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Y Madhavi
Agricultural College, Mahanandi, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India

RVSK Reddy
Dr. Y.S.R. Horticultural University, Andhra Pradesh, India

C Sreenivasa Reddy
Agricultural College, Mahanandi, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India

A Rajani
HRS, Lam, Guntur, Dr. Y.S.R. Horticultural University, Andhra Pradesh, India

N Ratna Kumari
Agricultural College, Bapatla, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India

Corresponding Author:
Y Madhavi
Agricultural College, Mahanandi, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India

Studies on heterosis for growth and yield characters in tomato (*Solanum lycopersicum* L.)

Y Madhavi, RVSK Reddy, C Sreenivasa Reddy, A Rajani and N Ratna Kumari

Abstract
The present investigation "Exploitation of heterosis and combining ability for yield, quality and processing in tomato (*Solanum lycopersicum* L)." was carried out during *rabi*, 2010-11 and *kharif*, 2011 at Vegetable Research Station, Rajendranagar, Hyderabad to study the heterosis. Six lines (EC-165749, LE-56, LE-62, LE-64, LE-65 and LE-67) were crossed with three testers (Punjab Chhuhara, Pant T-3 and Pusa Gaurav) in line x tester mating design. The resultant 18 F_1's were evaluated along with their parents and two standard checks (Lakshmi and US-618) for the characters *viz.*, plant height (cm), number of primary branches per plant, days to 50% flowering, number of fruits per cluster, average fruit weight (g) and fruit yield per plant (kg). Studies on heterosis revealed that majority of the hybrids exhibited relative heterosis, heterobeltiosis and standard heterosis in desirable direction. The potential crosses like LE-56 × Pant T-3, LE-56 × Pusa Gaurav, LE-64 × Punjab chhuhara and LE-56 × Punjab chhuhara exhibited high standard heterosis for fruit yield per plant, which offers scope for commercial exploitation through heterosis breeding.

Keywords: Tomato, heterosis, growth, yield, line x tester

Introduction
Tomato (S*olanum lycopersicum* Mill.) is an important vegetable crop to grower, consumer and processing industry with pressing demand to evolve high yielding varieties/ hybrids with varying qualities as per local demand. The understanding of inheritance of various characters and identification of superior parents and crosses are important pre-requisites for launching an effective and efficient breeding programme. The scenario of tomato production in the country has tremendously changed over the past few decades with increasing popularity of hybrids. It is imperative to obtain such hybrids which have high yielding potential along with excellent quality. Tomato offers much scope for improvement through heterosis breeding which can further be utilized for the development of desirable recombinants. Heterosis breeding or exploitation of hybrid vigour is an important method of plant breeding to develop hybrids with high yield potential, heterotic crosses are indicative of productive transgressive segregates and the extent of heterosis gives an idea of genetic control. Estimates of heterosis may help in deciding whether the hybrids are of economic value and worth exploiting. Of the various genetic approaches to break the yield barriers in tomato, heterosis breeding is most powerful one. Information on nature and magnitude of heterosis in different cross combinations which is a basic requisite for identification of the crosses that exhibit high amount of exploitable heterosis.

Materials and Methods
The present investigation was undertaken at an experimental farm of Vegetable Research Station, Dr. Y.S. R. Horticultural University, Rajendranagar, Hyderabad. The experimental material consists of nine parents *viz*; EC-165749, LE-56, LE-62, LE-64, LE-65, LE-67 used as lines (females) and Punjab Chhuhara, Pant T-3 and Pusa Gaurav as testers (males) and mated as per Line x Tester mating model of Kempthorne (1957) [1]. Thus a total of 18 hybrids were synthesized by making crosses between lines and the testers during rabi, 2010. All the 18 hybrids along with their corresponding nine parents and two standard checks *viz*; Lakshmi, and US-618 were evaluated in a randomized block design in three replications during kharif, 2011. The data was subjected to the analysis of variance for randomized block design as suggested by Panse and Sukhatme (1967) [2].

