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Research Article

Heterosis studies for agronomic trait under different environmental conditions in sesame (*Sesamum indicum* L.)

Narendra Kumar[1], S. B. S. Tikka, Bhagirath Ram[2], M. C. Dagla[1],
Department of Genetics and Plant Breeding, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Banaskantha - 385 506, Gujarat, India
[1]Directorate of Groundnut Research, Ivnagar road, P. B. No. 5, Junagadh - 362 001, Gujarat, India
[2]Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur - 321 303, Rajasthan, India
Email: narendrapb09@gmail.com

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Abstract
An investigation was carried out to study extent of heterosis under four different environments for yield and its component traits in sesame. Diallel mating design excluding reciprocals was used to develop 28 F_1 crosses from eight parents. Analysis of variance revealed highly significant differences among the parents vs hybrids was observed under four environments for all the characters, indicating the presence of significant amount of genetic variability for all traits under studied. Heterosis was worked out over mid parent, better parent and standard check, GT-2. For seed yield, crosses Pbtil-1 × AT-124, GT-10 × Pbtil-1 and GT-2 × PT-64 in E_1, crosses GT-10 × TMV-3, GT-2 × PT-64 and GT-10 × Pbtil-1 in E_2 and crosses TMV-3 × C-1013, TMV-3 × Pbtil-1 and GT-10 × Pbtil-1 in environment E_3 having high *per se* performance along with significant mid parent, batter parent and standard heterosis. Hence, these crosses would be exploited for isolating transgressive segregants for seed yield and its component traits for genetic improvement in sesame.

Keywords:
Sesame, heterosis, hybrids, environment

Introduction

Sesame (*Sesamum indicum* L.) is a very ancient oilseed crop of the tropic and warm sub-tropics regions. Sesame contains about 45 - 52% oil, 20 - 27% protein, 6 - 7% moisture, 16% carbohydrate and 6 - 8% crude fiber in its small oblong seeds, which are usually black, brown or white in colour. It is grown globally in an area of approximately 8.66 million ha with a total production about 4.64 million tons and productivity 537.6 kg/ha. It is mainly cultivated in developing countries of Asia and Africa continents, which accounting about 54.8% and 41.4% total production respectively. In India, it is cultivated in an area about 1.86 mha with production of 0.71mt and productivity of 380 kg/ha, which accounting about 21.50% and 15.28% global area and production respectively during 2011-2013 (FAOSTAT 2013). 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 presence of variability in the available material for yield and other agronomic traits is a prerequisite for initiating breeding programme. Genetic improvement of any trait is largely depends on the magnitude and direction of available heterosis. Since, genetic improvement through hybridization based methods followed by selection has been only marginal. The development of commercial hybrids has provided the most important tool in improving the yield of crop plant substantially. In India, hybrid technology has been exploited in self-pollinated crops for raising their productivity. The development of commercial hybrids could raise the productivity thereby automatically increase production level in sesame. The phenomenon of heterosis has proved to be the most important genetic tool in boosting the yield of self as well as cross pollinated crops and is recognized as the most important breakthrough in field of crop improvement.

Although sesame is largely a self-pollinated crop, high level of heterosis for yield and its components has been reported by Dikshit and Swain (2000); Mothilal and Ganesan (2005); Prajapati *et al*. (2010); Jadhav and Mohrir (2013); Vavdiya *et al*. (2013). The study on the magnitude of heterosis would helps in identifying promising cross combinations for exploitation of heterosis for genetic improvement of quantitative traits. Therefore, heterosis studies are most important as it provide useful information for the best performing hybrids. The present investigation was undertaken to measure the magnitude of heterosis in hybrids over mid parent, better parent and standard checks under different environmental conditions for seed yield and associated traits in sesame.

