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Study of heterosis over environments in tomato (*Solanum lycopersicum* L.)

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Abstract
A study was conducted in tomato to estimate the magnitude of heterosis for yield and its fourteen yield components. 32 F_1 hybrids generated by line x tester mating design comprising of eight lines and four testers and these F_1 along with 12 parents and one commercial check 'Abhinav' were evaluated at three research stations *viz.,* (Navsari, Surat and Hansot) of Navsari Agricultural University, Navsari, Gujarat (India) during late *kharif*- 2014-15 in randomized block design with three replications. The analysis of variance showed significant differences among the genotypes for all the traits. There was high heterosis in most of the hybrids which support the role of non-additive gene effects. Among the crosses, AVTO-5 x GT-2 showed high *sca* effect for fruit yield over environments. The maximum standard heterosis over commercial check was exhibited by the cross AVTO-5 x GT-2 followed by AVTO-7 x GT-2, AVTO-5 x JT-3, JTL-12-12 x GT-2 and JTL-12-12 x JT-3 for fruit yield and its one or more important component traits. In direct selection for traits such as plant height, number of clusters per plant, number of fruits per plant and average fruit weight could be done in order to achieve higher yield through heterosis breeding.

Keywords: Line x tester, heterosis, yield components and tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is native of Peru, Ecuador Bolivia Region of Andes, South America (Rick, 1969) [25]. Plant breeders have extensively explored and utilized heterosis to boost yield levels in several cross-pollinated crops in the recent past. However, tomato being a highly au-togamous species, the scope for exploitation of hybrid vigour depends on the direction and magnitude of heterosis, and ease with which hybrid seeds can be produced. The reproductive biology and production of appreciable quantity of seeds per fruit provide ample opportunity for manifestation of heterosis in tomato (Singh and Singh, 1993) [29]. Since the discovery of hybrid vigour by Shull (1908) [27] a tremendous progress has been made in the development of potential hybrids in tomato. Heterosis in tomato was first observed for higher yield and more number of fruits. Since then, heterosis for yield, its components and quality traits were extensively studied (Ahmad *et al.* 2011; Kurian *et al.* 2001) [2, 17]. Choudhary *et al.* (1965) [7] emphasized the extensive utilization of heterosis to step up tomato production but tomato hybrids perform differently under different agroclimatic conditions. Present investigation was undertaken to ascertain the nature and extent of heterosis for yield and its component characters in this crop over different environments.

Materials and Methods

The experimental materials were procured from Vegetable Research Scheme, Regional Horticulture Research Station, Navsari Agricultural University, Navsari (Gujarat) followed by selfing for maintenance. The experimental materials including eight lines and four testers was sown in crossing block to derive 32 F_1's following line × tester mating design during late *kharif* 2013-14. One popular locally adapted standard variety named Abhinav was used as check variety in present experiment. The twelve parents including eight lines AVTO- 6, AVTO- 7, NTL- 50, AVTO - 4, AVTO - 5, JTL-12-15, JTL-12-08, JTL-12-12 and four testers Arka Abha, GT-2, JT-3 and AT-3 along with its 32 derived F_1s and commercial check (Abhinav) were grown out in randomized block design (RBD) with three replications for possible evaluation during late *kharif* 2014-15 at three different locations *viz.,* Vegetable Research Scheme, Regional Horticulture Research Station (R.H.R.S.), Navsari (Environment E_1); Main Cotton Research Station, Surat (Environment E_2) and Cotton Wilt Research Station, Hansot, Dist. Bharuch (Environment E_3).

The experiment was laid out in randomized block design with three replications at three different locations. Ten plants of each entry were transplanted in first week of November 2014 at spacing of 75 cm x 60 cm. The standard cultural practices to raise tomato crop were followed as per the recommendations of the university. Observations were recorded on days to 50 % flowering, plant height at final harvest, number branches per plant at final harvest, number of clusters per plant, number of fruits per plant, average fruit weight, fruit yield per plant, pericarp thickness, total soluble solids, titrable acidity, ascorbic acid, lycopene content, reducing sugar per cent, total sugar per cent and non reducing sugar per cent and averaged replication wise mean data was used for statistical analysis. TSS reading was observed with help of refractometer in °Brix. The analysis of variance (ANOVA) for RBD was estimated crosswise according to Panse and Sukhtame (1989) [22] and ANOVA for line × tester analysis was done according to Kempthorne (1957) [12] and Singh and Chaudhary (1985) [28]. Heterosis over standard check (Abhinav) was estimated (Table 3).

