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Heterotic studies for yield and quality traits in tomato (*Lycopersicon esculentum* Mill.)

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Abstract
Sum total of 30 hybrids generated through crossing of 10 lines and 3 testers along with their parents and one standard check were used to study the heterosis for 13 yield and quality traits into randomized complete block design (RCBD) with three replications. Significant differences among diverse genotypes were obtained for all the traits studied. Most of the crosses showed higher heterosis involving at least one parent with high GCA effects. The top six heterotic crosses over standard check Avinash –II were DVRT-3 x PNR-7, A. Vikas x PNR-7, DVRT-5 x H-86, DVRT-6 x PC, PSH x PC and S-7 x PC with significant standard heterosis ranging from 46.69 to 102.49 per cent.

Keywords: Tomato, lines, testers, crosses and RCBD

Introduction
Tomato (*Lycopersicon esculentum* Mill.) is considered as one of the most popular and widely grown vegetable crops throughout the India and world. It has higher rank among forcing vegetables due to its remunerative price and round the year demand. It is a typical day neutral and mainly self pollinated crop, but a certain range of cross-pollination also occurs. Although tomato is a self-pollinated crop, heterosis is being commercially exploited on large scale, at present hybrids getting more and more popularity (Baishya, *et al.*, 2001) [3]. Heterosis breeding as a tool for genetic improvement in tomato has been advocated by Duhan, *et al*., 2005 [5]. Heterosis in tomato was first observed by Hedrick and Booth (1908) [7] for higher yield and more number of fruits per plant. It is reported that heterosis in tomato resulted in increased yield of 20 to 50% (Chaudhary *et al.*, 1965) [4]. Hybrids are preferred over pure line varieties in tomato on account of their superiority in marketable fruit yield, components traits and fruit quality. Now a days, farmers of India are more inclined to grow hybrid varieties having high yield potential and to get early harvest (short duration) and good quality fruits. But there is a lack of good hybrids especially in public sector. So, development of hybrid varieties of tomato is needed to support the farmer's interest. Therefore, the present experiment was carried out to identify best cross combinations for yield and quality components using line x tester mating design.

Materials and Methods
The present experiment was carried out during autumn season of 2015 and 2016 at Regional Research Station, Uchani, Karnal, Department of Vegetable Science, CCS Haryana Agricultural University, Hisar, Haryana. The experimental field is located at latitude of 29º 72' north, longitude of 76º 98' east and at an altitude of 253 meter above mean sea level under semi-arid and sub-tropics with hot and dry winds during summer months, warm and humid in monsoon and cold and dry weather in winter. The experimental material comprising of 13 genotypes (ten lines and three testers) were sown in crossing block during autumn 2015 for making crosses in a line x tester mating design and F_1 seeds were harvested during summer 2016. Thirty F_1 crosses along with 13 parents and one standard hybrid check (Avinash-2) were sown in the nursery during autumn 2016 and seedlings were transplanted in Randomized Complete Block Design (RCBD) with 3 replications accommodating 10 plants in each treatment at 60 cm x 45 cm spacing (Table 1.0). All the recommended cultural practices and plant protection schedules were adopted for raising the crop successfully. Five competitive plants were randomly selected from each genotype and its crosses in each replication for taking observations for 13 traits *viz.* plant height, number of branches per plant, days to 50% flowering, days to first harvesting, early fruit yield per plant, number of locules per fruit, fruit size (polar and equatorial diameter), total number of fruits per plant, total fruit yield per plant, specific gravity, total soluble solids, ascorbic acid and acidity and replication wise mean value was used for statistical analysis.

The data was analyzed by following the method as suggested by Arunachalam (1974) [1] The data was analyzed by following the method as suggested by Arunachalam (1974) [1] and ANOVA for line x tester analysis was done according to Kempthorne (1957) (Table 2.0). Heterosis over commercial check (economic heterosis) was estimated as per formula:

Heterosis (%) over standard check (SC or CH) = $\frac{F_1 - SC}{SC}$ x 100

Where, F_1= mean performance of cross, SC or CH is the mean performance of commercial variety/hybrid taken as standard/ commercial check. The significance was ascertained by the formula of Wynne *et al*., (1970) [19] at 0.05 and 0.01 per cent level of probability at error degree of freedom given in the analysis of variance table.