Material and Methods

The experimental materials comprising of a set of 36 genotypes including eight parents and their 28 F_1 crosses were produced using 8 × 8 half-diallel fashion following Model-I, Method-II of Griffing (1956). The experimental materials were evaluated in randomized complete block design replicated thrice in four environments at Main Castor and Mustard Research Station, S. D. Agricultural University, Sardarkrushinagar, Gujarat. The four environments were created by two dates of sowing (one month interval) and two fertility levels (low and high) *viz.*, E_1: low input timely sowing (N: 25 kg/ha, P_2O_5: 25 kg/ha, S: 20 kg/ha), E_2: high input timely sowing (N: 50 kg/ha, P_2O_5: 50 kg/ha, S: 40 kg/ha), E_3: low input delayed sowing (N: 25 kg/ha, P_2O_5: 25 kg/ha, S: 20 kg/ha) and E_4: high input delayed sowing (N: 50 kg/ha, P_2O_5: 50 kg/ha, S: 40 kg/ha). The experimental site is located at 24º12' N Latitude, 72º12' E Longitude and 154.5 m above mean sea level. Parents and crosses were planted in one row of 5 meters length per plot keeping the distance of 45 cm between rows and 15 cm within rows. The experimental area was provided with guard rows on all the side of each block. The recommended agronomical practices and plant protection measures were adopted for raising a good crop. Data on the days to 50% flowering and days to maturity were recorded on a whole plot basis for each genotype (parent and F_1) in each replication in all the environments. The remaining observation on plant height (cm), number of branches/plant, number of capsules/plant, number of seeds/capsule, capsule length (cm), 1000–seed weight (g) and seed yield/ plant (g) was recorded on randomly selected five competitive plants of each genotype from each replication in all the environments. The mean values were first subjected to the usual analysis followed for a randomized complete block design for individual environment as suggested by Panse and Sukhatme (1978) to test the significant differences between the genotypes for all the characters. The magnitude of heterosis for all the nine traits and expressed as percentage superiority or inferiority of the F_1 hybrids over mid parent (MP), better parent (BP) and standard check (GT-2) (SC) was calculated as per standard method suggested by Fonseca and Patterson (1968)

Results and Discussion

The analysis of variance was carried out and the mean squares in Table 1 revealed that revealed significant differences among parents and hybrids was observed for all traits. It is indicating that presence of the significant amount of genetic variability in the parental lines and among the crosses for these traits. The interaction between parents vs. crosses recorded highly significant differences for all the traits except days to maturity in environment E_3 and E_4. It showing that heterosis could be exploited for improvement of these traits.

Several workers observed significant differences among parents and hybrids for days to 50% flowering (Thiyagu *et al*., 2007; Rajput and Kute 2012), days to maturity (Thiyagu *et al*., 2007; Rajput and Kute 2012; Vavdiya *et al*., 2013) plant height (Thiyagu *et al*., 2007; Rajput and Kute 2012; Vavdiya *et al*., 2013; Parimala *et al*., 2013), number of branches/plant (Thiyagu *et al*., 2007; Rajput and Kute 2012), number of capsules/plant (Thiyagu *et al*., 2007; Rajput and Kute 2012; Jadhav and Mohrir 2013; Vavdiya *et al*., 2013; Parimala *et al*., 2013), number of seeds/capsule (Vavdiya *et al*., 2013; Parimala *et al*., 2013), capsule length (Rajput and Kute 2012; Vavdiya *et al*., 2013), 1000-seed weight (Rajput and Kute 2012; Jadhav and Mohrir 2013; Vavdiya *et al*., 2013) and seed yield/plant (Thiyagu *et al*., 2007; Rajput and Kute 2012; Jadhav and Mohrir 2013; Vavdiya *et al*., 2013; Parimala *et al*., 2013).

The estimates of heterosis showed that none of the hybrids were found to be significantly high heterosis (MP, BP, SH) for all the traits in all the environments. However, in each environment three crosses were selected based on high *per se* performance in desirable direction along with their respective MP, BP and SH (Table 2). The extent of heterosis for various characters was calculated as per cent increase or decrease over mid parent, better parent and best check variety (GT-2).