Observations were recorded for quantitative characters *viz*., plant height (cm), number of primary branches per plant, days to 50% flowering, number of fruits per cluster, average fruit weight (g) and fruit yield per plant (kg) in F_1s, parents and checks. The mean over the replications for all parents and hybrids for each character was calculated and used in estimation of heterosis. Heterosis was calculated as the percentage increase or decrease of F_1 mean (F_1) over the mean of mid parent (MP) and better parent (BP) of the respective crosses. Whereas for calculating standard heterosis for various characters, mean of the best yielding commercial F_1 hybrid was used. Significance for heterosis was tested by using error mean square as suggested by Turner (1953) [3].

Results and Discussion

Heterosis was estimated for growth and yield characters studied in 18 hybrids and was expressed as increase or decrease over mid parental value (relative heterosis), over better parent (heterobeltiosis) and over commercial checks (standard heterosis). The results are presented in the table 1, 2 and 3.

Relative heterosis ranged from -12.74 (EC-165749 × Punjab Chhuhara) to 37.46 per cent (LE-64 × Pant T-3) for plant height. Significant positive relative heterosis was recorded by 9 out of 18 hybrids, while heterobeltiosis ranged from -21.49 (EC-165749 × Punjab Chhuhara) to 32.43 per cent (LE-64 × Pant T-3). Three hybrids showed significant positive heterobeltiosis for this trait. The range of standard heterosis was from -8.09 (LE-56 × Punjab Chhuhara) to 71.07 per cent (LE-65 × Pusa Gaurav) over Lakshmi and -37.81 (LE-56 × Punjab Chhuhara) to 15.76 per cent (LE-65 × Pusa Gaurav) over US-618. Significant positive standard heterosis was recorded by 8 hybrids over both the checks Lakshmi and US-618.

Relative heterosis ranged from -22.06 (LE-62 × Pusa Gaurav) to 47.60 *per cent* (EC-165749 × Pant T-3) for number of primary branches per plant. Significant positive relative heterosis was recorded by 6 out of 18 hybrids, while heterobeltiosis ranged from -31.52 (LE-62 × Pusa Gaurav) to 42.79 per cent (EC-165749 × Pant T-3). Four hybrids showed significant positive heterobeltiosis for this trait. Standard heterosis ranged from -21.90 and -10.85 (LE-62 × Pusa Gaurav) to 26.86 and 44.81 (EC-165749 × Pant T-3) over Lakshmi and US-618 respectively. Among 18 hybrids studied, 6 hybrids over Lakshmi and 10 hybrids over US – 618 exhibited significant desirable standard heterosis. Plant height and number of primary branches per plant are considered as growth attributes. Taller plants in tomato had added advantage due to increase in yield. Hence, positive heterosis is desirable for plant height and number of primary branches per plant. Most of the crosses displayed negative standard heterosis for plant height over US-618, which is in the undesirable direction. While eight crosses were found to be significant positive standard heterosis over Lakshmi (up to 71.07%) for plant height. Number of primary branches per plant was observed appreciable amount of standard heterosis over Lakshmi (up to 26.86%) and US-618 (up to 44.81%). Dharmatti (1995) [4] and Patil (1997) [5] also reported the similar projections for plant height and number of primary branches per plant in tomato. Kumar *et al.* (2012) [6] also reported the similar projections for plant height in tomato.

Table 1: Estimates of heterosis over mid parent (MP), better parent (BP) and standard check for plant height and number of primary branches per plant in tomato