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

Where, F_1 = mean performance of cross, and SC = mean performance of standard check (Abhinav).

Results and Discussion

The pooled analysis of variance (Table 1) revealed, significant mean square for genotype, parents and hybrids indicated the presence of adequate variability. The mean squares due to parents vs. hybrids exhibited significant differences for all the traits suggested that the differences in the performance of the parents and hybrids were genuine for all traits in all environments and in pooled indicating the presence of average heterosis for these traits. The variance due to hybrids was highly significant for all the traits under individual environments as well as in pooled analysis signifying substantial variation among hybrids The interactions of hybrids x environments were significant for all the traits except plant height at final harvest, total soluble solids, titrable acidity, ascorbic acid lycopene content and reducing sugar (%) revealing that the hybrids were sensitive to environments. The parents vs. hybrids x environments interactions were non-significant for five traits *viz.,* days to 50 per cent flowering, plant height at final harvest, number of branches per plant at final harvest, ascorbic acid and total sugar which pointed out that environment had less influence on these traits. The magnitude of heterosis for different characters under study among the hybrid combinations are presented in Table 2 and 3.

Earliness to flowering is expressed as negative heterosis and it is an established manifestation of heterosis among the tomato hybrids. For days to 50 % flowering standard heterosis ranged from -11.90 per cent (AVTO-6 x GT-2 and AVTO-5 x GT-2) to 19.73 per cent (JTL-12-12 x Arka Abha). A total of five crosses were reported significant and negative heterosis over standard check, in which, top three crosses were AVTO-6 x GT-2 (-11.90 per cent), AVTO-5 x GT-2 (-11.90 per cent) and JTL-08-16 x GT-2 (-11.22 per cent). Almost identical results have been reported by Shende *et al.* (2012) [26] and Patwary *et al.* (2013) [24].

Increased plant height is an advantageous trait to understand higher marketable yield, provided the environmental conditions are otherwise conductive for growth and fruiting over a longer period. The range of standard heterosis varies from -17.53 per cent (AVTO-7 x Arka Abha) to 12.61 per cent (AVTO-5 x GT-2). A total of eight crosses were reported significant and positive heterosis over standard check, in which, top three crosses were AVTO-5 x GT-2 (12.61 per cent), AVTO-4 x AT-3 (11.84 per cent) and AVTO-6 x GT-2 (10.98 per cent). Almost similar results have been reported by Kumari and Sharma (2011) [16], Kumar *et al.* (2012) [14] and Yadav *et al.* (2013) [32].

The number of branches per plant is one of the major parameter contributing for total fruit yield per plant. The magnitude of standard heterosis for this trait across the environments ranged from -15.32 (JTL-12-12 x Arka Abha) to 24.25 per cent (AVTO-7 x JT-3). A total of seven crosses exhibited positive and significant standard heterosis, among them, top three crosses were AVTO-7 x JT-3 (24.25 per cent), AVTO-4 x GT-2 (22.61 per cent) and JTL-08-16 x GT-2 (19.00 per cent). Almost identical results have been reported by Duhan *et al*. (2005) [8].

Number of fruiting clusters per plant is another important trait that determine yield of tomato. The standard heterosis ranged from -12.96 per cent (JTL-08-15 x JT-3) to 49.01 per cent (AVTO-5 x AT-3). A total of six crosses reported significant and positive heterosis over standard check, in which, top three crosses were AVTO-5 x AT-3 (49.01 per cent), AVTO-5 x GT-2 (47.35 per cent) and AVTO-7 x JT-3 (42.10 per cent) for this trait. These results are in conformity with Kanthaswamy and Balakrishanan (1989) [11].