For days to 50% flowering, negative heterosis is desirable for this trait which indicates the earliness. Crosses GT-2 × C-1013 (-5.58,-5.17,-5.98), GT-2 × PT-64 (-5.53,-5.13,-5.13) in environment E_1 while the crosses Pbtil-1 × PT-64 (-4.53,-4.13,-6.45) in environment E_2 showing highly significant mid-parent (MP), batter parent (BP) and standard heterosis (SH) respectively (Table 2). Among the different environments, environment E_2 (14) followed by E_1 (9) recorded highest number of crosses showing desirable standard heterosis. It means that environment E_2 (timely sown and high input) is good for exploitation of standard heterosis for early flowering. Vavdiya *et al*. (2013) also reported negative heterosis for days to 50% flowering. Since the sesame is rainfed crop so that development of early maturing genotypes are prime objective of breeding programme thus hybrids showing high standard heterosis for earliness would be exploited to develop early genotypes in sesame cultivation in *kharif* as well as summer season. Early maturing is very desirable character especially in rainfed crop like sesame. For this also negative heterosis is desirable and hybrids with early maturity are more desirable as they produce more yields per day and fit well in different cropping systems. For days to maturity, only one hybrid GT-1 × GT-10 performed well in environment E_1 (-3.07,-2.41, -3.07), in environment E_2 (-2.11,-1.63,-2.27) and in the environment E_4 (-3.93, -3.75, -3.75) recorded significant MP, BP and SH respectively. It showing that that hybrid is very diverse in showing earliness across the environments hence such types of hybrids can be exploited in developing varieties suitable for rainfed conditions. While, hybrid GT-1 × AT-124 performed well in environment E_2 (-2.60) and in the environment E_3 (-3.16) recorded high standard heterosis. Among the different environments, environment E_4 (7) followed by E_3 (5) and E_1 (3) recorded highest number of crosses showing desirable standard heterosis for earliness (Table 2). It is indicating that late sown environments (E_3 and E_4) were good for exploitation of standard heterosis for earliness in sesame. Similar results of negative standard heterosis for days to maturity was also reported by Sankar and Kumar (2001); Parameshwarappa and Palakshappa (2013); Salunke *et al*. (2013).

Plant height is an important trait influencing sesame production, long plant height may be not preferred in commercial production due to lodging problem so that optimum height is desirable in sesame. Hybrid GT-1 × C-1013 in E_1 (-9.29,-13.05), in E_2 (-14.55,-15.19) in E_3 (-14.11, -15.05) and hybrid GT-1 × PT-64 in E_2 (-21.44,-15.62), E_3 (-10.06,-14.36) and in environment E_4 (-14.40,-16.69) recorded significantly high mid parent and standard heterosis respectively in three environment each for low plant height. Whereas the hybrid GT-1 × TMV-3 in environment E_1 (-12.77,-10.34,-11.68) and environment E_3 (-12.85,-11.14,-16.92) recorded highly significant mid parent, better parent and standard heterosis respectively in two environments for low plant height (Table 2). Hence, these crosses could be used for exploitation of heterosis in reducing plant height in sesame. Among the environments, environment E_3 (15) followed by E_2 (12) and E_1 (12) were the best environment for getting high number of crosses showing desirable standard heterosis for plant height. Similar work was also reported by Sumathi and Muralidharan (2008); Padmasundari and Kamala (2012); and Jatothu *et al*. (2013).

Number of capsules/plant is known to directly associate with seed yield. For this trait, cross GT-10 × AT-124 in E_1 (36.78, 30.84, 19.61), E_2 (37.42, 29.06, 23.56) and in environment E_4 (27.78, 25.13, 10.88) showing significantly high per cent MP, BP and standard heterosis respectively (Table 2). Among the environment, only E_1 (6) followed by E_2 (4) having more number of desirable crosses showing high standard heterosis for this trait. While in the environment E_3 and E_4 with one desirable cross in each environment were found for standard heterosis. In general low numbers of crosses showing standard heterosis as compare to those were observed for mid parent and better parent heterosis. Therefore, environment E_1 (low input timely sowing) and E_2 (high input timely sowing) were best for exploitation of heterosis for improving number of capsules/plant. Similar results on getting low number of crosses showing standard heterosis than better parent heterosis was also observed by Mothilal and Manoharan (2004); Padmasundari and Kamala (2012) and Jatothu *et al*. (2013).

Number of seeds/capsule is also an important yield component trait associated with higher seed yield in sesame. Cross Pbtil-1 × AT-124 recorded high significant BP and SH respectively in the environment E_2 (12.36, 11.68) and environment E_4 (12.56, 11.07) (Table 2). Whereas environment wise two crosses GT-1 × TMV-3 and GT-1 × PT-64 in environment E_1 and three crosses *viz*., GT-2 × C-1013, TMV-3 × C-1013 and GT-1 × GT-2 in environment E_3 showing significantly high mid parent, batter parent and standard heterosis. Among the environment, only E_3 (6) followed by E_1 (3), E_2 (2) and E_4 (1) having more number of desirable crosses showing high standard heterosis for this trait. Therefore environment E_3 could be best environment for improving number of seeds/capsule in sesame.

Capsule length is also important economic trait associated with seed yield in sesame. For capsule length, only three hybrids *viz*., Pbtil-1 × AT-124, GT-1 × TMV-3 and GT-2 × Pbtil-1 in environment E_2 exhibited significantly high mid parent and standard heterosis (Table 2) and only environment E_2 (6) has highest number of crosses showing high mid parent, batter parent and standard heterosis for capsule length. It is indicating that environment E_2 (high input timely sowing) was the best environment for exploitation of heterosis for getting high capsule length in sesame.

