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Studies on the Effect of Heterosis for Yield and Yield Contributing Plant Traits in Tomato (*Solanum lycopersicum* L.)

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A set of 24 cross combinations were developed through Line × Tester mating system involving 11 diverse genotypes of tomato and observations were taken for yield and yield attributing characters to study the extent of heterosis in the crosses. Tomato is an autogamous crop and has originated in the Peru region of South America. The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The analysis of variance revealed that there was a significant genotypic difference among the genotypes under study, showing considerable amount of genetic variability among them. The lines under study were found significant for all traits under consideration. Significant differences due to testers were observed for all traits except days to 50% flowering, number of primary branches per plant and number of fruits per plant.Out of 24 combinations 10 crosses showed significant negative heterosis over better parent for days to 50% flowering and cross VRT-101-A × Pant T-5 (-15.96%) followed by CTS-07 × Arka Abha (-15.73%) and Angha × Pant T-5 (-13.83%) recorded maximum negative significant heterosis. The cross combination Solan Vajra × Arka Abha, CTS-07 × Arka Abha and VRT-101-A × Arka Abha exhibited maximum per cent of positive significant heterobeltiosis in the extent of 23.30, 19.22 and 16.62% respectively in case of fruit yield.

Introduction

Tomato (*Solanum lycopersicum* L.) with chromosome number 2n=2x=24 is one of the most important and widely traded vegetable crop all over the world. It is an autogamous crop and has originated in the Peru region of South America. In many countries it is also labeled as "Poor man's orange" due to its alluring appearance and high nutritive value (Singh *et al.*, 2004).Globally tomato ranks second in importance following potato but tops the list in processed vegetables (Chaudhary, 1996). To cope up with the ever-increasing demand for vegetable in market and processing industries, it has become necessary to develop hybrids which have a complex of valuable attributes, *viz.*, earliness, uniformity, better quality, higher yield, resistance to diseases and pest and adaptability to wider environmental conditions. The relative ease in conducting emasculation, high percentage of fruit setting and favourable number of seeds per fruit in tomato facilitates the exploitation of heterosis. Hedrick and Booth (1907) first observed heterosis for number of fruits per plant as well as higher yield per plant in tomato. But there is a lack of good hybrids especially in public sector. So, development of hybrid varieties of tomato is highly needed to support the farmer's interest. Therefore, the present investigation was conducted using Line × Tester experimental design to identify the best cross combinations for yield and yield attributing plant traits in Tomato.

Materials and Methods

The current experiment was conducted at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during *rabi* seasons of 2017-18 and 2018-19.The experimental material consisted of eight lines *viz.*, CTS- 07, Angha, Solan Vajra, VRT-101-A, VRT-01, CO-3, VRT-06, H-88-78-1 and three testers namely ArkaAbha, Pusa-120, Pant-T5 which were collected from Department of Horticulture, Banaras Hindu University, Varanasi. The materials were selected on the basis of variability present in them when observed phenotypically. The crossing programme was carried out during the *rabi* season of 2017-18 by Line × Tester mating design from which 24 cross combinations were obtained. The F_1 along with their 11 parents were sown in the next season (2018-19) for their evaluation and generation of data. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. All the recommended cultural practices and plant protection methods were undertaken to raise a successful crop. Observations were taken for seven plant and yield characters *viz.*, days to 50% flowering, plant height (cm), number of primary branches per plant, number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant and fruit yield (q/ha). The statistical analysis of various parameters was done according to Panse and Sukhatme (1967).

