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Heterosis studies in Tomato (*Solanum lycopersicum* L.)

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Abstract
Heterosis was estimated over better parent, respectively among 45 F_1 hybrids for yield and related traits. The most desirable cross combination *viz*., KS-227 x Roma for fruit yield plant^{-1} also showed desirable better parent heterosis for days to first picking and fruit size. The cross combinations Local x Marglobe (number of primary branches plant^{-1}), DVRT-1 x S-II (average fruit weight), Arka Vikas x KS-227 (plant height), Marglobe x Roma (flesh thickness), KS-227 x Roma (number of fruits plant^{-1}), VLT-32 x Roma (total soluble solids) and VLT-32 x Shalimar-I (Vitamin C) showed highest better parent heterosis. These cross combinations also revealed high *per se* performance.

Keywords: Tomato, heterosis, germplasm

Introduction
In addition to cross pollinated species, the phenomenon of heterosis has also been commercially exploited in self-pollinated species wherever it was technically feasible because of manifestation of heterosis for different traits. Agricultural heterosis was observed nearly 100 years ago when hybrid plants out yielded their inbred parents and today this “hybrid vigor” is a major provider for global food production. The genetic basis of heterosis has been debated with respect to the relative importance of dominant, overdominance and epistasis where one of the problems has been the use of whole genome segregating populations where interactions often mask the effects of individual quantitative trait loci (QTL). In the present study, the heterosis was computed over better parent (heterobeltiosis) for each trait from the data pooled over environments.

Materials and Methods
Ten diverse genotypes of Tomato (*Solanum lycopersicum* L.) viz., Arka Vikas, KS-227, VLT-32, DARL-63, DVRT-I, Local, Marglobe, Shalimar-II, Roma and Shalimar-I were used in the present study. Forty five F_1 crosses were generated through 10 x 10 diallel mating design at Vegetable Experimental Farm, Division of Vegetable Science, SKUAST-K, Shalimar during the year 2010. The final experimental material comprised the ten parents and their 45 F1’s which were evaluated during *Kharif* 2010-11 at three locations: i) Experimental Farm of the Division of Vegetable Science, SKUAST-K, ii) Krishi Vigyan Kendra, Malangpora and iii) Faculty of Agriculture, SKUAST-K, Wadura, Sopore, Baramulla. The experiment was laid out in a completely randomized block design with three replications at each location. The row to row and plant to plant spacing was maintained at 60 x 45 cm. Recommended agronomic practices were followed to raise a good crop at all the three locations. Observations were recorded on five randomly selected competitive plants of each parent and F_1 in every replication for following traits *viz*., days to first fruit set, days to first picking, plant height (cm), number of primary branches per plant, fruit size (cm^2), flesh thickness (mm), number of fruits per plant, average fruit weight (g), fruit yield per plant (kg), number of locules, TSS (°Brix), Vitamin C (mg/100g), Lycopene (mg/100g), Acidity (%), Dry matter content in fruits (%) and Specific gravity. In the case of maturity traits (days to first fruit set and days to first picking), the data was recorded on the whole plot basis.
Heterosis (pooled over environments) was estimated in relation to better parent. This was calculated as increase or decrease of F_1’s over better parent. It was mathematically calculated by the following formula:

$$\text{Heterosis (\%) over better parent (B.P)} = \frac{F_1 - BP}{BP} X100$$

Where,

$\overline{F}_1$ = Mean performance of F_1 hybrid, and

$\overline{BP}$ = Parent having highest performance in the desired direction

$$S.E \text{ for } \overline{BP} = \frac{\pm\sqrt{2xMe}}{r}$$

CD = S.E (d) x 't' value at error degree of freedom at 5 per cent level of significance.

Results and Discussion

The scope for exploitation of hybrid vigour depends on the direction and magnitude of heterosis involved. Heterosis will also have a direct effect on the breeding methodology to be used for varietal improvement. The phenomenon of heterosis, though widely reported and utilised in allogamous crop species, has also been commercially exploited in some autogamous crop species. However, the economic exploitation of heterosis in crop plants is largely governed by the technical feasibility besides the manifestation of heterotic effect for different economic traits and other attributes. In the present study, heterosis over the better parent for each trait were computed over pooled environments. The results revealed a wide range of heterotic patterns for all the traits studied. Maximum range of heterosis was observed for most of the traits.

The characters like early maturity and flesh thickness are preferred in *tomato*, which enable plant breeders to develop varieties tolerant to biotic stresses like disease, insects and pests. They provide ample time for the cultivation of the succeeding crop. Therefore, the negative heterosis is desirable for these traits. Other yield-related characters, such as the number of primary branches plant^{-1}, fruit size, number of fruits plant^{-1}, average fruit weight and fruit yield plant^{-1} provide more opportunities for increasing yield, and hence, the positive heterosis is preferred. Since higher yields in F1 may be due to either dominace or epistatic gene action, the total effect partition of F1 progeny into general and specific combining ability effects deciphers the causes of heterosis.