In sesame, 1000-seed weight is serves as an indicator to the end product *i.e.*, seed yield. The low seed yields in sesame hybrids are attributed mainly to the 1000-seed weight (Jatothu *et al*., 2013). For 1000-seed weight, only one hybrid namely GT-2 × Pbtil-1 in the environment E_3 (26.32, 20.28) and E_4 (15.16, 19.70) recorded highly significant mid parent and standard heterosis respectively (Table 2). However, environment wise two hybrids namely GT-10 × TMV-3 and TMV-3 × AT-124 in environment E_3 and hybrids GT-2 × TMV-3 and PT-64 × AT-124 in environment E_4 showing highly significant MP, BP and standard heterosis. It was also observed that environment E_3 (7) followed by E_4 (4) has highest number of hybrids showing high standard heterosis for this traits. It is indicating that environment E_3 (low input delayed sowing) and E_4 (high input delayed sowing) were the best environment for improving 1000- seed weight in sesame. Padmasundari and Kamala (2012) and Jatothu *et al*. (2013) also reported high heterosis for 1000- seed weight in sesame.

Seed yield is one of the most important objectives of any of the plant breeding programme, thus the heterosis can be useful only with superiority over the standard checks (GT-2). None of the hybrids were found to be significantly high heterosis (MP, BP, SH) for all the environments. So that environment wise superior hybrids were selected for comparison and interpretation of results. For seed yield/plant in Table 2, only one diverse high yielding hybrid GT-10 × Pbtil-1 in three environments namely E_1 (61.19, 44.37, 45.11), E_2 (51.52, 28.67, 25.99) and E_3 (17.80, 17.48, 18.20) recorded highly significant mid parent, batter parent and standard heterosis respectively. Whereas hybrid GT-2 × PT-64 in two environment namely E_1 (53.10, 44.16, 44.16) and E_2 (38.09, 26.36, 26.36) showed highly significant mid parent, batter parent and standard heterosis respectively. Environment wise results indicated that hybrid Pbtil-1 × AT-124 in environment E_1 (low input timely sowing), hybrid GT-10 × TMV-3 in environment E_2 (high input timely sowing), hybrids *viz*., TMV-3 × C-1013 and TMV-3 × Pbtil-1 in environment E_3 (low input delayed sowing) recorded significantly high mid parent, batter parent and standard heterosis. Hence, these crosses could be used to exploit heterosis and to get genetic variability for quantitative traits in segregating generations to develop high yielding cultivars in sesame.

Among the environment, environment E_1 (46.23%) has highest per cent standard heterosis followed by E_2 (31.54%), E_3 (19.88%) and E_4 (15.75%). Similarly, environments E_1 (7) followed by environment E_2 (4) and E_3 (4) were best environment for getting more number of desirable hybrids showing high standard heterosis for seed yield in sesame. Similarly high standard heterosis for seed yield was also reported by Singh *et al*. (2005); Banerjee and Kole (2010); Jadhav and Mohrir (2013) and Parimala *et al*. (2013). For seed yield/plant, environment E_1 having very high range (-30.75-46.23) of standard heterosis followed by environment E_2 (-35.37-31.54%), environment E_3 (-24.46-19.88%) and in the environment E_4 (-22.68-15.75). It is suggesting that environment E_1 has highest standard heterosis followed by decreasing in environment E_2 and E_3. Therefore, superior hybrids from these environments would be exploited for isolating transgressive segregants for seed yield, days to 50% flowering, plant height, number of capsule/plant, number of branches/plant and capsule length in the later generations under timely sown environments (E_1 and E_2) while days to maturity, number of seeds/capsule and 1000-seed weight under late sown environments (E_3 and E_4).

From ongoing study it was observed that some hybrids showing significant heterosis for seed yield along with other components traits under different environments. Hybrid Pbtil-1 × AT-124 recorded high *per se* performance along with significantly high standard heterosis for days to 50% flowering in E_4, number of seeds/capsule in E_2 and E_4, capsule length in E_2. Hybrid GT-10 × TMV-3 also having high *per se* performance along with high standard heterosis for number of capsule/plant in E_1, 1000-seed weight in the environment E_3. Hence, these hybrids having high *per se* performance for yield and its components traits with high heterosis could be effectively used for isolating transgressive segregants, which would increase the frequency of desirable genes for yield component traits along with economic traits in sesame.

