12 in E_2, TBS-105 x V-29, TBS-10 x V-29 and TBS-7 x TBS-12 in E_3 and TBS-7 x TBS-12, TBS-10 x V-29 and TBS-105 x V-29 in E_4 disclosed significant positive heterosis, heterobeltiosis and standard heterosis respectively. Significant positive heterosis and heterobeltiosis in sesame were also reported by Prajapati, *et al*., (2010) [21], Padma Sundari and Kamla (2012) [19], Kumar, *et al*., (2015) [14], Shobha Rani, *et al*., (2015) [29], Patel, *et al*., (2016) [20], and Choudhary, *et al*., (2018) [5].

Long capsule consist of more number of seeds is a desirable trait for high seed yield. Three crosses in E_1, one in E_3 and E_4 exhibited significant positive heterosis, whereas two crosses in E_1 only showed significant positive heterobeltiosis and 13 crosses in E_1, 11 in E_2, five in E_3 and nine in E_4 reveled significant positive standard heterosis. Therefore environment E_1 was the best environment having high number of crosses for exploiting standard heterosis for getting long capsule length. The crosses TBS-7 x TBS-105, TBS-7 x R-20 and TBS-7 x R-09 displayed significant positive heterosis, heterobeltiosis and standard heterosis respectively in E_1, TBS-7 x R-20, TBS-7 x R-09 and TBS-3 x R-20 displayed significant positive standard heterosis in E_2, while TBS-7 x TBS-105, TBS-7xR-20 exhibited significant positive heterosis and standard heterosis respectively in E_3 and TBS-7 x TBS-105 (18.77, 26.07) exhibited significant positive heterosis and standard heterosis respectively in E_4. Prajapati, *et al*., (2010) [21] and Kumar, *et al*., (2015) [14] reported similar results.

More number of seeds per capsule is desirable character, which is revealed by the positive heterotic effects. Six crosses in E_1, five in E_2, ten in E_3 and six in E_4 manifested significant positive heterosis, whereas, two in E_1, four in E_3 and three in E_4 also exhibited significant positive heterobeltiosis and five crosses each in E_1 and E_3 and nine in E_4 exhibited significant positive standard heterosis (Table 2). Among the environments, E_1, E_3 and E_4 were the best environment for exploiting standard heterosis. Banarjee and Kole (2010) [3], Padma Sundari and Kamla (2012) [19], Kumar, *et al*., (2015) [14], Patel, *et al*., (2016) [20] and Virani, *et al*., (2017) [34] reported significant positive heterosis for number of seeds per capsule in sesame.

Test weight is an important yield contributing trait. One cross in E_2 exhibited significant heterosis, whereas none of the cross found significant positive heterobeltiosis. Two crosses in E_1, eight in E_2, two each in E_3 and E_4 exhibited significant positive standard heterosis. The crosses TBS-10 x TBS-12 and TBS-12 x TBS-105 in E_1, TBS-10 x R-20 and TBS-7 x R-20 in E_2 TBS-10 x TBS-12 and TBS-12 x TBS-105 in E_3 and TBS-10 x TBS-12 and TBS-12 x TBS-105 in E_4 displayed significant positive standard heterosis. Only one cross TBS-10 x R-20 in E_2 showed significant positive mid parent heterosis. Environment E_2 was the best environment for the exploitation of standard heterosis. (Mothilal and Ganesan 2005 [16], Misra, *et al*., 2008 [15], Banarjee and Kole 2010 [3], Imran, *et al*., 2017 [11], Nayak, *et al*., 2017 [18] and Chaudhary, *et al*., 2018) [5].