Results and Discussion

The analysis of variance implicates the presence of sufficient amount of variation for most of the traits in both lines and testers. The mean sum of squares due to parents was all significant for all the seven traits. The lines under study were found significant for all traits under consideration. Significant differences due to testers were observed for all traits except days to 50% flowering, number of primary branches per plant and number of fruits per plant.The mid parent heterosis and heterobeltiosis for all the genotypes for the seven traits are presented in Table 1 and 2. Usually positive heterosis is considered desirable for maximum number of traits but in case of trait like days to 50% flowering, negative heterosis is considered highly desirable. From the analysis, it was revealed that the range of heterosis over mid and better parent for this trait varied from -17.28 (VRT-101-A × Pant T-5) to 2.86% (Solan Vajra × Pant T-5) and -15.96 (VRT-101-A × Pant T-5) to 11.11 % (Solan Vajra × Pant T-5) respectively. A set of 11 out of 24 crosses expressed significant negative heterosis over mid parent in case of days to 50 % flowering whereas 10 crosses showed negative significant heterosis over better parent. Highest significant negative heterosis over mid parent was found in the cross VRT-101-A × Pant T-5 (-17.28 %) followed by VRT-101-A × Arka Abha (-16.58 %) and CTS-07 × Arka Abha (-16.20 %) whereas the cross combinations VRT-101-A × Pant T-5 (-15.96 %) followed by CTS-07 × Arka Abha (-15.73 %) and Angha × Pant T-5 (-13.83 %) recorded maximum negative significant heterobeltiosis. Such negative significant heterosis for this trait was also reported by Sekhar *et al.,* (2010); Islam *et al.,* (2012); Chauhan *et al.,* (2014) and Dagade *et al.,* (2015).

The average heterosis for plant height ranged from -7.94 (CTS-07 × Pant T-5) to 71.65 % (Angha× Pusa-120). Among the crosses, 14 crosses showed positive significant heterosis over mid parent for plant height and out of them, the cross Angha × Pusa-120 (71.65 %) followed by VRT-101-A × Pusa-120 (52.02 %) and CTS-07 × Pusa-120 (47.72 %) exhibited maximum significant heterosis in the desired direction. Heterosis over better parent for this trait ranged from -13.66 (Solan Vajra × Pusa-120) to 50.82 % (VRT-101-A × Pusa-120). Maximum significant heterosis over better parent for plant height was exhibited by the cross VRT-101-A × Pusa-120 (50.82 %) followed by Angha× Pusa-120 (45.75 %) and CTS-07 × Pusa-120 (38.36 %). Experiment conducted by Singh *et al.,* (2007); Soleiman *et al.,* (2013); and Amin *et al.,* (2017) also reported similar results on plant height.

Heterosis over mid parent for number of primary branches per plant ranged from -19.57 (VRT-06 × Pant T-5) to 51.72 % (CTS-07 × Pusa-120). Out of 24 crosses, maximum per cent of significant average heterosis was observed for the cross CTS-07 × Pusa-120 (51.72 %) followed by Solan Vajra × Arka Abha (41.67 %) and CO-3 × Pusa-120 (32.67 %). Similarly the range of heterosis over better parent varied from -30.19 (VRT-06 × Pant T-5) to 34.69 % (CTS-07 × Pusa-120). Seven out of 24 crosses showed positive significant heterosis over better parent.

Cross CTS-07 × Pusa-120 (34.69 %) exhibited maximum significant heterobeltiosis followed by Solan Vajra× Arka Abha (34.21 %) and Angha × Pant T-5 (22.45 %). The results of this finding were similar with the reports for higher number of branches per plant observed by Mohamed *et al.,* (2012); Yadav *et al.,* (2013); and Tamta *et al.,* (2017).

Heterotic effect was observed in case of number of fruit clusters per plant both over mid parent and better parent with a range of -32.30 (VRT-01 × Pant T-5) to 42.38 % (Angha × Pusa-120) and -33.52 (VRT-01 × Pant T-5) to 41.73 % (VRT-06 × Pusa-120) respectively. Higher number of fruit clusters per plant is beneficial for higher yield. The results revealed that significantly positive average heterosis was expressed by 17 crosses with maximum heterosis being exhibited by cross Angha × Pusa-120 (42.38 %) followed by cross VRT-06 × Pusa-120 (41.83 %) and VRT-101-A × Pusa-120 (35.76 %) over mid parent.