The number of fruits per plant is one of the major parameter contributing for total fruit yield per plant. The range of standard heterosis ranged from -9.11 per cent (AVTO-6 x Arka Abha) to 20.11 per cent (JTL-08-16 x JT-3). A total of seven crosses recorded significant and positive heterosis over standard check, of which, top three crosses were JTL-08-16 x JT-3 (20.11 per cent), AVTO-5 x GT-2 (19.50 per cent) and JTL-08-16 x GT-2 (18.93 per cent). The higher number of fruits per plant which resulted in higher fruit yield. Kumar *et al.* (2012) [14], Yadav *et al.* (2013) [32] and Chauhan *et al.* (2014) [6] made similar observation in tomato.

The eight crosses were exhibited positive and significant standard heterosis for average fruit weight, of which, top three crosses were AVTO-7 x JT-3 (24.91 per cent), AVTO-6 x AT-3 (24.24 per cent) and AVTO-5 x GT-2 (24.20 per cent). These results are in agreement with those reported by several workers like Kumari and Sharma (2011) [16], Yadav *et al.* (2013) [32], Agarwal *et al*. (2014) [1] and Chauhan *et al.* (2014) [6].

The total of seven crosses exhibited highly significant standard heterosis for fruit yield. The standard heterosis ranged from -12.97 per cent to 19.69 per cent for fruit yield. The maximum standard heterosis recorded over standard check by AVTO-5 x GT-2 was 19.69 per cent followed by AVTO-7 x GT-2 (13.53 per cent), AVTO-5 x JT-3 (13.04 per cent), JTL-12-12 x GT-2 (12.76 per cent) and JTL-12-12 x JT-3 (11.63 per cent). Such reports were in collaboration with reports of Kumari and Sharma (2011) [16], Kumar *et al.* (2012) [14], Angadi *et al.* (2012) [3], Gaikwad and Cheema (2012) [9], Makani *et al.* (2013) [18], Yadav *et al.* (2013) [32], Chauhan *et al*. (2014) [6], Agarwal *et al*. (2014) [1], Mali and Patel (2014) [19] and Patel *et al.* (2014) [23].

Table 1: Analysis of variance for fifteen characters pooled over environments in tomato

Source	d. f.	D50	PH	NBP	NCP	NFP	AFW	FYP	PT	TSS	TA	ASC	LC	TS	RS	NRS
Environments	2	334.93**	4061.36**	68.43**	115.70**	3376.92**	2349.08**	49.25**	31.30**	23.37**	1.14**	392.56**	29.16**	150.73**	72.08**	14.98**
Replications	2	1.74	176.96	1.96	5.12	28.03	103.15	0.23	0.26	0.02	0.00	3.87	0.99	0.16	0.08	0.04
Genotypes	43	132.90**	1236.42**	37.35**	43.04**	219.67**	2293.48**	3.47**	5.76**	3.11**	0.06**	55.67**	4.74**	4.49**	2.15**	0.71**
Parents	11	156.41**	780.79**	4.96**	1.91	45.92**	928.59**	1.37**	2.76**	1.56**	0.01**	12.83**	1.88**	1.97**	1.05**	0.28**
Females (F)	7	69.68**	585.70**	4.55**	2.21	34.10**	527.34**	0.42**	1.27**	0.63**	0.01**	9.62*	0.70*	0.73*	0.21	0.28**
Males (M)	3	80.10**	949.72**	2.35	1.80	14.38	791.38**	1.46**	3.88**	2.52**	0.01*	16.15**	1.29**	2.78**	1.30**	0.33**
Females vs Males (F vs M)	1	992.45**	1639.67**	15.74**	0.16	223.30**	4149.00**	7.73**	9.80**	5.25**	0.01	25.37*	11.93**	8.21**	6.22**	0.14
Parents vs. Hybrids (P vs. H)	1	1796.45**	14358.04**	818.09**	764.50**	6166.25**	29082.55**	87.52**	143.31**	56.93**	1.30**	1350.52**	122.37**	9.78**	3.55**	1.55**
Hybrids	31	70.89**	974.82**	23.65**	34.36**	89.50**	1913.63**	1.50**	2.39**	1.93**	0.03**	29.10**	1.95**	5.22**	2.49**	0.83**
Genotypes x Environments	86	7.18*	88.15**	2.68**	3.20**	22.49**	98.29**	0.33**	0.50**	0.21	0.01**	5.45*	0.47*	0.52**	0.38*	0.20**
Parents x Environments	22	5.30	139.03**	0.87	0.60	20.85**	57.86	0.18	0.43*	0.18	0.00	6.05	0.50	0.50	0.36	0.07
Females x Environments	14	4.85	110.20*	0.82	0.62	18.02*	45.23	0.19	0.38	0.14	0.00	8.34*	0.35	0.20	0.16	0.07
Males x Environments	6	1.21	189.99**	0.40	0.62	5.76	101.90*	0.10	0.53	0.21	0.00	0.30	0.34	0.62	0.36	0.05
(F vs M) x Environments	2	20.75*	187.97*	2.61	0.43	85.96**	14.15	0.41	0.48	0.32	0.00	7.30	2.04**	2.22**	1.76**	0.09
(P vs H) x Environments	2	4.00	147.05	1.12	6.38**	134.07**	137.68*	2.40**	0.83*	1.88**	0.08**	8.10	1.19*	0.36	0.93*	1.79**
Hybrids x Environments	62	7.95*	68.19	3.37**	4.02**	19.47**	111.37**	0.32**	0.52**	0.17	0.00	5.15	0.44	0.54**	0.38	0.20**
Pooled Error	258	5.37	55.47	1.32	1.35	10.08	41.49	0.15	0.25	0.16	0.00	4.08	0.33	0.33	0.28	0.06