Seed yield is most important objective of any plant breeding programme, therefore standard heterosis over the check AKT-101 had been estimated to exploit the heterosis. Among the environments all the crosses in E_1, 21 in E_2, 20 in E_3 and 25 in E_4 revealed significant positive heterosis, whereas 26 in E_1, 20 in E_2, 18 in E_3 and 24 in E_4 also exhibited significant positive heterobeltiosis and 27 crosses in E_1, 17 in E_2, 19 in E_3 and 20 in E_4 revealed significant positive standard heterosis over commercial check AKT-101. Only one cross TBS-105 x V-29 was found highly significant over mid parent, better parent and standard heterosis in the entire four environments (Table 2). The cross TBS-10 x V-29 and TBS-7 x TBS-12 in two environments namely E_3 and E_4 recorded highly significant MP, BP and SH respectively. Environment wise three best crosses were selected for comparison and interpretation. The crosses TBS-105 x R-09 (150.59, 148.42, 152.66), TBS-105 x V-29 (148.95, 141.62, 145.73), TBS-7 x V-29 (147.04, 140.41, 143.15) in E_1, R-09 x V-29 (169.23, 152.16, 108.53), TBS-7 x V-29 (157.63, 131.77, 109.40), TBS-105 x V-29 (130.27, 106.74, 87.65) in E_2, TBS-10 x V-29 (70.37, 70.2, 84.41), TBS-105 x V-29 (66.2, 58.4, 89.4), TBS-7 x TBS-12 (59.34, 53.24, 65.15) in E_3 and TBS-10 x V-29 (108.5, 99.9, 84.67), TBS-7 x TBS-12 (100.9, 85.68, 76.07), TBS-105 x V-29 (97.02, 95.9, 83.05) in E_4 revealed significant positive heterosis, heterobeltiosis and standard heterosis respectively (Table 2). Similar findings were also reported by Mothilal and Ganesan (2005) [16], Anuradha and Reddy (2008a) [2], Gaikwad, *et al*., (2009) [8], Banarjee and Kole (2010) [3], Padma Sundari and Kamla (2012) [19] and Kumar, *et al*., (2015) [14]. The environment E_1 followed by E_2 were the most suited environments to exploit the heterosis. Hence, these crosses could be used to exploit the heterosis for quantitative traits in segregating generations to develop high yielding cultivars in sesame.

High oil content is a positive character, therefore positive heterotic effects are desirable. One cross in E_4 showed significant positive heterosis and five in E_1 showed significant positive standard heterosis, three in E_2 and E_4 and two in E_3 showed desirable standard heterosis. The cross TBS-3 x TBS-10 in E_4 exhibited significant positive heterosis and TBS-12 x R-20 and TBS-7 x TBS-12 in E_1 showed significant positive standard heterosis. Significant positive heterosis for oil content were reported by Sharmila and Ganesh 2008 [28], Sumathi and Muralidharan 2008 [31] and Nayak, *et al*., 2017 [18].

The highest desirable heterobeltiosis and standard heterosis was found 152.16 percent (R-09 x V-29 in E_2) and 152.66 percent (TBS-105 x R-09 in E_1) for seed yield per plant followed by 149.03 percent (TBS-10 x R-09 in E_2) for a number of capsules per plant, 31.6 percent (TBS-105 x R-09 in E_1) for a number of branches per plant, 28.6 percent (TBS-7 x R-09 in E_1) for a number of seeds per capsule, 28.33 percent (R-20 x V-29 in E_3) for plant height, 21.5 percent (TBS-7 x TBS-105 in E_1) for a length of capsule, 13.98 percent (TBS-3 x TBS-10 in E_4) for oil content, -11.11 percent (R-20 x V-29 in E_3) for days to 50 percent flowering and -9.42 percent (TBS-3 x R-09 in E_1) for days to maturity.

Thirteen crosses out of 28 cross combinations exhibited significant heterobeltiosis in all the locations and 12 crosses in more than one location for seed yield per plant. Among 13 crosses, having significant better parent heterosis for seed yield per plant in all the locations had significant heterobltiosis for some of the other characters. Such crosses were TBS-7 x TBS-12, TBS-12 x R-09, TBS-105 x R-09, R-20 x V-29, TBS-3 x TBS-12, TBS-3 x R-09 and TBS-105 x V-29. These cross combinations were promising and considered for their use in yield improvement programme because of having a high heterotic effect for seed yield as well as some component traits. Supported findings in varying environments for different traits were also given by Anitha and Dorairaj (1991) [1], Ray and Sen (1992) [24], Ragiba and Reddy (2000) [22], Krishna Devi, *et al*., (2003) [13], Gupta, *et al*., (2005) [9] and Mothilal and Ganesan (2005) [16].