Table 1: List of tomato genotypes employed in line x tester analysis.

Sr. No.	Lines	Testers	Crosses		
1.	Pusa following Sadabahar	Punjab Chhuhara	PSH x PC	PSH x PNR-7	PSH x H-86
2.	Punjab Upma	PNR-7	P. Upma x PC	P. Upma x PNR-7	P. Upma x H-86
3.	S-12	H-86	S-12 x PC	S-12 x PNR-7	S-12 x H-86
4.	DVRT-6		DVRT-6 x PC	DVRT-6 x PNR-7	DVRT-6 x H-86
5.	DVRT-2		DVRT-2 x PC	DVRT-2 x PNR-7	DVRT-2 x H-86
6.	DVRT-5		DVRT-5 x PC	DVRT-5 x PNR-7	DVRT-5 x H-86
7.	NT-8		NT-8 x PC	NT-8 x PNR-7	NT-8 x H-86
8.	DVRT-3		DVRT-3 x PC	DVRT-3 x PNR-7	DVRT-3 x H-86
9.	S-7		S-7 x PC	S-7 x PNR-7	S-7 x H-86
10.	Arka Vikas		A. Vikas x PC	A. Vikas x PNR-7	A. Vikas x H-86

*Comercial check-Avinash-2 (SC/CH)

Results and Discussion

Analysis of variance showed highly significant differences among the parents and crosses for all thirteen characters studied. Among the different diverse parents, both male and female parents exhibited significant differences for most of the characters and the variance for parents *vs.* crosses found significantly positive for all the 13 characters experimented. The testers were found comparatively more variant than lines. The contribution of lines x testers also found significant for all characters (Table 2.0). The *per se* and heterotic performances of genotypes is presented in Table 4.0 and 5.0 respectively. The *per se* and heterotic performance for plant height ranged from 62.67-112.22 cm and -11.95 to 51.51 *per cent* respectively. Highest significant positive heterosis in sense of plant height was observed in cross PSH x PNR-7 (51.51%) followed by DVRT-6 x PNR-7 (47.01%) and DVRT-2 x PNR-7 (42.81%). It was most probably due to the involvement of parent PNR-7 which has highest plant height among the parents (107.56 cm). These finding were similar to the results of Fagaria *et al*., 2001, Sharma 2003 and Singh *et al*., 2007 [16]. The highest significant positive heterosis over check for number of branches per plant was recorded in cross P. Upma x PC (33.38%) followed by A. Vikas x PNR-7 (29.02%) and S-12 x PNR-7 (28.99%). The number of branches per plant is positively related with the plant yield. Early flowering is significant for higher early yield. The earliest cross combination for Days to 50% flowering was DVRT-3 x H-86 (38 days) which was followed by S-12 x H-86 and DVRT-6 x H-86 (42 days). For early flowering significant negative heterosis is desirable. The cross DVRT-3 x H-86 (-24.35%) was recorded highest negative heterosis over standard check Avinash-2. It was most probably because the combination of earliest line DVRT-3 (40 days) and tester H-86 (51.3 days). The early harvest increases profit margin from the crop and thus considered an important factor in tomato crop improvement programme. For the days to first harvesting maximum significant negative heterosis was observed in cross combination PSH x PC (-6.59%) followed by NT-8 x PNR-7 (-5.99%) and NT-8 x H-86 (-9.49%) expressed earliness over the check. The findings of Singh and Singh, 1993 [15], Vidyasagar *et al.,* 1997 [18] and Singh *et al*., 2007 [16] supports this result. The early fruit yield per plant is preferable character for developing high yielding hybrids. Presently, early and high yielding hybrids are in demand. The *per se* performance for early fruit yield per plant ranged from 0.22 to 0.73 Kg. The highest significant positive heterosis over the check was observed for DVRT-5 x H-86 (65.91%) followed by the cross combination PSH x PNR-7 (64.14%) and DVRT-3 x PNR-7 (60.61%). The highest negative heterosis over check was observed for PSH x PC (-32.36 %) followed by P. Upma x PC (-27.68%) showing better combination for lower number of locules per fruit. This might be due to involvement of parent Punjab Chhuhara which recorded lowest number of locules per fruit among testers (2.40). From the economic point of view less number of locules or negative heterosis is beneficial. Sharma 2003 and Tesi *et al*., 1970 reported hybrids with higher shape index possessed less number of locules per fruit. For the fruit size positive heterosis is desirable. Medium size fruits are much preferred for table purpose. The highest positive significant heterosis for polar diameter was recorded in A. Vikas x PC (65.13%) followed by PSH x PC (51.94%) and DVRT-5 x PNR-7 (38.76%) while for equatorial diameter highest positive significant heterosis was recorded in DVRT-3 x PNR-7 (48.78%) followed by A. Vikas x PNR-7 (43.68%). This might be due to involvement of parents having better fruit size.