The F1 heterosis over better parent for days to first fruit set ranged from -19.89 to 43.88 per cent, -9.19 to 6.68 per cent in days to first picking, -38.48 to 11.67 per cent in plant height, -34.56 to 9.59 per cent in number of primary branches plant^{-1}, -33.60 to 57.61 per cent in fruit size, 14.26 to 163.01% in fruit yield plant^{-1}, -25.32 to 68.11 in flesh thickness, -9.53 to 65.27 per cent in number of fruits plant^{-1}, -12.79 to 36.85 per cent in average fruit weight, -36.88 to 20.14 per cent in number of locules fruit^{-1}, -48.56 to 15.25 TSS and -45.60 to 23.53 per cent in vitamin C respectively (Table 1).

Yield is a complex character and highly influenced by environment. Grafius (1959) [2] suggested that there might not be genes for yield *per se* but for the components. Therefore, it would be interesting to know the relationship between the heterosis of component traits. During the present investigation F_1 heterosis over the better parent for fruit yield plant^{-1} and its important attributes namely number of fruits plant^{-1} and average fruit weight ranged from 14.26 to 163.01% and -9.53 to 65.27 % and -12.79 to 36.85 %, respectively.

Significant and desirable heterosis of variable magnitude for maturity and yield traits has been reported by several workers Rai *et al.* (1998) [4], Thakur *et al.* (2004) [7], Singh *et al.* (2005) [6], Joshi *et al.* (2006) [3], Asati *et al.* (2007) [1] and Rao *et al.* (2007) [5]. Rai (1998) [4] was of the view that heterosis in yield of tomato was primarily due to the number of fruits plant^{-1} interacting with average fruit weight. Similar views were shared by Joshi *et al.* (2006) [3]. According to them heterosis for yield appears to be due to increased number of fruits, fruit size, flesh thickness and combined heterosis for other yield contributing traits. The overall genetic analysis suggested high role of dominant genetic variation that could be cause for expression of heterosis. The results obtained from the present study suggest that judicious selection of parents having desirable maturity and yield attributing traits is necessary to exploit heterosis in tomato. In order to make hybrid production more feasible, the use of male sterile lines could help to overcome the problems associated with conventional hand emasculation and pollination practices.

Table 1: Estimation of heterosis (%) over better parent for maturity and yield attributing traits in Tomato (*Solanum lycopersicum* L.) (on pooled data over environments)

Crosses	Days to first fruit set	Days to first picking	Plant height (cm)	Number of primary branches plant^{-1}
A. Vikas x KS-227	5.57**	-0.049**	11.67**	-1.90
A. Vikas x VLT-32	0.98**	5.94**	-13.79**	-13.77**
A. Vikas x DARL-63	3.64*	0.79*	-0.21	-0.06
A. Vikas x DVRT-1	5.79**	-1.01**	-11.87**	9.59**
A. Vikas x Local	-1.28**	1.82**	-29.85**	4.07
A. Vikas x M.G	-5.85**	-1.34**	6.32**	8.47**
A. Vikas x S-II	19.98**	3.18**	-38.48**	-8.58**
A. Vikas x Roma	16.76**	6.68**	-35.80**	2.56
A. Vikas x S-I	5.94**	5.62**	-33.15**	7.02**
KS-227 x VLT-32	15.60**	3.12**	-32.84**	-6.74*
KS-227 x DARL-63	16.21**	-2.81**	-5.20**	-6.02*
KS-227 x DVRT-1	12.62**	-3.32**	-29.53**	-17.56**
KS-227 x Local	6.38**	-2.32**	-23.12**	-6.35*
KS-227 x M.G	13.02**	1.19**	-30.06**	-16.00**
KS-227 x S-II	38.29**	2.05**	-19.72**	0.72
KS-227 x Roma	10.54**	-9.19**	2.78**	6.30*
KS-227 x S-I	21.98**	2.64**	-8.99**	-34.56**
VLT-32 x DARL-63	19.09**	2.57**	-21.64**	-8.19**
VLT-32 x DVRT-1	20.68**	0.35**	-8.52**	-1.17
VLT-32 x Local	10.33**	0.89**	-9.33**	-0.39
VLT-32 x M.G	6.05**	4.07**	-12.91**	-26.76**
VLT-32 x S-II	24.49**	-0.62**	-9.59**	-0.78
VLT-32x Roma	14.32**	0.55**	-9.71**	-7.80**