Out of all the cross combinations obtained, 12 hybrids expressed significant positive heterosis over better parent for this trait. Maximum significant heterosis over better parent was exhibited by cross VRT-06 × Pusa-120 (41.73 %) followed by VRT-101-A × Pusa-120 (33.29 %) and Angha × Pusa-120 (27.61 %). The works by Patwary *et al.,* (2013) and Chauhan *et al.,* (2014) also reported similar findings.

Table.1 Estimation of heterosis over mid parent and better parent for days to 50% flowering, plant height (cm) and number of primary branches per plant in tomato

Crosses	Days to 50% flowering		Plant height(cm)		No. of primary branches per plant	
	MPH	BPH	MPH	BPH	MPH	BPH
CTS-07 x ArkaAbha	-16.20 **	-15.73 **	-3.89 *	-4.72 **	24.14 **	10.2
CTS-07 x Pusa-120	-5.68	-4.6	47.72 **	38.36 **	51.72 **	34.69 **
CTS-07 x Pant T-5	-6.01	-3.37	-7.94 **	-12.71**	-2.27	-12.24 *
Angha x ArkaAbha	-12.90 **	-10.00 *	-3.91 *	-12.87**	17.24**	4.08
Angha x Pusa-120	-12.57 **	-8.05 *	71.65 **	45.75 **	10.34	-2.04
Angha x Pant T-5	-14.74 **	-13.83 **	25.23 **	18.46 **	36.36**	22.45 **
SolanVajra x ArkaAbha	0.58	6.17	0.93	0.05	41.67 **	34.21 **
SolanVajra x Pusa-120	1.19	4.94	-7.82 **	-13.66**	27.78**	21.05 **
SolanVajra x Pant T-5	2.86	11.11 *	27.72 **	21.10 **	-4.11	-10.26
VRT-101 A x ArkaAbha	-16.58 **	-13.33 **	39.40 **	28.58 **	23.60 **	7.84
VRT-101 A x Pusa-120	-13.04 **	-8.05 *	52.02 **	50.82 **	10.11	-3.92
VRT-101 A x Pant T-5	-17.28 **	-15.96 **	39.78 **	23.73 **	-13.33 *	-23.53 **
VRT-01 x ArkaAbha	-0.55	0	3.19	-3.89 *	-10.59	-19.15 **
VRT-01 x Pusa-120	-4.49	-2.3	24.86 **	8.65 **	17.65**	6.38
VRT-01 x Pant T-5	-4.86	-3.3	-1.23	-3.91	-18.60**	-25.53 **
CO-3 x ArkaAbha	-8.99 **	-7.95 *	26.50 **	18.18 **	6.93	-14.29 **
CO-3 x Pusa-120	-12.00 **	-11.49 **	37.31 **	36.51 **	32.67**	6.35
CO-3 x Pant T-5	-14.29 **	-11.36 **	24.01 **	11.12 **	17.65**	-4.76
VRT-06 x ArkaAbha	1.09	3.33	-6.57 **	-10.12 **	5.49	-9.43
VRT-06 x Pusa-120	0.55	4.6	36.19 **	22.09 **	18.68**	1.89
VRT-06 x Pant T-5	-5.32	-5.32	1.66	1.01	-19.57 **	-30.19 **
H-88-78-1 x ArkaAbha	-2.65	2.22	-7.73 **	-10.53 **	21.52**	17.07 *
H-88-78-1 x Pusa-120	-1.08	5.75	27.81 **	15.43 **	26.58**	21.95 **
H-88-78-1 x Pant T-5	-7.77 *	-5.32	6.19 **	4.64 *	22.50**	19.51 **
S.E.Diff	0.98	1.13	1.37	1.58	0.15	0.18
CD 95 %	1.97	2.27	2.75	3.18	0.31	0.36

where, MPH- Mid Parent Heterosis, BPH- Better Parent Heterosis
*Significant at p=0.05, **Significant at p=0.01

Table.2 Estimation of heterosis over mid parent and better parent for number of fruit clusters per plant, number of fruits per cluster in tomato, number of fruits per plant and fruit yield (q/ha)