The per se performance for total number of fruits per plant ranged from 19.22 to 48.03. The cross combination DVRT-6 x PC (48.0) recorded highest number of fruits per plant followed by PSH x PC (44.82). Only eight out of 30 crosses marked significantly positive heterosis over the check. The maximum significant heterosis over check in cross combination DVRT-6 x PC (59.41%) was most probably due to crossing with tester Punjab Chhuhara which has highest number of fruits per plant among all the testers (29.55). Fagaria *et al.*, 2001, Kurian *et al*., 2001 [11], and Singh *et al*., 2007 [16] observed significant positive heterosis for higher number of fruits per plant in tomato suggesting good scope for yield improvement through its components. Expression of heterosis for fruit yield and its attributing traits was related to the GCA effects of parents. Most of the crosses showing higher heterosis involved at least one parent with high GCA effects. The top six heterotic crosses over standard check

Avinash-2 were DVRT-3 x PNR-7, A. Vikas x PNR-7, DVRT-5 x H-86, DVRT-6 x PC, PSH x PC and S-7 x PC. They showed significant standard heterosis over check ranging from 46.69 to 102.49 per cent. The relative performance of these crosses in respect of all the 13 traits studied along with the check and the parental lines of respective crosses which are mention in Table 3.0. These six productive crosses had higher *per se* value than the standard check in respect of all the traits except to number of locules and specific gravity. This indicates that higher productivity in these crosses is attributed to better growth and yield parameters observed in crosses compared to parents. The specific gravity is a quality parameter while going for processing. The *per se* performance for specific gravity ranged from 0.95 to 1.14g/cm^3. Only 15 out of 30 crosses exhibited significant negative heterosis over check. The cross combination A. Vikas x PC (-10.38%) showed highest significant negative heterosis followed by DVRT-5 x PC (-9.43%) and P. Upma x PC (-9.12%). Total soluble solids content is also one of the most important quality parameters in the processing industry. The highest mean was noted in cross combination NT-8 x PC (5.05%) which was closely followed by S-7 x H-86 (5.03%). The most significant positive heterosis over check Avinash-2 was recorded in NT-8 x PC (17.4%) followed by S-7 x H-86 (17.02%) and NT-8 x PNR-7 (14.53%). This might be due to involvement of lines and testers having higher *per cent* of TSS content. The earlier reports of Sharma *et al*., 2001, Duhan *et al*., 2005 [5], Singh *et al*., 2007 [16], Kumari and Sharma, 2011 [9] and Agarwal *et al*., 2014 [2] supports the present findings.

