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Heterosis in oblong fruited tomato (*Solanum lycopersicum*) hybrids for growth and yield traits

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ABSTRACT

In the present investigation, oblong fruited nine tomato lines were crossed in full diallel mating design to produce 72 F_1 hybrids. Heterobeltiosis and standard heterosis were estimated for growth, fruit yield and quality traits in F_1 hybrids. The parental lines, viz. BRML (P_3), Arka Ashish (P_4), Vybhav (P_5), IIVR-L (P_6), EC 608406 (P_7) and EC 608395 (P_8) were found most promising for exploiting heterosis. Considering all the cross combinations individually, the hybrid combinations that out fielded their parents for a maximum number of components for heterobeltiosis and standard heterosis coupled with highper se values were; IIVR-L×Arka Ashish (P_6× P_4), IIVR-L×Vybhav (P_6× P_5), EC 608406 × BRML (P_7× P_3), EC 608395 ×IIVR-L (P_8× P_6) and EC 608406 ×IIVR-L (P_7× P_6). However, hybrids those performed better for yield parameters were not heterotic significantly for quality parameters except P_7× P_3. The standard heterosis noted in outperforming hybrids P_7× P_3 (23.99% and 19.80%) and P_6× P_4 (18.97% and 14.95%) over check hybrids NUN 5024 and COTH-3 respectively. The yield per plant based on per se values were also highest in hybrids P_7× P_3 (3.91 kg) and P_6× P_4 (3.75 kg). These promising hybrids could beused for dual purpose (fresh market as well as processing), since they have improved economic traits besides good fruit quality parameters (high TSS) and oblong in shape.

Key words: Heterobeltiosis, Hybrids, Standard heterosis, Tomato

Tomato is an economically important, extremely popular and widely grown vegetable crop in India as well as in the world. Hitherto, tomato crop improvement work was mostly focused on increasing yield and disease resistant breeding, whereas the work on increasing quality and nutrients content in fruit is meagre. The nutritional importance of this crop indicates, there is a need to formulate breeding programme, and develop cultivars rich in lycopene, carotene, processing traits with high fruit quality coupled with high yield (Dar and Sharma 2011). Tomato has achieved a spectacular status of functional food because of its rich nutritional composition and widespread consumption (Singh *et al.* 2010).

Heterosis for yield reflects through the heterosis in the individual component traits, a quick and convenient way of combining desirable characters, has greater significance in the production of F_1 hybrids in tomato. Hybrid vigour results in the phenotypic superiority of an offspring over its parents with respect to traits such as growth rate, reproductive success and yield (Lippman and Zamir 2006, Herbst *et al.* 2017).

In tomato, consumer preference depends upon fruit colour, shape and size. The oblong type hybrids are preferred, which could facilitate better packing, and less liable to damage during transportation due to its thick pericarp. Even though a large number of hybrids have been released so far, most of them are of round in shape, however some of the oblong/square blocky fruited hybrids are released by the private sector but their seeds are costly. The hybrids available in the market do not have good processing qualities, leading to limited development of value added products (Pandiarana *et al.* 2015). Oblong fruited hybrids can be used for fresh market as well as for processing because of their high TSS and dry matter content. Considering, the aforesaid aspects, the present study was aimed to select the oblong fruited genotypes of diverse origin, estimating the extent of heterosis in the cross combinations for growth, high yield and quality in tomato for open field cultivation.

MATERIALS AND METHODS

The present study was carried out at the experimental field of TNAU, Coimbatore, during 2012–14. The research field is situated at 11°N latitude and 77°E longitude and at an elevation of 426.6 msl.

Experimental material: Nine superior tomato lines, viz. IIHR 709 (P_1), IIHR 2388 (P_2), BRML (P_3), Arka Ashish

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(P_4), Vybhav (P_5), IIVR-L (P_6), EC 608406 (P_7), EC 608395 (P_8) and EC 608456 (P_9) were selected based on their per se performance and genetic divergence from previously screened oblong fruited genotypes (Khapte and Jansirani 2014). In the first season, parental lines were grown to obtain their selfed seed for further hybridization programme. In the second season these nine parental lines were crossed in full diallel mating design and 72 F_{1s} were obtained.