* and ** Significant at 5 % and 1 % levels of probability, respectively.

D50 = Days to 50 % flowering
PH = Plant height at final harvest (cm)
NBP = Number of branches per plant at final harvest
NCP = Number of clusters per plant
NFP = Number of fruits per plant
AFW = Average fruit weight (g)
FYP = Fruit yield per plant (kg)
PT = Pericarp thickness (mm)
TSS = Total soluble solids (oBrix)
TA = Titrable acidity (%)
ASC = Ascorbic acid (mg/100g)
LC = Lycopene content (mg/100g)
TS = Total sugar (%)
RS = Reducing sugar (%)
NRS = Non-reducing sugar (%)

Table 2: Promising hybrids for fruit yield per plant with standard heterosis, *gca* effects, *sca* effects and component traits showing significant desired heterosis based on pooled over environments.

Sr. No.	Hybrids	Fruit yield per plant (kg)	Standard heterosis (%)	*gca* effects		*sca* effects	Useful and significant for component traits
				P_1	P_2		Standard heterosis (%)
1.	AVTO-5 x GT-2	5.70	19.69**	0.35**	0.29**	0.39**	Days to 50 % flowering, plant height at final harvest (cm), number of branches per plant at final harvest, number of clusters per plant, number of fruits per plant, average fruit weight (g), pericarp thickness (mm), TSS (°Brix), titrable acidity (%), ascorbic acid (mg/100 g), lycopene content (mg/100g), total sugar (%), reducing sugar (%) and non-reducing sugar (%).
2.	AVTO-7 x GT-2	5.50	13.53**	0.21**	0.29**	0.23	Days to 50 % flowering, plant height at final harvest (cm), number of fruits per plant, average fruit weight (g), pericarp thickness (mm) and TSS (°Brix).
3	AVTO-5 x JT-3	5.40	13.04**	0.35**	0.13**	0.23	Number of fruits per plant, pericarp thickness (mm), TSS (°Brix) and ascorbic acid (mg/100 g).
4	JTL-12-12 x GT-2	5.34	12.76**	0.22**	0.29**	0.19	Number of branches per plant at final harvest, number of clusters per plant, number of fruits per plant, average fruit weight (g), pericarp thickness (mm), TSS (°Brix), lycopene content (mg/100g), total sugar (%) and reducing sugar (%).
5.	JTL-12-12 x JT-3	5.27	11.63**	0.22**	0.13**	0.30**	Number of clusters per plant, average fruit weight (g), pericarp thickness (mm), lycopene content (mg/100g) and reducing sugar (%).

*, ** Significant at 5 and 1 per cent probability levels.