Table 2: Analysis of variance for various characters in a line x tester set of tomato

Sr. No.	Characters	Mean squares						
		Replications (2#)	Parents (12#)	Lines (9#)	Testers (2#)	Crosses (29#)	Parent *vs.* crosses (1#)	Line x Tester (18#)
1.	Plant height (cm)	97.88	413.91*	31.96*	140.48	653.98*	3846.54*	99.44*
2.	Number of branches per plant	1.52	2.24*	2.44*	2.47*	5.48*	0.92*	4.73*
3.	Days to 50% flowering	6.57	73.51*	87.39	2.71*	141.7*	7.12*	61.59*
4.	Days to first harvesting	15.26	56.95*	60.70*	35.04*	58.18*	69.85*	27.01*
5.	Early fruit yield per plant (kg)	0.00	0.06*	0.08	0.00*	0.05*	0.22*	0.05*
6.	Number of locules per fruit	0.06	1.55*	1.55*	2.26*	0.53*	0.21*	0.37*
7.	Fruit size (cm)							
a.	Polar diameter	0.16	2.43*	0.58*	9.20*	0.68*	0.44*	0.55*
b.	Equatorial diameter	0.32	0.37*	0.47	0.10*	0.22	0.42*	0.15*
8.	Total number of fruits per plant	2.79	169.32*	178.65*	81.02*	120.82*	128.48*	91.37*
9.	Total fruit yield per plant (g)	76029.48	202135.53*	151233.26*	529945.44*	393410.07*	2192269.27*	448031.73*
10.	Specific gravity (g/cm^3)	0.00	0.01*	0.01*	0.00*	0.01*	0.01*	0.00*
11.	Total soluble solids (^{0}Brix)	0.03	1.45*	1.05*	3.98*	0.73*	0.02*	0.65*
12.	Ascorbic acid (mg/100g fruit juice)	8.21	31.19*	39.63*	8.81*	39.96*	12.04*	5.13*
13.	Acidity (%)	0.00	0.03*	0.03*	0.01*	0.03*	0.01*	0.01*

Degree of freedom, * Significant at 5% level of significance

Table 3: Promising hybrids for fruit yield per plant with standard check, their SCA, GCA effects and component characters showing significant desired heterosis in tomato.

Most heterotic crosses	Fruit yield/plant (g)	Heterosis over check (%)	SCA	GCA		Significant standard heterosis for other traits in desired direction
				L	T	
DVRT-3 x PNR-7	2314	102.49*	-224.16**	431.69**	-16.51	PH,EFYP,PD,ED,TNFP,AA,A
A. Vikas xPNR-7	1918	67.78*	-321.71**	-83.09**	-16.51	PH,NBP,DFPF,DFH,EFYP,ED,TSS
DVRT-5 x H-86	1913	67.4*	-299.49**	131.02**	42.82	EFYP,ED,TNFP,A
DVRT-6 x PC	1910	67.1*	491.87**	105.47**	-26.31	NBP,DFPF,PD,TNFP
PSH x PC	1680	46.98*	319.98**	47.36*	-26.31	EFYP,PD,ED,TNFP,AA,A
S-7 x PC	1677	46.69*	357.42**	6.578	-26.31	DFPF,EFYP,ED,AA

*Significant at 5% level of significance ** Significant at 1% level of significance
PH: Plant height NBP: No. of branches/plant DFPF: Days to 50% flowering
DFH: Days to first harvesting EFYP: Early fruit yield/plant PD: Polar diameter
ED: Equatorial diameter TNFP: Total no. of fruits/plant TSS: Total soluble solids
AA: Ascorbic acid A: Acidity