VLT-32x S-I	3.92**	-5.13**	-1.20	3.29
DARL-63x DVRT-1	18.09**	-1.48**	-21.13**	-14.10**
DARL-63x Local	21.65**	-2.02**	-3.83**	1.84
DARL-63x M.G	20.00**	0.94**	-4.32**	-23.08**
DARL-63x S-II	43.52**	6.06**	1.67*	-18.23**
DARL-63x Roma	30.96**	1.10**	-2.53**	-10.81**
DARL-63 x S-I	18.99**	3.18**	-12.03**	-24.92**
DVRT-1 x Local	26.06**	-2.86**	9.63**	8.47**
DVRT-1 x M.G	28.33**	-0.19**	-11.23**	-20.46**
DVRT-1 x S-II	17.59**	-3.34**	2.73**	2.51
DVRT-1x Roma	12.98**	0.25*	-4.69**	-0.39
DVRT-1 x S-I	6.82**	-0.05**	-15.62**	-10.09**
Local x M.G	-19.89**	-5.11**	-3.09**	7.02**
Local x S-II	-7.25**	-3.80**	2.71**	-1.09
Local x Roma	13.43	1.20**	-5.95**	-2.29
Local x S-I	15.85**	-0.94**	-1.78*	-23.08**
M.G x S-II	28.77**	-2.21**	-15.08**	-6.35*
M.G x Roma	34.63*	-4.67**	-18.19**	4.07
M.G x S-I	17.02*	-8.61*	-5.29**	5.13
S-II x Roma	43.88**	5.59**	-5.39**	-16.00**
S-II x S-I	42.09**	1.85**	-11.89**	2.56
Roma x S-I	28.30**	-0.05**	-11.75**	-24.58**

*, ** Significant at 5 and 1 per cent levels, respectively

Table 2: Estimation of heterosis (%) over better parent for maturity and yield attributing traits in Tomato (*Solanum lycopersicum* L.)

Crosses	Fruit size (cm^2)	Flesh thickness (mm)	Number of fruits plant^{-1}	Av. fruit weight
A. Vikas x KS-227	1.36	-18.56**	12.21**	34.25**
A. Vikas x VLT-32	43.35**	-25.32**	4.67**	31.70**
A. Vikas x DARL-63	27.20**	-6.24	5.19**	26.85**
A. Vikas x DVRT-1	26.48**	-7.67*	5.89**	11.55**
A. Vikas x Local	35.29**	2.55	3.08**	23.47**
A. Vikas x M.G	33.66**	-24.21**	20.52**	26.86**
A. Vikas x S-II	12.17**	1.08	-1.96*	8.37**
A. Vikas x Roma	-0.41	20.65**	0.45	15.21**
A. Vikas x S-I	16.76**	-19.03**	5.89**	33.01**
KS-227 x VLT-32	0.02	-18.60**	-0.85	32.74**
KS-227 x DARL-63	11.75**	-11.48**	0.73	28.62**
KS-227 x DVRT-1	-21.46**	-4.96	0.67	28.68**
KS-227 x Local	-0.81	15.65**	2.68**	36.12**
KS-227 x M.G	-20.60**	12.90**	-9.53**	15.66**
KS-227 x S-II	-18.79**	26.29**	0.00	-0.45
KS-227 x Roma	50.10**	-20.97**	26.73**	22.84**
KS-227 x S-I	1.99	0.48	0.68	24.58**
VLT-32 x DARL-63	2.56*	0.86	12.62**	21.85**
VLT-32 x DVRT-1	-1.83	2.31	13.70**	14.64**
VLT-32 x Local	57.61**	-1.36	12.96**	22.30**
VLT-32 x M.G	0.69	-0.88	-0.72	17.80**
VLT-32 x S-II	-20.36**	-13.17**	1.95*	12.15**
VLT-32x Roma	-16.07**	-6.79	5.42**	10.76**
VLT-32x S-I	-9.17**	-5.02	11.68**	25.01**
DARL-63x DVRT-1	-25.50**	-10.68**	17.05**	24.90**
DARL-63x Local	-18.63**	-8.03*	14.34**	33.61**
DARL-63x M.G	-22.68**	-11.55**	-0.42	15.14**
DARL-63x S-II	-27.00**	-10.62**	1.47	3.96**
DARL-63x Roma	-17.16**	-10.22**	6.39**	-3.29**
DARL-63 x S-I	1.26	-7.10	15.32**	29.19**
DVRT-1 x Local	12.13**	-6.31	10.38**	22.43**
DVRT-1 x M.G	7.61**	-4.68	-2.20**	19.06**
DVRT-1 x S-II	23.99**	-22.13**	21.35**	34.21**
DVRT-1x Roma	-22.35**	-2.65	5.04**	13.76**
DVRT-1 x S-I	15.38**	-2.17	65.27**	6.05**
Local x M.G	34.99**	-17.73**	17.96**	36.85**
Local x S-II	20.63**	-22.04**	22.45**	17.86**
Local x Roma	-21.88**	18.23**	-0.12	-4.44**
Local x S-I	-10.69**	-0.82	14.61**	14.83**
M.G x S-II	-13.98**	34.35**	-2.20**	-2.88**
M.G x Roma	-4.94**	39.59**	-1.31	-7.22**
M.G x S-I	-11.93**	-4.77	0.95	-6.07**
S-II x Roma	-33.60**	68.11**	2.14**	-10.68**