Table 3: The estimation of standard heterosis under pooled over standard check

Hybrids	D50	PH	NBP	NCP	NFP	AFW	FY	PT	TSS	TA	AC	LC	TS	RS	NRS
AVTO-6 x Arka Abha	0.68	-9.32**	-13.54**	-9.42	-9.11*	-3.71	-6.98	-6.16	-4.01	0.40	11.68**	-14.76*	-11.58*	-6.54	-20.06**
AVTO-6 x GT-2	-11.90**	10.98**	-1.29	-0.87	3.43	14.89**	10.56**	11.09**	24.82**	-3.63	9.70**	-5.87	-12.76*	-13.47	-11.68*
AVTO-6 x JT-3	0.00	-10.86**	-12.18**	-6.83	-5.06	-1.38	-7.14	-6.06	13.76**	-1.21	-5.49	-11.90	-16.70**	-13.78	-21.79**
AVTO-6 x AT-3	3.06	-7.89**	5.91	2.74	-4.61	24.24**	1.62	-6.84	3.07	4.23	-4.66	-13.40*	-13.86**	-9.97	-20.48**
AVTO-7 x Arka Abha	0.68	-17.53**	-8.68*	-6.83	-6.72	-3.01	-6.91	-5.22	-7.16	-1.01	-2.98	-8.63	17.27**	17.31*	17.02**
AVTO-7 x GT-2	-10.20**	9.46**	-7.31	-5.83	18.88**	21.87**	13.53**	17.13**	14.16**	-2.02	-5.83	8.99	-3.26	-6.86	2.57
AVTO-7 x JT-3	4.42	10.47**	24.25**	42.1**	9.90**	24.91**	7.77*	0.69	1.84	-0.40	-6.51*	11.83	-19.17**	-24.48**	-10.48
AVTO-7 x AT-3	3.74	-10.98**	14.51**	3.73	1.75	-6.49	-4.52	5.53	-6.02	7.66	-5.71	-6.42	-20.75**	-23.54**	-16.24**
NTL-50 x Arka Abha	3.40	-7.44*	-2.68	-8.45	-5.91	-16.55**	-9.36*	-5.70	-10.18*	4.84	-8.91**	-8.45	-15.54**	-20.08**	-8.07
NTL-50 x GT-2	-10.54**	-6.02*	3.01	-6.48	3.98	-13.48**	-0.49	-3.66	-3.75	-3.02	-5.83	4.38	-20.69**	-18.41*	-24.57**
NTL-50 x JT-3	5.44	-6.06*	-5.62	-0.77	-0.29	-15.25**	0.80	2.48	9.37*	8.27	-7.71*	-11.03	-16.17**	-10.35	-26.09**
NTL-50 x AT-3	-4.42	-4.95	-11.56**	-7.86	-3.16	-16.99**	-3.86	1.22	-8.92*	22.18**	-6.01	13.12*	-20.41**	-21.30**	-19.02**
AVTO-4 x Arka Abha	1.02	-3.30	-12.15**	-0.76	-5.86	-5.72	-5.31	-5.05	-6.63	-2.42	-2.93	-2.78	-23.80**	-22.56**	-25.93**
AVTO-4 x GT-2	-1.36	7.16*	22.61**	-4.25	6.21	-7.79*	-5.13	-2.27	-3.15	25.40**	3.00	-5.31	-24.09**	-28.26**	-17.08**
AVTO-4 x JT-3	8.50*	-5.02	-5.06	16.10**	0.45	-12.26**	-7.33*	-4.42	0.91	23.59**	3.02	14.43*	7.81	14.03	-2.67
AVTO-4 x AT-3	4.08	11.84**	-2.63	-8.10	1.39	-2.03	-3.49	-5.57	-2.47	-4.64	-6.01	-6.93	-8.40	2.23	-26.24**
AVTO-5 x Arka Abha	5.78	-3.85	1.54	-11.55	3.69	0.22	-8.08*	0.30	-3.58	-9.27	-2.60	-4.77	-15.00**	-9.63	-23.94**