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Table 1. Analysis of variance (mean squares) for various characters in different environments in sesame

	Env.	Replication	genotype	Parent	Hybrid	P vs.H	Error
df		2	35	7	27	1	70
Days to 50% flowering	E_1	0.95	3.93**	2.42**	3.91**	15.08**	0.66
	E_2	0.25	3.14**	1.66**	3.55**	2.63*	0.54
	E_3	0.73	4.34**	3.71**	4.45**	5.97*	1.11
	E_4	1.23	5.24**	2.38**	5.86**	8.45**	0.7
Days to maturity	E_1	2.53	7.44**	3.80*	8.28**	10.01**	1.34
	E_2	5.79*	11.36**	10.57**	11.76**	6.22*	1.53
	E_3	2.4	9.45**	3.52*	11.25**	2.46	1.44
	E_4	1.81	12.78**	11.98**	13.29**	4.45	2.42
Plant height	E_1	130.42	145.26**	168.59**	112.78**	858.92**	48.5
	E_2	15.71	326.57**	218.60*	223.07**	3876.80**	84
	E_3	46.1	75.56**	34.97*	82.42**	174.36**	15.6
	E_4	39.94	223.83**	514.17**	151.68*	139.44	80.9
Number of branches/plant	E_1	0.17	2.36**	1.02**	2.62**	4.97**	0.16
	E_2	0.04	2.22**	1.26**	2.48**	1.68*	0.41
	E_3	0.06	1.65**	0.84**	1.83**	2.49**	0.22
	E_4	0.21	1.23**	0.84**	1.27**	3.10**	0.13
Number of capsules/plant	E_1	17.85	276.51**	197.79**	249.80**	1548.94**	28.6
	E_2	29.47	212.76**	94.19**	225.14**	708.19**	31.6
	E_3	8.07	40.82**	23.81**	45.06**	45.33*	11
	E_4	11.45	28.01**	13.25*	31.00**	50.57**	5.08
Number of seeds/capsule	E_1	0.51	72.90**	33.02*	74.86**	299.11**	14.9
	E_2	27.06	61.61**	42.56*	65.81**	81.80*	19.8
	E_3	12.37	33.57**	39.63**	31.78**	39.44*	8.68
	E_4	12.75	66.00**	59.36**	66.17**	108.05*	20.2
Capsule length (cm)	E_1	0	0.04*	0.01	0.05*	0.10*	0.02
	E_2	0.03	0.07**	0.02	0.08**	0.11*	0.02
	E_3	0.05	0.09**	0.02	0.10**	0.15*	0.04
	E_4	0.02	0.12**	0.16**	0.10**	0.12*	0.03
1000–seed weight (g)	E_1	0.11	0.22**	0.14*	0.24**	0.34*	0.06
	E_2	0.09	0.27**	0.12*	0.31**	0.35**	0.05
	E_3	0.02	0.26**	0.1	0.31**	0.30*	0.05
	E_4	0.01	0.40**	0.22*	0.40**	1.78**	0.08
Seed yield/ plant (g)	E_1	1.73	9.31**	3.05*	10.30**	26.17**	1.31
	E_2	1.63	10.18**	6.87**	10.78**	17.18**	1.31
	E_3	0.48	1.20**	0.45	1.39**	1.31*	0.3
	E_4	0.13	1.18**	0.76	1.23**	2.89*	0.55

Env.- Environment; *, ** Indicate significance at P = 0.05 and P = 0.01 levels, respectively.

Table 2. Top three crosses based on *per se* performance along with their heterosis, heterobeltiosis and standard heterosis under different environment for yield and other traits in sesame.