Table 1: Mean squares for parents and F1s at four environments for different characters in sesame

Source of variation	Env.	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No of branches/plant	Number of capsules/plant	Length of capsule (cm)	Number of seeds/capsule	1000 seed weight (g)	Seed yield/ plant (g)	Oil content (%)
Replication	E_1	1	0.36	16.48	3.34	0.02	0.008	0.008	11.57	0.003	0.15	0.09
	E_2	1	0	38.15	11.77	0.19	34.93	0.001	7.70	0.01	0.19	0.19
	E_3	1	11.35	3.94	71.74	0.07	10.57	0.067	4.61	0.008	0.33	0.12
	E_4	1	4.29	3.61	0.76	0.01	0.01	0.021	13.54	0.021	2.05	2.17
Genotypes	E_1	66	6.02*	23*	316.39**	0.29**	1387.7**	0.14**	83.64**	0.29*	33.50**	35.19**
	E_2	66	7.84*	30.94**	848.86**	0.33**	705.7**	0.14**	82.98*	0.43	38.50**	45.60**
	E_3	66	6.89**	12.93*	315.11*	0.18**	263.20**	0.20**	94.62**	0.29*	26.02**	36.77*
	E_4	66	8.00**	8.21*	184.79*	0.15**	216.77**	0.13**	91.70**	0.40*	18.74**	29.99*
Parents (P)	E_1	7	4.77	14.77	783.56**	0.22**	132.57*	0.13	59.2	0.25	0.23	32.05
	E_2	7	2.53	19.26	688.3**	0.26*	23.99	0.06	59.48*	0.69**	1.27	62.91**
	E_3	7	2.91	17.34	849.22**	0.38**	13.19	0.13	57.83	0.27	1.30	57.34*
	E_4	7	4.82	11.56	382.1**	0.05	9.23	0.12	49.01	0.26	0.81	56.5**
Hybrids (F_1)	E_1	55	5.40	23.58	156.16**	0.31**	1246.2**	0.12*	78.41**	0.25*	28.02**	37.16**
	E_2	55	6.58	30.95**	904.49**	0.27**	752.3**	0.14**	68.77	0.40**	37.22**	44.74**
	E_3	55	6.16**	11.63	227.69	0.12*	300.7**	0.19*	86.64**	0.26*	27.57**	36.04*
	E_4	55	7.72**	7.64	136.48	0.15**	244.29**	0.10*	91.44	0.39*	14.84**	27.3*
P *vs* F_1	E_1	1	55.00**	55.00	4049.9**	0.18	16741**	0.25	427.18**	0.045	538.9**	0.01
	E_2	1	95.81**	69.47*	46.03	0.02	4306.5*	0	443.39**	0.21	398.1**	13.28
	E_3	1	5.01	41.57*	1278.3*	0.51**	434.68**	0.30	466.22**	0.06	79.25**	5.62
	E_4	1	0.07	2.46	67.43*	0.61**	463.18**	0.50**	302.49**	0.03	302**	0.28
Error	E_1	66	3.97	15.27	81.29	0.06	49.26	0.06	46.57	0.16	1.63	18.66
	E_2	66	5.18	13.5	108.12	0.09	28.40	0.07	46.52	2.92	2.92	21.32
	E_3	66	3.16	8.59	176.67	0.07	24.85	0.11	39.10	0.16	1.79	20.63
	E_4	66	2.96	5.46	103.78	0.07	17.22	0.06	36.53	0.23	0.92	16.82

*, ** Significant at 5% and 1% level respectively

Table 2: Best three direct crosses based on *per se* performance along with their heterosis, heterobeltiosis and standard heterosis under four environments for yield and other component traits in sesame