Crosses	No. of fruit clusters per plant		No. of fruits per cluster		No. of fruits per plant		Fruit yield (q/ha)	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
CTS-07 x ArkaAbha	-0.45	-3.32	-16.36 **	-25.14 **	32.95 **	18.34 **	22.18 **	19.22 **
CTS-07 x Pusa-120	21.90 **	21.86 **	5.44	3.44	10.76 **	0.62	23.14 **	15.09 **
CTS-07 x Pant T-5	-15.28 **	-26.48 **	12.26 **	4.18	-0.82	-9.17 **	-3.92 *	-13.07**
Angha x ArkaAbha	26.00 **	10.03 **	20.39 **	15.57 **	12.28 **	-9.99 **	-10.73**	-18.28**
Angha x Pusa-120	42.38 **	27.61 **	13.61 **	3.73	-0.87	-19.13**	0.43	-4.12 **
Angha x Pant T-5	28.37 **	1.59	13.49 **	13.31 **	-0.77	-18.48**	14.51 **	13.15 **
SolanVajra x ArkaAbha	18.57 **	16.54 **	10.94 **	5.84	44.42 **	27.26 **	28.06 **	23.30 **
SolanVajra x Pusa-120	16.29 **	14.85 **	-20.03 **	-32.43 **	-10.43**	-19.48**	9.32 **	0.89
SolanVajra x Pant T-5	12.47 **	-1.38	-10.66 **	-17.90 **	16.30 **	5.39 *	9.09 **	-2.49
VRT-101 A x ArkaAbha	22.19 **	20.82 **	14.76 **	-1.14	31.83 **	28.16 **	19.87 **	16.62 **
VRT-101 A x Pusa-120	35.76 **	33.29 **	2.7	0.19	-20.24**	-20.69**	-14.56**	-20.36**
VRT-101 A x Pant T-5	13.90 **	0.4	18.66 **	5.8	4.87	4.53	5.81 **	-4.52 **
VRT-01 x ArkaAbha	-2.16	-11.46**	20.36 **	6.94 *	-38.59**	-56.09**	18.26 **	11.80 **
VRT-01 x Pusa-120	23.17 **	8.56 **	3.21	-17.92 **	-27.67**	-47.55**	22.63 **	11.21 **
VRT-01 x Pant T-5	-32.30**	-33.52**	9.37 **	-6.1	-41.58**	-57.40**	-22.29**	-31.69**
CO-3 x ArkaAbha	9.99 **	0.85	9.82 **	1.33	-9.66 **	-36.07**	-2.85	-12.04**
CO-3 x Pusa-120	4	-7.16 *	10.29 **	-9.42 **	9.99 **	-21.10**	17.26 **	2.06
CO-3 x Pant T-5	-2.01	-5.14	11.60 **	-0.66	3.26	-25.52**	6.53 **	-9.99 **
VRT-06 x ArkaAbha	19.94 **	16.38 **	-1.08	-1.64	5.63	3.84	-2.93	-13.28**
VRT-06 x Pusa-120	41.83 **	41.73 **	-11.44 **	-21.68 **	32.50 **	27.40 **	35.56 **	16.50 **
VRT-06 x Pant T-5	15.16 **	-0.15	-8.45 *	-11.49 **	-9.04 **	-13.29**	-7.76 **	-23.01**
H-88-78-1 x ArkaAbha	11.11 **	7.62 *	29.34 **	25.00 **	6.38 **	-22.52**	-22.53**	-25.98**
H-88-78-1 x Pusa-120	18.16 **	11.24 **	-3.46	-12.40 **	26.41 **	-6.58 **	-13.09**	-20.38**
H-88-78-1 x Pant T-5	1.93	-6.60 *	-1.77	-2.3	-2.1	-27.22**	-16.52**	-25.91**
S.E.Diff	0.39	0.45	0.16	0.18	0.60	0.69	5.83	6.74
CD 95 %	0.79	0.91	0.32	0.37	1.21	1.40	11.74	13.56

where, MPH- Mid Parent Heterosis, BPH- Better Parent Heterosis
***Significant at p=0.05, **Significant at p=0.01**