Character	Env.	Best performing crosses	Mean value	Mid parent heterosis			Heterobeltiosis			Standard heterosis		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Days to 50 % flowering	E_1	GT-1 × PT-64	36	-10.0**	-10.0 -	13	-8.47**	-8.47 -	9	-7.69**	-7.69 -	9
		GT-2 × C-1013	36.7	-5.58**	5.63		-5.17**	7.02		-5.98**	4.27	
		GT-2 × PT-64	37	-5.53**			-5.13**			-5.13**		
	E_2	GT-2 × TMV-3	38.7	-6.83**	-6.83 -	10	-6.45**	-6.45 -	6	-6.45**	-6.45 -	14
		Pbtil-1 × PT-64	38.7	-4.53**	3.77		-4.13**	5.08		-6.45**	2.42	
		GT-2 × GT-10	39	-4.10**			-2.50			-5.65**		
	E_3	Pbtil-1 × AT-124	36.3	-6.03**	-6.33 -	5	-4.39	-5.93 -	2	-2.68	-2.68 -	0
		Pbtil-1 × PT-64	37	-6.33**	3.80		-5.93**	7.89		-0.89	9.82	
		Pbtil-1 × C-1013	37	-5.53**			-5.13*			-0.89		
	E_4	Pbtil-1 × AT-124	37.7	-3.42*	-3.80 -	2	0.00	-3.39 -	0	-4.24*	-4.24 -	1
		GT-2 × C-1013	38	-3.80*	8.62		-3.39	10.53		-3.39	8.47	
		GT-2 × PT-64	38.3	-0.86			0.88			-2.54		
Days to maturity	E_1	GT-1 × GT-10	94.7	-3.07**	-3.07 -	3	-2.41*	-2.41 -	2	-3.07**	-3.07 -	3
		GT-1 × TMV-3	95.0	-3.06**	3.41		-2.06*	4.88		-2.73**	3.41	
		GT-1 × GT-2	95.7	-1.71*			-1.37			-2.05*		
	E_2	GT-1 × AT-124	100.0	-1.15	-2.56 -	3	-0.33	-1.63 -	0	-2.60*	-2.60 -	0
		GT-1 × GT-10	100.3	-2.11*	3.45		-1.63	5.67		-2.27*	3.57	
		GT-1 × C-1013	100.3	-0.66			0.33			-2.27*		
	E_3	AT-124 × C-1013	81.0	-2.41*	-3.72 -	5	-2.02	-2.77 -	1	-3.95**	-3.95 -	5
		GT-1 × AT-124	81.7	-1.80	3.56		-1.21	5.65		-3.16**	4.35	
		PT-64 × C-1013	81.7	-2.20*			-2.00			-3.16**		
	E_4	GT-1 × GT-10	85.7	-3.56**	-3.93 -	3	-3.02*	-3.75 -	3	-3.75*	-3.75 -	7
		GT-1 × Pbtil-1	85.7	-3.20*	4.76		-3.02*	7.00		-3.75*	3.75	
		GT-2 × GT-10	85.7	-3.93**			-3.75*			-3.75*		

Env.- Environment; SDH- No. of crosses showing desirable heterosis

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Table 2. Continued

Character	Env.	Best performing crosses	Mean value	Mid parent heterosis			Heterobeltiosis			Standard heterosis		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Plant height (cm)	E_1	GT-1 × C-1013	131.5	-9.29**-	-13.65 -	9	-0.85	-11.94 -	6	-13.05**	-13.05 -	12
		GT-1 × Pbtil-1	133.3	13.65**	8.90		-11.94**	15.33		-11.90**	1.15	
		GT-1 × TMV-3	133.6	-12.77**			-10.34**			-11.68**		
	E_2	GT-1 × GT-2	129.0	-18.07**	-21.44 -	17	-16.99**	-24.78 -	13	-16.99**	-16.99 -	12
		GT-1 × PT-64	131.1	-21.44**	3.99		-24.78**	5.46		-15.62**	1.12	
		GT-1 × C-1013	131.8	-14.55**			-11.54*			-15.19**		
	E_3	GT-1 × TMV-3	78.3	-12.85**	-14.11 -	12	-11.14**	-15.60 -	10	-16.92**	-16.92 -	15
		GT-1 × C-1013	80.1	-14.11**	11.58		-15.60**	12.55		-15.05**	3.43	
		GT-1 × PT-64	80.7	-10.06**			-8.19*			-14.36**		
	E_4	GT-1 × PT-64	82.2	-14.40*	-14.40 -	4	-14.59	-14.59 -	0	-16.79*	-16.79 -	3
		GT-1 × AT-124	83.0	-12.42	9.12		-11.47	8.26		-15.95*	7.49	
		GT-2 × GT-10	83.4	-12.23			-8.65			-15.54*		
Number of branches/ plant	E_1	TMV-3 × PT-64	6.6	27.74**	-54.67 -	1	30.26**	-54.05 -	2	28.57**	-55.84 -	2
		GT-10 × TMV-3	6.3	6.74	27.74		-4.04	30.26		23.38	28.57	
		GT-10 × Pbtil-1	5.7	-4.49			7.59			10.39		
	E_2	TMV-3 × PT-64	6.9	38.26**	-21.79 -	6	71.67**	-27.38 -	7	43.06**	-15.28 -	7
		GT-10 × Pbtil-1	6.8	29.11**	38.26		37.84**	71.67		41.67**	43.06	
		GT-10 × C-1013	6.8	27.50**			34.21**			41.67**		
	E_3	TMV-3 × AT-124	6.3	22.08**	-30.61 -	2	38.24**	-35.44 -	3	44.62**	-24.62 -	4
		TMV-3 × C-1013	6.1	21.05**	22.08		39.39**	39.39		41.54**	44.62	
		GT-10 × C-1013	5.5	13.10			24.24**			26.15**		
	E_4	GT-10 × C-1013	6.4	27.15**	-34.13 -	2	50.00**	-37.50 -	4	9.09	-37.50 -	0
		TMV-3 × AT-124	5.9	7.55	27.15		10.56	50.00		1.14	9.09	
		GT-10 × Pbtil-1	5.7	6.25			16.44**			-3.41		