S. No	Cross	Plant height (cm)				Number of primary branches per plant			
		MP	BP	Lakshmi	US-618	MP	BP	Lakshmi	US-618
1	EC -165749 × Punjab Chhuhara	-12.74	-21.49	-5.05	-35.75**	-6.78	-16.54**	-6.20	7.08
2	EC -165749 × Pant T-3	1.08	-8.48	10.69	-25.10**	47.60**	42.79**	26.86**	44.81**
3	EC -165749 × Pusa Gaurav	-2.88	-5.10	14.77	-22.34*	7.08	5.58	-6.20	7.08
4	LE-56 × Punjab Chhuhara	-1.81	-4.92	-8.09	-37.81**	-9.03*	-15.55**	-5.08	8.35
5	LE-56 × Pant T-3	22.76	18.05	15.77	-21.66*	24.52**	15.97**	11.65*	27.45**
6	LE-56 × Pusa Gaurav	18.46	5.70	21.99	-17.45	13.12**	7.30	3.31	17.92**
7	LE-62 × Punjab Chhuhara	35.73**	15.95	58.20**	7.05	0.26	-0.47	13.51*	29.58**
8	LE-62 × Pant T-3	27.40**	9.49	49.38**	1.08	6.92	-7.61	5.37	20.28**
9	LE-62 × Pusa Gaurav	32.10**	21.92*	66.34**	12.56	-22.06**	-31.52**	-21.90**	-10.85
10	LE-64 × Punjab Chhuhara	-7.82	-11.80	-6.68	-36.85**	-1.74	-6.62	4.96	19.81**
11	LE-64 × Pant T-3	37.46**	32.43*	40.12**	-5.18	-13.32**	-21.10**	-20.12**	-8.82
12	LE-64 × Pusa Gaurav	29.46**	24.07*	43.20**	-3.10	30.40**	20.82**	22.31**	39.62**
13	LE-65 × Punjab Chhuhara	25.11*	4.07	51.58**	2.57	-14.86**	-16.07**	-2.89	10.85
14	LE-65 × Pant T-3	27.62**	6.78	55.52**	5.24	8.73	-6.61	8.06	23.35**
15	LE-65 × Pusa Gaurav	31.06**	17.46	71.07**	15.76	13.70**	-0.71	14.88**	31.13**
16	LE-67 × Punjab Chhuhara	12.20	4.56	1.08	-31.60**	-6.15	-15.29**	-4.79	8.68
17	LE-67 × Pant T-3	27.51*	18.05	15.77	-21.66*	40.81**	35.02**	22.19**	39.48**
18	LE-67 × Pusa Gaurav	-1.13	-14.79	-1.66	-33.46**	-8.41	-10.50	-19.01**	-7.55
	S.Ed	9.13	10.54	10.54	10.54	0.35	0.40	0.40	0.40

* Significant at 5% level ** Significant at 1% level

Table 2: Estimates of heterosis over mid parent (MP), better parent (BP) and standard check for days to 50% flowering and number of fruits per cluster in tomato

S. No	Cross	Days to 50% flowering				Number of fruits per cluster			
		MP	BP	Lakshmi	US-618	MP	BP	Lakshmi	US-618
1	EC -165749 × Punjab Chhuhara	3.70	1.03	10.11*	3.16	11.97	5.93	2.08	5.50
2	EC -165749 × Pant T-3	6.25	2.00	14.61**	7.37	-16.31	-20.54	-31.69**	-29.40**
3	EC -165749 × Pusa Gaurav	-4.26	-6.25	1.12	-5.26	-25.34**	-32.89**	-27.66**	-25.23*
4	LE-56 × Punjab Chhuhara	-2.59	-3.09	5.62	-1.05	31.94**	24.11**	35.71**	40.27**
5	LE-56 × Pant T-3	-11.22**	-13.00**	-2.25	-8.42	39.04**	18.65*	29.74**	34.09**
6	LE-56 × Pusa Gaurav	-8.33*	-8.33*	-1.12	-7.37	11.00	10.21	20.52*	24.56*
7	LE-62 × Punjab Chhuhara	1.54	1.02	11.24*	4.21	10.66	9.16	5.19	8.72
8	LE-62 × Pant T-3	-8.08*	-9.20*	2.25	-4.21	42.75**	30.19**	22.08*	26.17**
9	LE-62 × Pusa Gaurav	3.09	2.04	12.36**	5.26	8.89	1.81	9.74	13.42
10	LE-64 × Punjab Chhuhara	-4.95	-8.57*	7.87	1.05	7.98	4.13	8.05	11.68
11	LE-64 × Pant T-3	-6.34	-8.57*	7.87	1.05	13.63	-0.88	2.86	6.31
12	LE-64 × Pusa Gaurav	-10.45**	-14.29**	1.12	-5.26	9.76	7.71	16.10	20.00*
13	LE-65 × Punjab Chhuhara	4.52	1.96	16.85**	9.47*	18.34*	7.82	3.90	7.38
14	LE-65 × Pant T-3	1.98	0.98	15.73**	8.42*	-20.33	-21.31	-37.66**	-35.57**
15	LE-65 × Pusa Gaurav	2.02	-0.98	13.48**	6.32	25.00**	8.43	16.88	20.81*
16	LE-67 × Punjab Chhuhara	-9.27**	-13.89**	4.49	-2.11	29.64**	28.44**	26.10**	30.34**
17	LE-67 × Pant T-3	-1.92	-5.56	14.61**	7.37	-11.18	-20.63*	-22.08*	-19.46*
18	LE-67 × Pusa Gaurav	-7.84*	-12.96**	5.62	-1.05	33.92**	27.95**	37.92**	42.55**
	S.Ed	1.07	1.24	1.24	1.24	0.20	0.23	0.23	0.23