In the third season, seeds of 9 parental lines, 72 F_1 hybrids and 2 commercial check hybrids (NUN-5024 and COTH-3) were sown and one month old seedlings were transplanted in a randomized block design with three replications spacing at 60 cm × 45 cm for evaluation trial. The prominently grown hybrids in this area were selected as checks; NUN-5024 (oblong fruit shape) and COTH-3 (flat round fruit shape). Five randomly selected competitive plants from each row in each replication were tagged for the purpose of recording the observations on different characters.

Experimental Data

Growth and yield parameters

The experimental data on plant height (cm), primary branch number, days to first flowering, flower number per truss, percent fruit set, fruit number per plant were recorded on the single plant basis. The samples of 15 arbitrarily selected fruits were taken to measure the fruit characteristics, viz. fruit length (cm), diameter (cm), fruit shape index, fruit weight (g), fruit firmness (kg/cm^2), pericarp thickness (mm), locule number per fruit and total soluble solids (%). Fruit firmness was determined by using digital fruit penetrometer (Dhatt and Singh 2004). The red ripe fruits were punctured at two places opposite to each other in radial axis with a plunger (6 mm) and the pressure required was recorded and expressed in kg/cm^2. The fruits were cut at the equatorial plane and the pericarp thickness (mm) was measured with the help of digital vernier calliper. A drop of fruit juice was placed on digital refractometer and brix value was noted in percent at room temperature. All harvested fruits of each plant were counted and weighed to determine the number of fruits per plant, fruit weight (g) and yield per plant (kg).

Fruit quality parameters

The titratable acidity as per cent of citric acid was estimated by following the method of AOAC (1975). Ascorbic acid content (mg/100 g) of tomato fruit was estimated using 2, 6-dichlorophenol indophenol method (Casanas *et al.* 2002). Lycopene and carotene content was estimated as per the method given by the Ranganna (1979). The estimation of total sugars was carried out using the protocol given by Hedge and Horreiter (1962).

Statistical analysis

The experimental data were statistically analysed using standard method of the randomized block design (Gomez and Gomez 1984). The magnitude of heterosis was estimated over better parent and check hybrids. Percent increase or decrease of F_{1s} over better parent (BP) and check hybrid (CH) value was measured as suggested by Kempthorne (1957). The statistical analysis was performed by statistical software INDOSTAT version 8.2.

RESULTS AND DISCUSSION

Analysis of variance: The analysis of variance for different traits selected for the study showed significant variances at genotypic level which proved their worthiness while selecting these genotypes. In any crop breeding programme, it is prerequisite to select parents of the best performance, so that best performing hybrids could be developed and could be achieved by studying the mean performance of parents. It is equally important to select hybrids of high performance to achieve specific objectives of any breeding programme. Dod *et al.* (1992) opined that per se performance should be given an equal importance while judging the hybrid combinations for exploitation of heterosis.

Heterosis: The estimates of heterosis were computed for all the 20 traits studied in the 72 cross combinations of tomato and expressed in percentage over better parental value (heterobeltiosis) and standard heterosis over check hybrids (NUN 5024 and COTH-3). Heterosis estimates over better parental and standard check values (Tables 1-3), reflected significant effect in desirable directions on different F_1 hybrids for the growth, yield, fruit quality and biochemical parameters. The top two significant heterotic hybrids in desirable direction have been mentioned in Table 1-3 along with their per se performance. The hybrids were selected based on both significant heterobeltiosis and standard heterosis over check hybrids with high per se values.

Heterosis for growth parameters: Plant height and primary branch numbers are important traits to measure growth and vigour of plants. Although there were so many heterotic hybrids for most of the growth parameters, but the hybrid $P_1 \times P_5$ showed significant positive heterobeltiosis, whereas the hybrid $P_7 \times P_3$, $P_1 \times P_5$ and $P_7 \times P_6$ were found to be highly heterotic over checks with high per se values for most of the growth parameters and found to be potential hybrid combinations. Among 72 hybrid combinations only hybrid $P_8 \times P_9$ was found to be heterotic over standard check hybrid COTH-3 for plant height (Table 1). The results concerning plant height, primary branch number, earliness are in agreement with Singh and Asati (2011) and Singh *et al.* (2012) and Solieman (2013), who found significant differences among the tomato hybrids for heterosis of these characters.