AVTO-5 x GT-2	-11.90**	12.61**	18.87**	47.35**	19.50**	24.20**	19.69**	18.75**	20.43**	23.79**	10.30**	21.85**	20.29**	19.10**	22.05**
AVTO-5 x JT-3	-4.08	-3.78	4.12	7.62	17.66**	-0.27	13.04**	20.22**	12.87**	-6.05	6.89*	-5.13	-11.60*	-15.64*	-5.08
AVTO-5 x AT-3	0.00	10.15**	10.34*	49.01**	1.52	23.30**	-3.04	0.21	-3.50	-3.83	-1.76	13.81*	-16.68**	-15.67*	-18.39**
JTL-08-16 x Arka Abha	5.10	-3.49	-3.63	-11.98*	0.94	-15.69**	-12.97**	-12.10**	-9.07*	-11.49*	8.92**	-8.43	-13.31**	-14.10	-12.10*
JTL-08-16 x GT-2	-11.22**	9.54**	19.00**	7.46	18.93**	-13.85**	-8.26*	-6.04	-10.63*	-5.85	8.39**	-13.42*	-18.74**	-14.47*	-25.83**
JTL-08-16 x JT-3	5.78	-2.92	-0.68	-8.91	20.11**	-23.18**	-3.96	-13.04**	-9.02*	-10.89*	-1.90	-5.00	-29.22**	-27.63**	-31.95**
JTL-08-16 x AT-3	13.27**	4.78	-3.13	-2.90	4.20	-24.43**	-7.70*	-10.71*	-14.16**	23.19**	1.35	-10.44	-19.80**	-21.62**	-17.08**
JTL-08-15 x Arka Abha	12.24**	-14.57**	-10.12*	-12.76	-0.05	-15.27**	-10.81**	-3.56	-9.70*	1.01	4.82	-8.01	-14.87**	-21.81**	-3.40
JTL-08-15 x GT-2	5.44	-6.55*	-10.34*	-3.91	0.46	-12.98**	-9.08*	-1.20	11.67**	5.44	4.31	13.79*	19.90**	19.23**	20.90**
JTL-08-15 x JT-3	12.93**	-6.12*	-6.66	-12.96*	4.02	-12.67**	-8.38*	0.84	-1.46	6.65	-3.25	9.48	-13.73**	-14.60*	-12.31*
JTL-08-15 x AT-3	13.27**	-6.30*	-6.75	-3.11	-1.10	-17.51**	-7.47*	0.46	-7.94	20.97**	-0.16	-4.56	-14.38**	-23.19**	0.26
JTL-12-12 x Arka Abha	19.73**	-14.10**	-15.32**	-7.07	-6.13	-4.50	-8.82*	0.23	-11.04*	4.44	-4.33	-6.47	0.73	-4.44	9.22
JTL-12-12 x GT-2	11.90**	-14.84**	18.97**	26.92**	9.86**	22.77**	12.76**	17.48**	14.34**	4.64	-4.41	17.73**	14.71**	18.63*	8.07
JTL-12-12x JT-3	18.37**	-11.08**	-8.98*	32.87**	-2.97	22.52**	11.63**	12.14**	-7.11	7.86	-5.45	14.02*	8.75	17.43*	-5.81
JTL-12-12 x AT-3	11.56**	-10.64**	-10.89**	-6.87	-5.43	-4.99	-5.01	1.24	-14.41**	7.26	2.80	-5.51	-9.20	-8.46	-10.58
S.Em.±	1.12	3.32	0.58	0.58	1.41	3.30	0.17	0.25	0.19	0.03	0.95	0.28	0.28	0.26	0.12
CD @ 5 %	2.21	6.55	1.14	1.15	2.79	6.51	0.34	0.49	0.38	0.06	1.88	0.56	0.56	0.51	0.24
CD @ 1 %	2.92	8.65	1.50	1.52	3.68	8.58	0.45	0.64	0.50	0.07	2.48	0.74	0.73	0.67	0.32