* Significant at 5% level ** Significant at 1% level

Table 3: Estimates of heterosis over mid parent (MP), better parent (BP) and standard check for average fruit weight and fruit yield per plant in tomato

S. No	Cross	Average fruit weight (g)				Fruit yield per plant (kg)			
		MP	BP	Lakshmi	US-618	MP	BP	Lakshmi	US-618
1	EC -165749 × Punjab Chhuhara	50.28**	26.26**	10.78	18.51**	27.94**	10.67	-2.35	-9.04
2	EC -165749 × Pant T-3	25.06**	6.23	-9.26	-2.93	23.45**	10.00	-9.41	-15.62**
3	EC -165749 × Pusa Gaurav	40.01**	34.91**	-13.13*	-7.07	26.98**	19.56*	-12.79*	-18.77**
4	LE-56 × Punjab Chhuhara	17.46**	6.66	-6.42	0.11	40.57**	36.00**	20.00**	11.78*
5	LE-56 × Pant T-3	45.09**	33.35**	13.91*	21.86**	56.82**	56.68**	29.26**	20.41**
6	LE-56 × Pusa Gaurav	-1.30	-6.27	-32.88**	-28.20**	58.94**	49.73**	23.53**	15.07**
7	LE-62 × Punjab Chhuhara	37.37**	22.25**	7.26	14.74*	34.88**	25.67**	10.88	3.29
8	LE-62 × Pant T-3	2.39	-7.80	-21.24**	-15.75*	29.13**	24.29**	2.35	-4.66
9	LE-62 × Pusa Gaurav	54.90**	50.34**	2.86	10.03	-10.65	-12.55	-33.38**	-37.95**
10	LE-64 × Punjab Chhuhara	-2.98	-13.46	-24.07**	-18.78**	44.53**	37.67**	21.47**	13.15*
11	LE-64 × Pant T-3	25.73**	13.48	-3.06	3.70	-10.79	-12.14	-27.65**	-32.60**
12	LE-64 × Pusa Gaurav	81.88**	76.07**	21.10**	29.55**	51.68**	45.12**	15.88**	7.95
13	LE-65 × Punjab Chhuhara	10.13	-8.16	-19.42**	-13.80*	41.71**	26.83**	11.91*	4.25
14	LE-65 × Pant T-3	-21.73**	-34.02**	-43.63**	-39.70**	-1.35	-8.93	-25.00**	-30.14**
15	LE-65 × Pusa Gaurav	37.52**	31.33**	-15.43*	-9.54	45.77**	42.54**	3.97	-3.15
16	LE-67 × Punjab Chhuhara	44.96**	28.34**	12.60*	20.46**	32.16**	12.33	-0.88	-7.67
17	LE-67 × Pant T-3	41.67**	26.91**	8.41	15.97*	28.57**	12.50	-7.35	-13.70*
18	LE-67 × Pusa Gaurav	-6.95	-9.17	-38.58**	-34.30**	19.21*	10.08	-19.71**	-25.21**
	S.Ed	3.40	3.92	3.92	3.92	0.11	0.13	0.13	0.13