The relative heterosis measured over the mid parental value for number of fruits per cluster varied from -20.03 (Solan Vajra × Pusa-120) to 29.34% (H-88-78-1 × Arka Abha). Regarding heterobeltiosis, the range varied from -32.43 (SolanVajra × Pusa-120) to 25.00 % (H-88-78-1 × Arka Abha). Among the crosses, four crosses displayed significant heterosis in positive direction with maximum per cent of significant heterobeltiosis in the positive direction being recorded in cross H-88-78-1 × Arka Abha (25.00 %) followed by Angha × Arka Abha (15.57 %) and Angha × Pant T-5 (13.31 %). The results from the work done by Rao *et al.,* (2007) and Gul *et al.,* (2010)revealed similar findings showing significant positive heterosis over mid parent and better parent for number of fruits per cluster in tomato.

For number of fruits per plant, the heterosis over mid parent and better parent was found to be within the range -41.58 (VRT-01 × Pant T-5) to 44.42 % (Solan Vajra×Arka Abha) and -57.40 (VRT-01 × Pant T-5) to 28.16 % (VRT-101-A × Arka Abha) respectively. Among all the cross combinations, 10 hybrids over mid parent and only five crosses over better parent exhibited positive significant heterosis. Highest per cent of significant average heterosis was observed in the cross Solan Vajra × Arka Abha (44.42 %) followed by CTS-07 × Arka Abha (32.95 %) and VRT-06 × Pusa-120 (32.50 %). Maximum significant heterobeltiosis was observed in cross VRT-101-A × Arka Abha (28.16 %) followed by VRT-06 × Pusa-120 (27.40 %) and Solan Vajra × Arka Abha (27.26 %). Significant positive heterosis over mid parent and better parent for this trait was reported by Singh *et al.,* (2007); Kumari *et al.,* (2010); Chauhan *et al.,* (2014); Gowda *et al.,* (2019);and Salim *et al.,* (2019) for number of fruits per plant in tomato which suggested scope for yield improvement.

Heterosis over mid parent and better parent for fruit yield was observed to be significant in both the direction. The mid parent heterosis for this character varied from -22.53 to 35.56 per cent in cross H-88-78-1 × Arka Abha and VRT-06 × Pusa-120 respectively. Out of 24 crosses, 13 crosses expressed significant heterosis over mid parent in the desired direction. The cross VRT-06 × Pusa-120 (35.56 %) expressed maximum percent of significant relative heterosis followed by Solan Vajra × Arka Abha (28.06 %) and CTS-07 × Pusa-120 (23.14 %). Eight F_1's out of 24 crosses expressed positive significant heterosis over better parent ranging from -31.69 (VRT-01 × Pant T-5) to 23.30 % (Solan Vajra × Arka Abha). The cross combinations Solan Vajra × Arka Abha, CTS-07 × Arka Abha and VRT-101-A × Arka Abha exhibited maximum per cent of positive significant heterobeltiosis in the extent of 23.30, 19.22 and 16.62 % respectively. Similar results in case of tomato were also reported by Ahmed *et al.,* (2011); Agarwal *et al.,* (2014); Gowda *et al.,* (2019); and Salim *et al.,* (2019) for improved fruit yield.

The preponderance of both additive and non-additive gene actions for yield, its components and quality parameters is greatly suggested for both selection and heterosis breeding for the improvement of tomato crop. From the present study, it was observed that the cross VRT-101-A × Pant T-5 followed by CTS-07 × Arka Abha was found to have high significant negative heterosis over both the mid and better parent in case of days to 50 % flowering which is considered desirable, cross combination of Solan Vajra × Arka Abha was having highly significant heterosis over both the mid parent and better parent for number of primary branches, number of fruits per plant and fruit yield. The heterosis over mid and better parent was significantly high in case of plant height and number of primary branches per plant was observed for the cross CTS-07

× Pusa-120. Thus, hybrids exhibiting highly significant heterosis in the desired direction for yield and other yield attributing characters should be given focus for utilizing it in further breeding programme and evaluation and making it preferable for commercial cultivation.

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