Character	Env	Best direct crosses	Mean value	Mid parent heterosis (%)			Heterobeltiosis (%)			Standard heterosis (%)		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Days to 50% flowering	E_1	TBS-3 x R-09	42.00	-6	-4 to11	0	-9.42	-4.6 to 12.35	0	-1.14	-9.89 to 2.20	01
		TBS-3 x V-29	41.50	-4.5			-4.52			-3.43		
		TBS-7 x R-09	46.00	-3.9			-8.38			0		
	E_2	TBS-3 x V-29	40.50	-2.41	-2.41 to 15.3	0	-3.57	-3.57 to 14.63	0	-10.99*	-10.99 to 4.4	02
		TBS-3 x R-20	40.50	-1.81			-3.57			-10.99*		
		TBS-3 x R-09	42.50	-1.16			-3.41			-6.59		
	E_3	R-20 x V-29	36.00	-10.00*	-10 to 4.82	1	-11.11*	-11 to 4.82	1	-4.00	-4 to 14.67	0
		TBS-10 x TBS-12	39.00	-5.45			-6.02			4.00		
		TBS-10 x V-29	39.50	-3.66			-4.82			5.33		
	E_4	TBS-10 x V-29	37.00	-7.5*	-7.5 to 6.75	3	-7.5	-9.52 to 4.82	3	-1.33	-2.67 to 17.33	0
		TBS-7 x V-29	38.00	-7.32*			-9.52*			1.33		
		R-20 x V-29	36.50	-7.01			-8.75*			-2.67		
Days to maturity	E_1	TBS-3 x R-09	86.50	-6.00	-6 to 7.39	0	-9.42*	-9.42 to 6.78	1	-1.14	-3.43 to 11.43	0
		TBS-3 x V-29	84.50	-4.5			-4.52			-3.43		
		TBS-7 x R-09	89.00	-3.9			-8.38			00		
	E_2	TBS-3 x TBS-105	86.00	-4.71	-4.71 to 8.48	0	-6.52	-7.12 to 5.14	0	-0.58	-1.73 to 12.72	0
		TBS-3 x R-09	88.00	-3.96			-7.12			1.73		
		TBS-7 x R-09	88.50	-3.15			-6.6			2.31		
	E_3	TBS-3 x V-29	86.00	-3.91	-3.91 to 5.72	0	-4.44	-6.74 to 3.3	1	-5.49	-2.75 to 6.59	0
		TBS-3 x R-09	90.00	-3.49			-6.74*			-1.10		
		TBS-3 x TBS-105	90.00	-0.55			-1.1			-1.10		
	E_4	TBS-7 x R-09	88.50	-4.07	-4.07 to 7.3	0	-4.32	-5.43 to 4.05	1	2.31	-0.58 to 9.25	0
		TBS-7 x TBS-12	87.50	-3.31			-4.89			1.16		
		TBS-7 x TBS-10	88.00	-3.03			-4.35			1.73		

Character	Env	Best direct crosses	Mean value	Mid parent heterosis (%)			Heterobeltiosis (%)			Standard heterosis (%)		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Plant height (cm)	E_1	TBS-12 x R-20	139.84	46.71**	-5.8 to 46.7	17	24.3**	-16.6 to 24.3	7	45.41**	17.85 to 57.37	28
		TBS-7 x R-20	130.84	38.70**			18.4*			36.05**		
		TBS-105 x R-20	130.17	33.61**			11.6			35.36**		
	E_2	TBS-3 x R-20	129.82	38.49**	-23.52 to 38.49	7	13.06	-26.59 to 13.06	0	31.08**	-15896 to 34.77	17
		TBS-10 x R-20	125.01	33.97**			9.69			26.22*		
		TBS-7 x R-20	126.50	32.9**			7.49			27.73**		
	E_3	R-20 x V-29	131.00	29.94*	-17.59 to 29.94	3	28.33	-21.84 to 28.33	1	-0.19	-6.71 to 5.66	0
		TBS-3 x R-20	137.67	23.63*			11.77			4.9		
		TBS-10 x R-20	138.50	21.91*			8.49			5.53		
	E_4	TBS-12 x V-29	145.34	20.78**	-13.79 to 20.78	3	4.81	-15.7 to 8.84	0	22.99**	2.26 to 24.68	14
		TBS-3 x V-29	137.50	20.44**			8.84			16.36		
		R-09 x V-29	142.17	17.42*			1.43			20.31*		
No of branches/plant	E_1	TBS-105 x R-20	3.84	35.40**	-10 to 35.4	11	21.17**	-14.3 to 31.16	6	35.27**	-23.63 to 52.73	17
		TBS-105 x R-09	4.17	35.12**			31.60**			46.91**		
		TBS-7 x TBS-105	4.33	29.93**			23.10**			52.43**		
	E_2	R-09 x R-20	4.34	42.83**	-16.19 to 42.83	4	29.99**	-21.14 to 29.99	2	58.79**	-8.42 to 58.79	15
		R-20 x V-29	3.90	25.10**			11.43			42.86**		
		TBS-7 x TBS-105	4.25	23.10**			13.79			55.68**		
	E_3	TBS-7 x R-20	4.17	28.15**	-13.7 to 28.15	7	13.64	-13.76 to 13.64	0	42.88**	8.58 to 42.88	22
		TBS-105 x R-20	4.17	28.06**			13.49			42.88**		
		TBS-105 x R-09	4.17	21.87**			13.49			42.88**		
	E_4	TBS-105 x R-20	3.75	20.68**	-5.24 to 20.68	3	14.85	-7.9 to 17.13	1	20.97*	-5.97 to 29.03	03
		TBS-10 x R-09	4.00	18.52**			17.13*			29.03**		
		TBS-7 x TBS-105	3.75	16.64*			14.85			20.97*		