* Significant at 5% level ** Significant at 1% level

Heterosis in negative direction was considered to be desirable for days to 50% flowering. Relative heterosis ranged from -11.22 (LE-56 × Pant T-3) to 6.25 per cent (EC-165749 × Pant T-3). Significant negative relative heterosis was recorded in 6 hybrids. In hybrids heterobeltiosis ranged from -14.29 (LE-64 × Pusa Gaurav) to 2.04 per cent (LE-62 × Pusa Gaurav). 8 hybrids showed significant desirable heterobeltiosis. None of the hybrids showed significantly negative standard heterosis for this trait. The most important character contributing towards early yield is days to 50% flowering. The earliness of F_1 hybrids is an economically valuable property of heterosis breeding in tomato. Negative heterosis is considered to be desirable since earliness is preferred over late flowering in different situations. None of the crosses exhibited significant negative standard heterosis over the checks.

The relative heterosis ranged from -25.34 (EC-165749 × Pusa Gaurav) to 42.75 per cent (LE-62 × Pant T-3). Positive significant relative heterosis was noticed in 7 out of 18 hybrids for number of fruits per cluster. The heterobeltiosis was ranged from -32.89 (EC-165749 × Pusa Gaurav) 30.19 per cent (LE-62 × Pant T-3) with 5 hybrids showing positive significant heterobeltiosis. Standard heterosis ranged from -37.66 and -35.57 (LE-65 × Pant T-3) to 37.92 and 42.55 (LE-67 × Pusa Gaurav) over Lakshmi and US-618, respectively. Among 18 hybrids studied, 6 hybrids over Lakshmi and 8 hybrids over US – 618 exhibited significant desirable standard heterosis. For number of fruits per cluster positive heterosis is desirable. The cross LE-67 × Pusa Gaurav (37.92% and 42.55%) recorded highest standard heterosis over Lakshmi and US-618 for number of fruits per cluster. Dharmatti (1995)

[4], Patil (1997) [5] and Kumar *et al.* (2012) [6] for number of fruits per cluster reported significant positive standard heterosis.

The relative heterosis ranged from -21.73 (LE-65 × Pant T-3) to 81.88 per cent (LE-64 × Pusa Gaurav). Significant positive relative heterosis was recorded in 12 hybrids for average fruit weight. Heterobeltiosis ranged from -34.02 (LE-65 × Pant T-3) to 76.07 per cent (LE-64 × Pusa Gaurav) and 9 hybrids exhibited significant positive heterobeltiosis. The range of standard heterosis was from -43.63 (LE-65 × Pant T-3) to 21.10 per cent (LE-64 × Pusa Gaurav) over Lakshmi and -39.70 (LE-65 × Pant T-3) to 29.55 (LE-64 × Pusa Gaurav) over US-618. Significant positive standard heterosis was recorded by 3 hybrids over Lakshmi and 6 hybrids over US-618. Average fruit weight is considered to be associated directly with fruit yield per plant, for which positive heterosis is desirable. The cross LE-64 × Pusa Gaurav (21.10% and 29.55%) for average fruit weight recorded highest significant standard heterosis over Lakshmi and US-618. These results are in accordance with the findings of Tendulkar (1994) [7], Patil (1997) [5] and Kumar *et al.* (2012) [6] for average fruit weight.