Table 4: *Per se* performance of lines, testers and crosses of tomato

Parents/ Crosses	Plant height (cm)	No. of branches per plant	Days to 50% flowering	Days to first harvesting	Early fruit yield/plant (kg)	No. of locules	Polar dia. (cm)	Equatorial dia. (cm)	Total no. of fruits/plant	Fruit yield/plant (g)	SG (g/cm^3)	TSS (^{0}Brix)	Ascorbic acid (mg/100gm juice)	Acidity (%)
Punjab Chhuhara	73.44	7.22	53.20	91.98	0.44	2.40	6.63	3.96	29.55	1379	0.97	4.30	24.47	0.60
PNR-7	107.56	8.67	52.30	90.44	0.43	2.82	3.47	4.18	26.69	567	1.03	5.48	21.18	0.70
H-86	66.67	7.00	51.30	85.44	0.49	4.07	3.74	4.30	19.47	1160	0.98	3.18	23.67	0.73
Pusa Sadabahar	70.56	7.67	45.33	83.33	0.70	3.53	3.22	4.13	32.65	1067	1.18	5.13	27.67	0.82
Punjab Upma	64.61	6.55	52.30	84.67	0.64	2.52	4.70	4.31	24.03	1207	0.98	3.84	25.67	0.78
S-12	65.56	6.67	48.10	84.44	0.49	3.84	3.42	4.02	31.72	953	1.03	4.42	27.27	0.77
DVRT-6	62.67	7.56	47.50	85.78	0.53	2.08	3.49	3.38	42.17	1153	1.02	4.48	21.87	0.74
DVRT-2	72.33	7.44	58.00	95.33	0.51	4.23	4.22	4.55	25.05	1082	1.04	4.08	20.00	0.52
DVRT-5	64.89	9.33	50.10	84.78	0.32	2.20	3.64	3.49	43.52	1037	1.05	4.42	20.82	0.83
NT-8	63.00	8.33	48.60	84.67	0.36	3.67	3.44	4.24	35.87	1308	1.03	3.89	19.67	0.76