Character	Env	Best direct crosses	Mean value	Mid parent heterosis (%)			Heterobeltiosis (%)			Standard heterosis (%)		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Number of capsules/pl	E_1	TBS-105 x R-20	142.50	166.36**	-3.3 to 166	24	133.61**	-7.91 to 134	23	139.50**	-10.92 to 180.95	28
		TBS-105 x R-09	167.17	148.27**			126.93**			180.95**		
		TBS-7 x V-29	150.50	132.14**			125.76**			152.94**		
	E_2	TBS-10 x R-09	149.01	150.42**	-2.53 to 150.42	8	149.03**	-8.91 to 149.03	15	131.02**	-16.79 to 131.02	12
		R-09 x V-29	134.34	137.43**			126.18**			109.82**		
		TBS-10 x TBS-12	107.67	93.70**			81.97**			66.93**		
	E_3	TBS-105 x V-29	86.00	75.51**	-16.17 to 75.51	10	69.74**	-18.4 to 69.74	7	70.87**	-13.23 to 70.87	11
		TBS-10 x V-29	81.52	61.69**			52.37**			61.97**		
		TBS-7 x TBS-12	84.00	55.76**			54.60**			66.9**		
	E_4	TBS-7 x TBS-12	85.61	69.52**	-12.15 to 69.52	12	66.23**	-13.92 to 66.23	11	64.62**	-14.76 to 64.62	11
		TBS-10 x V-29	80.17	55.65**			55.14**			54.16**		
		TBS-105 x V-29	80.68	53.41**			50.79**			55.13**		
Length of capsules (cm)	E_1	TBS-7 x TBS-105	3.39	22.76**	-12.00 to 22.8	3	21.54*	-15.4 to 21.5	2	26.78**	-3.37 to 37.27	13
		TBS-7 x R-20	3.40	21.75**			21.43*			27.34**		
		TBS-7 x R-09	3.30	17.02*			15.59			23.60*		
	E_2	TBS-7 x R-20	3.39	15.92	-13.91 to 15.92	0	13.4	-18.25 to 13.4	0	28.99**	-2.28 to 28.71	11
		TBS-7 x R-09	3.36	13.73			12.4			27.57*		
		TBS-3 x R-20	3.29	13.08			11.17			24.90*		
	E_3	TBS-7 x TBS-105	3.40	20.78*	-11.13 to 20.78	1	18.06	-15.19 to 18.06	0	28.3*	-0.19 to 32.26	05
		TBS-7 x R-20	3.38	19.43			17.36			27.55*		
		TBS-7 x R-09	3.28	15.09			13.89			23.77		
	E_4	TBS-7 x TBS-105	3.39	18.77*	-3.88 to 18.77	1	16.72	-9.75 to 16.72	0	26.07**	-0.74 to 30.91	09
		TBS-105 x R-20	3.19	15.5			13.75			18.62		
		TBS-7 x R-20	3.22	14.69			11.03			19.93		