Env.- Environment; SDH- No. of crosses showing desirable heterosis

Contd..

Table 2. Continued.

Character	Env.	Best performing crosses	Mean value	Mid parent heterosis			Heterobeltiosis			Standard heterosis		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Number of capsules/ plant	E_1	TMV-3 × C-1013	80.3	53.84**	-8.96 - 53.84	13	31.85**	-19.03 - 32.94	9	27.32**	-32.40 - 27.32	6
		GT-10 × TMV-3	76.1	28.37**			24.95**			20.66**		
		GT-10 × AT-124	75.5	36.78**			30.84**			19.61**		
	E_2	GT-10 × AT-124	80.5	37.42**	-18.72 - 37.42	11	29.06**	-20.49 - 29.06	8	23.56**	-33.15 - 23.56	4
		GT-10 × C-1013	75.7	35.11**			21.51**			16.33*		
		TMV-3 × Pbtil-1	75.6	31.24**			22.57**			16.10*		
	E_3	TMV-3 × PT-64	46.2	29.43**	-16.71 - 29.43	6	17.53*	-20.49 - 17.53	2	18.62*	-22.64 - 18.62	1
		TMV-3 × AT-124	44.0	22.41**			12.01			13.05		
		GT-10 × PT-64	43.1	23.86**			14.82*			10.74		
	E_4	GT-10 × AT-124	44.9	27.78**	-14.28 - 27.78	12	25.13**	-18.31 - 25.13	6	10.88*	-20.10 - 10.88	1
		Pbtil-1 × PT-64	43.6	13.75**			10.08*			7.67		
		GT-10 × C-1013	43.3	19.62**			13.92**			6.96		
Number of seeds/ capsule	E_1	GT-1 × TMV-3	71.5	21.16**	-14.72 - 24.39	12	13.50**	-13.54 - 24.53	5	14.04**	-17.39 - 14.04	3
		GT-1 × PT-64	70.4	24.13**			20.48**			12.34*		
		GT-2 × TMV-3	69.0	9.90*			9.63			10.16*		
	E_2	Pbtil-1 × C-1013	73.8	8.46	-11.64 - 11.51	5	14.07*	-17.13 - 14.07	3	11.88*	-12.69 - 11.88	2
		Pbtil-1 × AT-124	73.6	7.58			12.36*			11.68*		
		GT-2 × TMV-3	72.4	9.36			8.87			9.86		
	E_3	GT-2 × C-1013	69.9	11.49**	-12.51 - 18.43	7	9.05*	-14.43 - 16.59	4	14.04**	-6.53 - 14.04	6
		TMV-3 × C-1013	68.9	13.07**			7.60*			12.51**		
		GT-1 × GT-2	68.9	17.39**			12.40**			12.40**		
	E_4	Pbtil-1 × AT-124	76.3	12.65**	-7.17 - 16.50	4	17.94**	-16.40 - 17.94	1	11.07**	-16.80 - 11.07	1
		Pbtil-1 × C-1013	75.0	7.91			9.86			9.22		
		GT-2 × GT-10	72.6	15.85**			5.73			5.73		

Env.- Environment; SDH- No. of crosses showing desirable heterosis

Contd..

Table 2. Continued.