The range of relative heterosis was from -10.79 (LE-64 × Pant T-3) to 58.94 per cent (LE-56 × Pusa Gaurav) with 15 hybrids exhibiting significantly positive relative heterosis. The heterobeltiosis ranged from -12.55 (LE-62 × Pusa Gaurav) to 56.68 per cent (LE-56 × Pant T-3) and 10 hybrids recorded positive significant heterobeltiosis for fruit yield per plant. Standard heterosis ranged from -33.38 (LE-62 × Pusa Gaurav) to 29.26 per cent (LE-56 × Pant T-3) with 6 hybrids exhibited significant positive standard heterosis over Lakshmi and 4 hybrids exhibiting positively significant standard heterosis over US-618, it ranged from -37.95 per cent (LE-62 × Pusa Gaurav) to 20.41 per cent (LE-56 × Pant T-3). The hybrids LE-56 × Pant T-3 (20.41), LE-56 × Pusa Gaurav (15.07), LE-64 × Punjab Chhuhara (13.15) and LE-56 × Punjab Chhuhara (11.78) recorded high standard heterosis over best commercial check US-618. Significantly positive heterosis has been observed mainly in terms of fruit yield per plant in crosses over their mid and better parents. The crosses LE-56 × Pusa Gaurav, LE-56 × Pant T-3, LE-64 × Pusa Gaurav, LE-65 × Pusa Gaurav and LE-64 × Punjab Chhuhara were the top five heterotic crosses, manifesting an relative heterosis of 58.94, 56.82, 51.68, 45.77 and 44.53%, respectively, while the crosses LE-56 × Pant T-3, LE-56 × Pusa Gaurav, LE-64 × Pusa Gaurav, LE-65 × Pusa Gaurav and LE-64 × Punjab Chhuhara were the top five crosses, displaying a heterobeltiosis of 56.68, 49.73, 45.12, 42.54 and 37.67, respectively for fruit yield per plant. The significantly positive heterobeltiosis for fruit yield per plant could be apparently due to preponderance of fixable gene effects. Similar results were also found by Dharmatti (1995) [4], Makesh *et al*. (2002) [8]), Tiwari and Lal (2004) [9], Premalakshmi (2005) [10] and Indurani and Veraragavatham (2008) [11]. Four hybrids over US-618 and six hybrids over Lakshmi registered significant positive standard heterosis. In general, the crosses *viz.*, LE-56 × Pant T-3 (29.26% and 20.41%), LE-56 × Pusa Gaurav (23.53% and 15.07%), LE-64 × Punjab Chhuhara (21.47% and 13.15%) and LE-56 × Punjab Chhuhara (20.00% and 11.78%) were the outstanding crosses based on standard heterosis over Lakshmi and US-618, respectively as far as fruit yield per plant is concerned. I t is apparent that the high heterosis for fruit yield per plant may probably be due to dominance nature of genes. These results are in accordance with the earlier findings of Tendulkar (1994) [7], Dharmatti (1995) [4], Patil (1997) [5], Sharma *et al*. (2001) [12], Makesh *et al*. (2002) [8], Padma *et al*. (2002) [13], Bhatt *et al.* (2004) [14], Tiwari and Lal (2004) [9] and Kumar *et al.* (2012) [6].

The present investigation on heterosis revealed that high yielding hybrids were not produced by crossing two high yielding parents alone, but also by one high yielding and the other high and or average yielding parents. These findings suggest that it could be possible to achieve yield improvement in this crop through heterosis breeding, involving genetically distant germpasm lines with high or average *per se* performance, as parents. In the present study, the moderate extent of relative heterosis and heterobeltiosis as observed for yield and yield components. The extent of heterosis over standard checks (Lakshmi and US-618) for fruit yield per plant (29.26% and 20.41%) appears to be sufficient for exploitation of heterosis commercially. The potential crosses like LE-56 × Pant T-3, LE-56 × Pusa Gaurav, LE-64 × Punjab chhuhara and LE-56 × Punjab chhuhara exhibited high standard heterosis for fruit yield per plant, which offers scope for commercial exploitation through heterosis breeding.

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