S-II x S-I	-7.02**	-0.89	2.07**	-1.41
Roma x S-I	0.77	0.07	7.34**	-12.79**

*, ** Significant at 5 and 1 per cent levels, respectively

Table 3: Estimation of heterosis (%) over better parent for maturity and yield attributing traits in Tomato (*Solanum lycopersicum* L.)

Crosses	Fruit yield plant^{-1}	Locule number	Total Soluble Solids (ºBrix)	Vitamin C (mg/100 mg)
A. Vikas x KS-227	25.46**	-35.18**	3.54	-11.03**
A. Vikas x VLT-32	21.79**	-11.75**	-21.96**	-9.17**
A. Vikas x DARL-63	28.51**	-7.41	1.41	-19.50**
A. Vikas x DVRT-1	18.53**	-30.83**	-10.98**	14.53**
A. Vikas x Local	15.07**	-35.49**	14.75**	-36.03**
A. Vikas x M.G	49.69**	-6.85	-4.15	-3.64**
A. Vikas x S-II	15.27**	-3.15	-20.71**	-45.60**
A. Vikas x Roma	14.26**	-36.39**	0.39	-36.66**
A. Vikas x S-I	20.57**	-6.76	-2.71	-26.29**
KS-227 x VLT-32	64.53*	-8.77*	3.16	13.97**
KS-227 x DARL-63	64.80**	-11.25**	-38.12**	8.34*
KS-227 x DVRT-1	79.61**	-13.66**	-17.80**	-35.23**
KS-227 x Local	75.14**	-9.58*	-48.56**	-27.00**
KS-227 x M.G	28.99**	13.66**	-6.02*	-28.46**
KS-227 x S-II	32.60**	-6.61	-22.37**	-22.42**
KS-227 x Roma	83.14**	16.07**	0.98	-6.54**
KS-227 x S-I	80.45**	-36.88**	-7.04**	-9.75**
VLT-32 x DARL-63	80.00**	-12.37**	-1.14	-28.00**
VLT-32 x DVRT-1	78.55**	-11.14**	-7.47**	-34.00**
VLT-32 x Local	70.14**	-12.28**	-26.96**	-40.31**
VLT-32 x M.G	43.60**	-11.05**	-5.42*	-39.86**
VLT-32 x S-II	37.86**	-0.61	-4.73*	-36.85**
VLT-32x Roma	36.95**	3.51	15.25**	-25.81**
VLT-32x S-I	82.32**	1.75	-8.00**	23.53**
DARL-63x DVRT-1	84.00**	9.39*	-21.01**	-5.30**
DARL-63x Local	80.70**	3.46	-0.32	-24.65**
DARL-63x M.G	35.51**	13.28**	-6.38**	-12.73**
DARL-63x S-II	34.35**	20.14**	-10.33**	-25.77**
DARL-63x Roma	49.42**	0.71	-1.02	-25.16**
DARL-63 x S-I	87.08**	14.80**	-13.24**	-5.06**
DVRT-1 x Local	71.05**	4.79	0.26	-15.26**
DVRT-1 x M.G	39.10**	-5.12	-12.70**	-31.97**
DVRT-1 x S-II	69.15**	-3.23	-5.72*	-10.21**
DVRT-1x Roma	44.11**	-29.79**	1.49	-27.97**
DVRT-1 x S-I	163.01**	-34.25**	-43.02**	-23.03**
Local x M.G	72.81**	-10.03*	-3.43	-8.88**
Local x S-II	73.52**	-8.87*	0.80	-2.59**
Local x Roma	51.50**	-7.19	-7.27**	-43.24**
Local x S-I	78.36**	-12.16**	-5.23*	-16.53**
M.G x S-II	24.95**	-6.97	-28.66**	-37.96**
M.G x Roma	27.64**	-31.90**	-11.80**	-34.95**
M.G x S-I	38.88**	-5.73	10.77**	-24.23**
S-II x Roma	26.26**	-27.49**	-3.75	-30.63**
S-II x S-I	32.82**	-2.71	-31.77**	-27.77**
Roma x S-I	34.18**	-3.87	-41.10**	-20.61**

*, ** Significant at 5 and 1 per cent levels, respectively

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