Heterosis for fruit parameters: The oblong fruits are preferred which facilitates better packing, transport and less liable to damage due to thick pericarp. The hybrid $P_7 \times P_3$ was most promising which reported high heterobeltiosis and standard heterosis with maximum per se value over both the check for fruit length and fruit weight. Maximum fruit length (fruit shape index >1) of the fruit is important criteria for tomato processing, and the produce to be transported to distant places (Bhutani and Kalloo 1991). The fruit

Table 1 Heterosis and mean (per se) performance of top performing F1 hybrids for growth parameters in tomato

Character	Heterobeltiosis (%)	Per se	Standard heterosis over NUN 5024 (%)	Per se	Standard heterosis over COTH-3 (%)	Per se	SE	CD (P=0.05)
Plant height (cm)	P6× P8 (30.15**) P1× P3 (25.15**)	97.62 99.42	P8× P9 (14.76**) P9× P8 (12.64**)	104.00 102.10	P8× P9 (5.16**) NS	104.00 NS	1.32	3.69
Primary branch number	P1× P8 (48.33**) P1× P5 (37.86**)	7.87 8.57	P7× P3 (34.78**) P1× P5 (27.91**)	9.03 8.57	P7× P3 (63.49**) P1× P5 (55.16**)	9.03 8.57	0.13	0.35
Days to first flowering	P3× P1 (-19.61**) P1× P5 (-17.78**)	27.33 24.67	P1× P5 (-20.43**) P8× P5 (-16.13**)	24.67 26.00	P1× P5(-19.57**) P8× P5(-15.22**)	24.67 27.00	0.72	2.02
Flower number per truss	P7 × P6 (28.03**) P5× P6 (20.33**)	7.11 7.22	P5× P6 (24.91**) P7× P6 (23.01**)	7.22 7.11	P5× P6(27.41**) P7× P6(25.47**)	7.22 7.11	0.25	0.70
Per cent fruit set (%)	P8× P2 (16.92**) P7× P2(15.67**)	78.33 77.50	P9× P3 (8.79**) P7 × P6 (4.85**)	83.81 80.78	P9× P3 (11.24**) P7× P6 (7.21**)	83.81 80.78	0.93	2.59

**Significant at P ≤ 0.01 level and *Significant at P ≤0.05 level.

Table 2 Heterosis and mean (per se) performance of top performing F1 hybrids for fruit parameters in tomato

Character	Heterobeltiosis (%)	Per se	Standard heterosis over NUN 5024 (%)	Per se	Standard heterosis over COTH-3 (%)	Per se	SE	CD (P=0.05)
Fruit length (cm)	P1× P6 (20.55**) P7× P3 (16.21**)	6.43 7.24	P7 × P3 (29.21**) P3 × P1 (21.95**)	7.24 6.83	P7 × P3 (64.80**) P9 × P3 (50.23**)	7.24 6.60	0.13	0.35
Fruit diameter (cm)	P9 × P1 (14.25**) P5 × P6 (9.41**)	4.57 4.35	P3 × P1 (16.72**) P2 × P7 (11.56**)	5.28 5.05	NS NS	NS NS	0.12	0.35
Fruit shape index	P1 × P4 (35.99**) P8 × P9 (20.12**)	1.54 1.33	P1 × P6 (24.80**) P1 × P4 (24.26**)	1.54 1.54	P1 × P6 (61.32**) P1 × P4 (60.63**)	1.54 1.54	0.04	0.13
Fruit number per plant	P6 × P4 (65.46**) P6 × P5 (37.23**)	67.84 56.24	P6 × P4 (71.89**) P6 × P5 (42.56**)	67.84 56.24	P6 × P4 (52.61**) P6 × P5 (26.57**)	67.84 56.24	0.54	1.51
Fruit weight (g)	P7 × P3 (22.92**) P9 × P3 (14.13**)	88.09 81.79	P7 × P3 (10.37**) NS	88.09 NS	P7 × P3 (20.13**) P9 × P3 (11.53**)	88.09 81.79	0.90	2.52