Character	Env	Best direct crosses	Mean value	Mid parent heterosis (%)			Heterobeltiosis (%)			Standard heterosis (%)		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Number of seeds/capsule	E_1	TBS-7 x R-09	74.25	29.98**	-12 to 30	6	28.57**	-18.6 to 28.6	2	25.85*	-9.32 to 36.86	05
		TBS-105 x R-09	69.05	23.56*			23.01*			17.8		
		TBS-7 x R-20	74.50	20.64*			13.3			26.27*		
	E_2	TBS-10 x R-09	75.17	24.76*	-9.42 to 24.76	5	20.58	-17.61 to 20.58	0	13.6	-11.58 to 13.35	00
		TBS-10 x TBS-12	73.01	23.13*			17.12			10.34		
		TBS-3 x TBS-12	73.17	22.55*			15.84			10.59		
	E_3	TBS-3 x TBS-10	77.17	27.02**	-7.81 to 27.02	10	21.20*	-14.71 to 25.28	4	30.05**	-7.86 to 36.51	05
		TBS-7 x R-09	72.67	26.93**			25.28*			22.47*		
		TBS-10 x R-09	71.33	24.77**			23.33*			20.22		
	E_4	TBS-7 x R-09	74.50	26.99**	-11.32 to 26.99	6	23.48*	-17.3 to 24.79	3	24.17*	-9.72 to 32.77	09
		TBS-105 x R-09	73.01	26.42**			24.79*			21.68*		
		TBS-7 x TBS-12	72.50	23.93**			20.16*			20.83*		
1000 seed weight (gm)	E_1	TBS-3 x R-09	4.65	15.9	-13 to 15.9	0	6.9	-19.6 to 11	0	14.8	-10 to 28.9	02
		TBS-10 x TBS-12	5.01	14.8			11			23.7*		
		TBS-12 x TBS-105	5.22	11.8			8.3			28.91**		
	E_2	TBS-10 x R-20	4.46	23.03*	-12.34 to 23.03	1	4.08	-20.61 to 4.55	0	27.43*	-15.29 to 40.57	08
		TBS-7 x R-20	4.39	15.91			-4.77			25.43*		
		TBS-12 x R-20	4.07	11.91			-5.47			16.14		
	E_3	TBS-3 x R-09	4.65	15.4	-13.21 to 15.4	0	5.93	-20.25 to 10.95	0	14.41	-10.1 to 28.33	02
		TBS-10 x TBS-12	5.02	14.56			10.95			23.52*		
		TBS-12 x TBS-105	5.21	11.32			7.64			28.33**		
	E_4	TBS-3 x R-09	4.61	15.56	-11.72 to 15.56	0	4.9	-18.39 to 12.04	0	14.69	-8.84 to 29.64	02
		TBS-10 x TBS-12	5.03	15.25			12.04			25.16*		
		TBS-12 x TBS-105	5.21	12.97			10.04			29.64*		

Character	Env	Best direct crosses	Mean value	Mid parent heterosis (%)			Heterobeltiosis (%)			Standard heterosis (%)		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Seed yield/plant (gm)	E_1	TBS-105 x R-09	24.42	150.59**	16.21 to 150.59	28	148.42**	15.78 to 148.42	26	152.66**	20.69 to 152.66	27
		TBS-105 x V-29	23.75	148.95**			141.62**			145.73**		
		TBS-7 x V-29	23.50	147.04**			140.41**			143.15**		
	E_2	R-09 x V-29	25.07	169.23**	2.14 to 169.23	21	152.16**	-2.7 to 152.16	20	108.53**	-18.64 to 109.4	17
		TBS-7 x V-29	25.17	157.63**			131.77**			109.4**		
		TBS-105 x V-29	22.56	130.27**			106.74**			87.65**		
	E_3	TBS-10 x V-29	20.88	70.37**	-18.39 to 70.37	20	70.2**	-21.08 to 70.2	18	84.41**	-14.84 to 89.4	19
		TBS-105 x V-29	21.44	66.2**			58.4**			89.4**		
		TBS-7 x TBS-12	18.70	59.34**			53.24**			65.15**		
	E_4	TBS-10 x V-29	19.99	108.5**	2.08 to 108.5	25	99.9**	0.58 to 99.9	24	84.67**	-5.59 to 84.67	20
		TBS-7 x TBS-12	19.06	100.9**			85.68**			76.07**		
		TBS-105 x V-29	19.82	97.02**			95.9**			83.05**		
Oil content (%)	E_1	TBS-12 x R-20	47.17	17.3	-11 to 17.3	0	5.58	-19.8 to 9.15	0	26.97*	-6.06 to 32.72	05
		TBS-7 x TBS-12	48.38	15.2			8.29			30.23**		
		TBS-7 x V-29	47.05	13			7.08			26.64		
	E_2	R-09 x R-20	44.04	18.76	-14.79 to 18.76	0	9.98	-23.01 to 9.98	0	18.36	-8.18 to 34.48	03
		TBS-10 x R-09	41.90	9.39			4.65			12.62		
		TBS-10 x R-20	38.24	8.21			4.58			2.78		
	E_3	TBS-10 x R-09	42.87	16.55	-16.3 to 16.55	0	5.87	-23.81 to 7.92	0	12.97	-14.19 to 20.09	02
		TBS-10 x R-20	38.79	12.41			7.92			2.21		
		TBS-3 x TBS-10	40.03	11.37			3.12			5.48		
	E_4	TBS-3 x TBS-10	42.29	22.46*	-19.65 to 22.46	1	13.98	-23.89 to 13.98	0	15.58	-7.43 to 26.02	03
		TBS-10 x R-20	40.72	19.78			13.02			11.30		
		TBS-10 x V-29	42.86	13.98			-0.89			17.15		

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