* and ** Significant at 5% and 1% levels of probability, respectively.

Pericarp thickness is the most important parameter that can manipulate processing as well as easy long distance transportation (Kumari *et al.* 1998) [15]. All the top five high yielding hybrids showed significant and positive standard heterosis for this trait, of which, top three crosses were AVTO-5 x JT-3 (20.22 per cent), AVTO-5 x GT-2 (18.75 per cent) and JTL-12-12 x GT-2 (17.48 per cent). Almost identical results have been reported by Angadi *et al.* (2012) [3] and Kumar *et al.* (2013) [13].

Total soluble solids directly influence flavor of tomato and is an important quality parameter in the processing industry. Eight crosses exhibited positive and significant standard heterosis, for average fruit weight of which, top three crosses were AVTO-6 x GT-2 (24.82 per cent), AVTO-5 x GT-2 (20.43 per cent) and JTL-12-12 x GT-2 (14.34 per cent). Almost similar results have been reported by Kumari and Sharma (2011) [16], Angadi *et al.* (2012) [3], Yadav *et al.* (2013) [32] and Kumar *et al.* (2013) [13].

In sour segment of tomato, quality parameter like titrable acidity, play a critical role (Stevens, 1986) [30]. For the titrable acidity content, standard heterosis ranged from -11.49 % (JTL-08-16 x Arka Abha) to 25.40 % (AVTO-4 x GT-2) over standard check 'Abhinav'. Six crosses exhibited positive and significant standard heterosis, of which, top three crosses were AVTO-4 x GT-2 (25.40 per cent), AVTO-5 x GT-2 (23.79 per cent) and AVTO-4 x JT-3 (23.59 per cent). This types of findings also reported by Kumar *et al.* (2013) [13].

Ascorbic acid content is nutritionally an important constituent. For the ascorbic acid content, standard heterosis ranged from -8.91 % (NTL-50 x Arka Abha) to 11.68 % (AVTO-6 x Arka Abha) over standard check. Six crosses exhibited positive and significant standard heterosis, of which, top three crosses were AVTO-6 x Arka Abha (11.68 per cent), AVTO-5 x GT-2 (10.30 per cent) and AVTO-6 x GT-2 (9.70 per cent). This also confirmed by Kumari and Sharma (2011) [16] and Kumar *et al.* (2013) [13].

High lycopene content is the most important desirable quality parameter for increasing marketing value and consumer prefer the good colour of tomato (Valverde *et al*. 2002) [31]. The estimates of heterosis ranged from -14.76 per cent (AVTO-6 x Arka Abha) to 21.85 per cent (AVTO-5 x GT-2) over standard check. Seven crosses exhibited positive and significant standard heterosis, of which, top three crosses were AVTO-5 x GT-2 (21.85 per cent), JTL-12-12 x GT-2 (17.73 per cent) and AVTO-4 x JT-3 (14.43 per cent). This types of findings also reported by Angadi *et al.* (2012) [3], Angadi and Dharmatti (2012) [4] and Kumar *et al.* (2013) [13].

Reducing sugar is another important trait that determines the keeping quality of the fruit (Malundo *et al.* 1995) [20]. The standard heterosis ranged from -28.26 (AVTO-4 x GT-2) to 19.23 per cent (JTL-08-15 x GT-2). Total five crosses exhibited positive and significant standard heterosis, of which, top three crosses were JTL-08-15 x GT-2 (19.23 per cent), AVTO-5 x GT-2 (19.10 per cent) and JTL-12-12 x GT-2 (18.63 per cent). This types of findings also reported by Chattopadhyay and Paul (2012) [5].

For total sugar content, standard heterosis ranged from -29.22 (JTL-08-16 x JT-3) to 20.29 per cent (AVTO-5 x GT-2). Only four crosses exhibited positive and significant standard heterosis, of which, top three crosses were AVTO-5 x GT-2 (20.29 per cent), JTL-08-15 x GT-2 (19.90 per cent) and AVTO-7 x Arka Abha (17.27 per cent). This also confirmed by Mondal *et al.* (2009) [21].

For non-reducing sugar content, standard heterosis ranged from -31.95 (JTL-08-16 x JT-3) to 22.05 per cent (AVTO-5 x GT-2). Out of 32 crosses, only three crosses *viz.,* AVTO-5 x GT-2 (22.05 per cent), JTL-08-15 x GT-2 (20.90 per cent) and AVTO-7 x Arka Abha (17.02 per cent) recorded positive and significant standard heterosis for this trait.

It can be concluded from the result that tomato hybrid AVTO-5 x GT-2 produced highest fruit yield per plant also having high standard heterosis which useful in desired direction for all the traits.

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