DVRT-3	69.33	6.78	40.00	83.89	0.22	3.33	3.82	4.49	19.22	564	1.02	3.91	27.13	0.77
S-7	64.67	7.56	42.33	81.44	0.36	3.30	3.68	4.28	31.13	1340	1.09	5.24	23.53	0.80
Arka Vikas	66.78	8.66	54.30	93.44	0.28	3.56	3.53	4.38	28.52	900	1.01	3.32	17.67	0.58
PSH x PC	77.89	8.78	43.33	83.41	0.61	2.39	5.11	3.98	44.82	1680	0.98	3.94	29.37	0.86
P. Upma x PC	71.44	10.11	55.67	92.83	0.46	2.56	4.66	4.04	32.94	1036	0.96	4.37	21.47	0.62
S-12 x PC	71.67	6.78	55.00	92.33	0.60	3.24	3.98	4.07	35.89	1174	1.03	4.62	28.57	0.66
DVRT-6 x PC	77.56	9.00	55.67	88.87	0.54	2.83	4.33	3.86	48.03	1910	1.01	3.70	21.43	0.63
DVRT-2 x PC	70.89	5.11	58.33	94.70	0.33	3.26	4.11	3.91	25.20	796	1.08	4.29	23.07	0.56
DVRT-5 x PC	67.22	7.00	46.33	93.44	0.40	2.92	3.96	4.04	25.83	1283	0.96	3.56	21.33	0.66
NT-8 x PC	68.67	8.78	44.00	85.20	0.49	3.53	3.67	4.20	29.93	1171	0.99	5.05	19.50	0.74
DVRT-3 x PC	66.22	8.00	46.00	85.56	0.65	3.43	4.33	4.40	26.07	1468	1.09	3.92	26.67	0.70
S-7 x PC	73.44	7.11	55.33	92.47	0.61	3.67	3.93	4.54	34.96	1677	0.97	3.73	23.60	0.62
A. Vikas x PC	85.11	8.55	60.00	94.75	0.47	2.79	5.55	4.27	30.20	932	0.95	4.83	18.40	0.55
PSH x PNR-7	112.22	8.11	47.33	84.67	0.72	3.09	3.96	3.99	41.41	1520	1.02	4.57	26.17	0.76
P. Upma x PNR-7	102.00	7.11	49.67	85.97	0.66	2.96	4.28	4.16	32.28	1021	0.98	4.56	18.03	0.71
S-12 x PNR-7	92.78	9.78	51.67	85.73	0.45	3.33	3.85	4.23	32.04	1154	0.98	3.50	27.90	0.61
DVRT-6 x PNR-7	108.89	8.22	58.00	93.41	0.44	3.47	3.17	3.98	34.34	914	1.14	4.69	22.03	0.58
DVRT-2 x PNR-7	105.78	8.89	58.33	94.88	0.33	3.40	3.87	4.23	22.10	978	1.03	4.35	18.33	0.60
DVRT-5 x PNR-7	97.56	7.33	62.67	95.33	0.38	2.76	4.66	4.46	26.13	1213	0.98	3.67	20.40	0.58
NT-8 x PNR-7	99.44	8.44	44.00	83.95	0.51	4.25	3.69	3.93	33.07	1441	1.05	4.93	18.67	0.78
DVRT-3 x PNR-7	94.56	7.78	44.00	84.91	0.71	3.62	4.15	4.91	37.96	2314	0.98	3.53	27.34	0.79
S-7 x PNR-7	105.67	9.56	52.00	87.34	0.65	2.99	3.51	4.17	32.10	1344	0.98	4.64	20.63	0.74
A. Vikas x PNR-7	91.78	9.78	62.00	96.38	0.68	3.36	3.73	4.71	30.03	1918	1.04	4.87	18.20	0.58
PSH x H-86	65.22	7.78	48.33	86.50	0.41	3.33	3.80	4.05	28.43	959	0.97	3.95	27.40	0.74
P.Upma x H-86	67.22	7.67	44.00	85.47	0.71	3.62	4.20	4.71	30.18	1402	0.98	3.97	20.90	0.78
S-12 x H-86	71.22	9.56	42.00	84.12	0.65	3.38	3.96	4.35	31.93	1314	1.03	4.40	27.07	0.82
DVRT-6 x H-86	77.89	8.22	42.00	85.88	0.39	2.87	3.89	4.44	36.04	1509	1.05	3.50	20.13	0.84
DVRT-2 x H-86	69.11	5.11	53.33	92.75	0.44	3.53	4.26	4.61	20.36	1358	1.08	3.93	18.23	0.59
DVRT-5 x H-86	75.11	7.11	42.00	84.34	0.73	4.02	3.65	4.28	42.46	1913	1.05	4.43	21.00	0.78
NT-8 x H-86	70.56	7.00	42.33	84.08	0.52	3.80	3.81	4.02	34.50	1306	1.04	4.87	21.07	0.83
DVRT-3 x H-86	73.78	6.22	38.00	84.16	0.64	3.56	4.04	4.58	28.23	1530	1.10	4.19	26.80	0.89
S-7 x H-86	74.11	5.45	50.67	85.92	0.52	3.44	3.64	4.19	29.89	1016	1.04	5.03	19.93	0.75
A.Vikas x H-86	76.44	7.00	48.00	85.53	0.27	3.20	3.71	4.39	26.87	918	0.98	4.12	20.10	0.65
Avinash-2 (Check)	74.07	7.58	50.23	89.30	0.44	3.54	3.36	3.28	30.13	1143	1.06	4.30	21.00	0.68
Mean	78.35	7.78	49.85	88.04	0.50	3.27	4.00	4.20	31.45	1251	1.02	4.26	22.62	0.71
Range	62.67-112.22	6.55-10.11	38-62.67	81.44-96.38	0.22-0.73	2.08-4.25	3.22-6.63	3.38-4.91	19.22-48.03	564-2314	0.95-1.14	3.32-5.24	17.67-29.37	0.52-.86
C.D.	10.91	1.37	3.79	3.67	0.11	0.62	0.64	0.7	5.28	232.42	0.05	0.35	1.9	0.04
CV (%)	8.57	10.92	4.84	2.56	12.94	11.63	9.91	10.3	10.3	11.43	3.05	5.11	5.4	3.62
SE (d)	5.48	0.69	1.9	1.84	0.05	0.31	0.32	0.35	2.65	116.71	0.02	0.18	1.0	0.021
SE(m) (+/-)	3.88	0.49	1.35	1.3	0.04	0.22	0.23	0.25	1.88	82.53	0.01	0.13	0.71	0.015

Table 5: Heterotic performance of F_1 hybrids over check (Economic heterosis)