Character	Env.	Best performing crosses	Mean value	Mid parent heterosis			Heterobeltiosis			Standard heterosis		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Capsule length (cm)	E_1	GT-1 × AT-124	2.9	3.87	-10.81 -	0	2.75	-10.87 -	0	3.25	-12.26 -	0
		GT-1 × C-1013	2.9	4.21	4.21		2.15	2.75		2.64	3.25	
		GT-1 × GT-2	2.8	2.28			2.03			2.52		
	E_2	Pbtil-1 × AT-124	2.9	8.59*	-10.89 -	7	4.50	-11.18 -	5	11.98*	-11.59 -	6
		GT-1 × TMV-3	2.9	14.25**	14.25		11.43**	11.70		11.72*	11.98	
		GT-2 × Pbtil-1	2.8	11.45*			10.94*			10.94*		
	E_3	Pbtil-1 × C-1013	2.8	8.62	-15.88 -	0	8.13	-17.77 -	0	3.25	-22.40 -	0
		Pbtil-1 × PT-64	2.7	6.48	9.43		6.41	11.65		1.75	3.25	
		Pbtil-1 × AT-124	2.7	9.43			6.42			1.63		
	E_4	GT-2 × GT-10	3.0	7.66	-12.34 -	1	-4.53	-20.71 -	0	-4.53	-26.21 - -	0
		Pbtil-1 × C-1013	2.9	2.67	11.15		-1.37	8.81		-6.80	4.53	
		PT-64 × AT-124	2.8	11.15*			8.81			-8.09		
1000–seed weight (g)	E_1	Pbtil-1 × AT-124	4.25	11.84*	-14.26 -	1	10.39	-16.05 -	0	1.67	-26.16 -	0
		GT-2 × Pbtil-1	4.04	1.89	11.84		-3.35	10.39		-3.35	1.67	
		AT-124 × C-1013	3.99	7.84			3.64			-4.55		
	E_2	Pbtil-1 × C-1013	4.48	14.43**	-17.16 -	2	10.62*	-17.70-	1	3.94	-20.03 -	0
		GT-1 × PT-64	4.45	2.03	14.43		1.75	10.62		3.25	3.94	
		Pbtil-1 × AT-124	4.45	7.62*			5.45			3.25		
	E_3	GT-2 × Pbtil-1	3.44	26.32**	-18.28 -	9	20.28**	-19.39 -	6	20.28**	-17.13 -	7
		GT-10 × TMV-3	3.42	18.82**	26.32		17.66**	20.28		19.58**	20.28	
		TMV-3 × AT-124	3.36	15.86**			13.90*			17.48**		
	E_4	GT-2 × TMV-3	4.01	27.30**	-9.59 -	12	21.52**	-15.76 -	7	21.52**	-15.76 -	4
		GT-2 × Pbtil-1	3.95	15.16*	27.30		10.96	23.51		19.70**	21.52	
		PT-64 × AT-124	3.95	24.41**			21.54**			19.70**		

Env.- Environment; SDH- No. of crosses showing desirable heterosis

Contd..

Table 2. Continued.

Character	Env.	Best performing crosses	Mean value	Mid parent heterosis			Heterobeltiosis			Standard heterosis		
				Value	Range	SDH	Value	Range	SDH	Value	Range	SDH
Seed yield/ plant (g)	E_1	Pbtil-1 × AT-124	12.22	67.55**	-20.24 -	12	53.90**	-26.41 -	7	46.23**	-30.75 -	7
		GT-10 × Pbtil-1	12.13	61.19**	67.55		44.37**	53.90		45.11**	46.23	
		GT-2 × PT-64	12.05	53.10**			44.16**			44.16**		
	E_2	GT-10 × TMV-3	13.04	30.38**	-23.16 -	11	26.64**	-31.14 -	4	31.54**	-35.37 -	4
		GT-2 × PT-64	12.53	38.09**	51.52		26.36**	28.67		26.36**	31.54	
		GT-10 × Pbtil-1	12.49	51.52**			28.67**			25.99**		
	E_3	TMV-3 × C-1013	6.45	32.65**	-18.75 -	6	25.63**	-24.92 -	5	19.88*	-24.46 -	4
		TMV-3 × Pbtil-1	6.42	22.01**	32.65		19.18*	25.63		19.26*	19.88	
		GT-10 × Pbtil-1	6.36	17.80*			17.48*			18.20*		
	E_4	GT-10 × TMV-3	7.74	44.54**	-16.31 -	3	40.81**	-19.94 -	3	15.75	-22.68 -	0
		GT-10 × AT-124	7.44	36.72**	44.54		35.35**	40.81		11.27	15.75	
		TMV-3 × C-1013	7.15	34.42**			31.86**			6.88		

Env.- Environment; SDH- No. of crosses showing significant desirable heterosis