Crosses	Plant ht. (cm)	No. of branches per plant	Days to 50% flowering	Days to first harvesting	Early fruit yield per plant (kg)	No. of locules	Polar dia. (cm)	Equato rial dia. (cm)	Total no. of fruits/plant	Total fruit yield/plant (g)	TSS (^{0}Brix)	Ascorbic acid(mg/100g fruit juice)	Acidity (%)	S.G.(g/ cm^3)
PSH x PC	5.16	15.83	-13.73*	-6.59*	38.89*	-32.36*	51.94*	21.33*	48.74*	46.98*	-8.49*	39.84*	26.47*	-7.17*
P. Upma x PC	-3.54	33.38*	10.82*	3.96	4.55	-27.68*	38.70*	23.24*	9.33	-9.40	1.71	2.22	-8.58*	-9.12*
S-12 x PC	-3.24	-10.58	9.50*	3.39	35.61*	-8.35	18.44	24.20*	19.13*	2.75	7.36	36.03*	-2.45	-2.52
DVRT-6 x PC	4.71	18.73*	10.82*	-0.49	21.97	-19.96*	28.81*	17.78	59.41*	67.10*	-13.91*	2.06	-7.35*	-4.72*
DVRT-2 x PC	-4.29	-32.57*	16.13*	6.05*	-25.76*	-7.91	22.36*	19.27	-16.35	-30.40*	-0.27	9.84*	-18.14*	1.82
DVRT-5 x PC	-9.25	-7.65	-7.76*	4.64*	-9.85	-17.61*	17.96	23.32*	-14.28	12.28	-17.25*	1.59	-2.94	-9.43*
NT-8 x PC	-7.29	15.79	-12.40*	-4.59*	10.86	-0.38	9.25	27.93*	-0.65	2.46	17.40*	-7.14	8.82*	-6.92*
DVRT-3 x PC	-10.60	5.50	-8.42*	-4.18*	47.47*	-3.17	28.96*	34.20*	-13.49	28.41*	-8.84*	26.98*	2.94	2.52
S-7 x PC	-0.84	-6.19	10.16*	3.55	37.88*	3.58	17.04	38.31*	16.02	46.69*	-13.22*	12.38*	-8.82*	-8.74*
A. Vikas x PC	14.91*	12.84	19.45*	6.11*	7.58	-21.06*	65.13*	30.12*	0.23	-18.44	12.4*	-12.32*	-19.12*	-10.38*
PSH x PNR-7	51.51*	6.99	-5.77	-5.19*	64.14*	-12.71	17.89	21.68*	37.44*	32.98*	6.28	24.60*	12.25*	-4.09
P. Upma x PNR-7	37.71*	-6.20	-1.12	-3.73	49.24*	-16.51	27.34*	26.73*	7.14	-10.66	6.10	-14.13*	4.90	-7.86*
S-12 x PNR-7	25.26*	28.99*	2.86	-4.00	3.03	-5.84	14.59	28.84*	6.35	1.00	-18.60*	32.86*	-9.80*	-7.42*
DVRT-6 x PNR-7	47.01*	8.44	15.47*	4.60*	0.76	-1.88	-5.80	21.34*	13.97	-20.00	9.15*	4.92	-14.61*	7.80*
DVRT-2 x PNR-7	42.81*	17.27	16.13*	6.25*	-25.76*	-3.95	15.32	28.82*	-26.64*	-14.46	1.20	-12.70*	-11.76*	-3.02
DVRT-5 x PNR-7	31.71*	-3.25	24.76*	6.76*	-12.88	-22.16*	38.76*	36.03*	-13.26	6.15	-14.77*	-2.86	-15.20*	-7.99*
NT-8 x PNR-7	34.26*	11.40	-12.40*	-5.99*	16.16	20.06*	9.80	19.72	9.75	26.08*	14.53*	-11.08*	15.20*	-0.63
DVRT-3 x	27.66	2.64	-12.40*	-4.92*	60.61*	2.32	23.51	49.78*	25.98*	102.49*	-17.87*	30.19*	15.69*	-7.36*

PNR-7	*						*							
S-7 x PNR-7	42.66*	26.09*	3.52	-2.20	47.73*	-15.44	4.44	27.27*	6.54	17.62	7.79	-1.75	8.14*	-7.52*
A. Vikas x PNR-7	23.91*	29.02*	23.43*	7.92*	54.04*	-5.18	11.13	43.68*	-0.32	67.78*	13.14*	-13.33*	-14.95*	-2.01
PSH x H-86	-11.95	2.59	-3.78	-3.14	-7.32	-5.84	13.01	23.37*	-5.64	-16.11	-8.06	30.48*	8.82*	-8.49*
P. Upma x H-86	-9.25	1.13	-12.40*	-4.29*	62.12*	2.32	24.96*	43.47*	0.18	22.68*	-7.60	-0.48	14.71*	-7.61*
S-12 x H-86	-3.84	26.06*	-16.38*	-5.80*	48.48*	-4.61	18.00	32.55*	5.96	15.00	2.21	28.89*	21.08*	-3.14
DVRT-6 x H-86	5.16	8.47	-16.38*	-3.83	-10.35	-19.02*	15.74	35.50*	19.62*	32.01*	-18.64*	-4.13	23.53*	-1.38
DVRT-2 x H-86	-6.69	-32.56*	6.18	3.86	-0.25	-0.19	26.77*	40.40*	-32.44*	18.79	-8.72*	-13.17*	-13.19*	1.51
DVRT-5 x H-86	1.41	-6.19	-16.38*	-5.55*	65.91*	13.65	8.52	30.56*	40.91*	67.40*	2.98	0.00	15.20*	-0.63
NT-8 x H-86	-4.74	-7.67	-15.72*	-5.84*	17.42	7.34	13.52	22.54*	14.50	14.22	13.14*	0.32	22.06*	-2.20
DVRT-3 x H-86	-0.39	-17.90	-24.35*	-5.76*	45.20*	0.44	20.33*	39.63*	-6.29	33.86*	-2.56	27.62*	30.39*	3.71
S-7 x H-86	0.06	-28.16*	0.87	-3.78	18.94	-2.70	8.21	27.74*	-0.81	-11.15	17.02*	-5.08	10.29*	-1.45
A. Vikas x H-86	3.21	-7.65	-4.44	-4.22*	-39.39*	-9.60	10.56	33.71*	-10.82	-19.70	-4.19	-4.29	-3.92	-7.61*
Range	-11.95-51.51	-32.57-33.38	-24.35-24.76	-6.59-7.92	-39.39-65.91	-32.36-20.06	-5.80-51.94	17.78-49.78	-32.44-59.41	-30.04-102.49	-18.64-17.4	-14.13-39.84	-19.12-30.39	-10.38-7.8

*Significant over check at 5% level of significance.

Ascorbic acid is a nutritional parameter. It is the substitute of anti-oxidents and Vitamin C. Ascorbic acid content of tomato fruits varied from 17.62 to 29.3 mg/100g fruit juice. Out of 30 crosses made only 11 marked significantly positive heterosis over the check Avinash-2 and the maximum was observed in cross combination PSH x PC (39.84%) which was closely followed by S-12 x PC (36.03%). This might be due to combination of lines and testers having higher content of ascorbic acid. The findings of Kumar *et al*., 2013 [10], Kumari and Sharma, 2011 [9] and Reddy *et al*., 2013 [12] are also in favor of present study. The lowest value for titrable acidity was recorded in cross combination *A. Vikas* x PC (0.55%) followed by DVRT-2 x PC (0.56%). Heterosis for acidity is considered in both directions, *i.e*., negative as well as positive. The highest negative heterosis was recorded in *A. Vikas* x PC (-19.12%) followed by DVRT-2 x PC (-18.14%) and DVRT-5 x PNR-7 (-15.2%) whereas highest positive heterosis was noted in DVRT-3 x H-86 (30.39%) followed by PSH x PC (26.74%).

Conclusion

The results from the present study clearly indicate that only a single yield attribute with high heterosis is not sufficient to cause the quantum jump in the fruit yield but it is the combined interaction effects of major yield contributors. The critical study of the top six performing hybrids thus clearly indicates that as the high heterosis for fruit yield coupled with high heterosis for other yield attributing traits suggests that there is a predominance of additive gene action for fruit yield heterosis.

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