**Significant at P ≤0.01 level and *Significant at P ≤0.05 level.

length and diameter in tomato hybrids is also associated with their genetic makeup, and governed by the cell size and intercellular space of the flesh (Khapte *et al.* 2018). The results are in confirmation with finding of (Shende *et al.* 2012 and Pandiarana *et al.* 2015) for fruit length and (Solieman *et al.* 2013) for fruit weight in tomato hybrids. For fruit diameter the hybrid $P_3 \times P_1$ and $P_2 \times P_7$ were heterotic over check hybrid NUN 5024 and no hybrids were heterotic over check hybrid COTH-3 for fruit diameter. The hybrid $P_1 \times P_4$ reported high value of heterobeltiosis, whereas the hybrid $P_1 \times P_6$ was highly heterotic over checks for fruit shape index. The fruit number per plant and fruit weight are the major yield contributing characters, higher number fruits per plant with higher fruit weight could contribute to yield per plant. The hybrid $P_6 \times P_4$ and $P_6 \times P_5$ showed significant positive heterobeltiosis as well as standard heterosis for number of fruits per plant, however, the only hybrid $P_7 \times P_3$ was highly heterotic for fruit weight over both checks used and results are in concurrence with Sekhar *et al.* (2010) (Table 2).

Heterosis for fruit firmness and yield parameters: Hybrids $P_3 \times P_4$ and $P_7 \times P_3$ showed significant positive heterobeltiosis and standard heterosis for fruit firmness and pericarp thickness (Table 3). The hybrids $P_7 \times P_3$ and $P_6 \times P_4$ reported high heterotic values over better parents and standard check with high per se values for yield per plant and total soluble solids. Significant positive heterobeltiosis for total soluble solids has also been documented previously in tomato hybrids (Dhadde *et al.* 2009). Heterosis for locule number over check NUN 5024 were non-significant in negative direction however all hybrids recorded negative heterosis over check COTH-3. Kurian *et al.* (2001) inferred that from the quality point of view, reduction of locule number is desirable and negative estimates are valuable. In studies by previous researcher using different parental background and environments have also found significant negative heterobeltiosis for the number of locules per fruit (Ahmad *et al.* 2011, Sekhar *et al.* 2010 and Angadi *et al.* 2012). For the prime character yield per plant the hybrids $P_6 \times P_4$, $P_6 \times P_5$ and $P_7 \times P_3$ showed superior and significant heterobeltiosis and standard heterosis, whereas $P_7 \times P_3$ surpassed other hybrids and results are in corroboration with (Yadav *et al.* 2013). The high yield in hybrids $P_6 \times P_4$, $P_6 \times P_5$ and $P_7 \times P_3$ is attributed due to maximum number of primary branches, fruit number per plant and fruit weight.

Heterosis for fruit biochemical parameters: Many hybrids were heterotic over better parental values for fruit biochemical parameters (Table 3). The hybrids $P_9 \times P_3$ and

Table 3 Heterosis and mean (per se) performance of top performing F1 hybrids for fruit yield and quality parameters in tomato

Character	Heterobeltiosis (%)	Per se	Standard heterosis over NUN 5024 (%)	Per se	Standard heterosis over COTH-3 (%)	Per se	SE	CD (P=0.05)
Fruit firmness (kg/cm^2)	P6× P2 (27.87**)	6.39	P3× P4 (29.66**)	7.34	P3× P4 (53.31**)	7.34	0.26	0.73
	P3× P4 (22.39**)	7.34	P7× P4 (22.37**)	6.93	P7× P4 (44.68**)	6.93		
Pericarp thickness (mm)	P7× P8 (25.80**)	6.29	P3× P4 (33.15**)	6.64	P3× P4 (50.19**)	6.64	0.24	0.67
	P9 × P1 (24.39**)	5.42	P7× P3 (30.11**)	7.72	P7× P3 (46.77**)	7.72		
Locule number per fruit	P5× P1 (-33.33**)	2.00	NS	NS	P5× P1 (-53.85**)	2.00	0.26	0.73
	P9× P5 (-33.33**)	2.00	NS	NS	P6× P1 (-53.85**)	2.00		
Yield per plant (kg)	P6× P4 (83.70**)	3.75	P7× P3 (23.99**)	3.91	P7× P3 (19.80**)	3.91	0.04	0.11
	P6× P5 (58.43**)	3.41	P6× P4 (18.97**)	3.75	P6× P4 (14.95**)	3.75		
Total soluble solids (%)	P4× P5 (25.93**)	6.30	P7× P6 (33.21**)	7.37	P7× P6 (24.44**)	7.37	0.08	0.21
	P1× P4 (25.40**)	6.27	P7× P3 (17.00**)	6.47	P7× P3 (9.29**)	6.47		
Acidity (%)	P9× P5 (38.10**)	0.58	P7× P1 (20.00**)	0.66	P7× P1 (53.49**)	0.66	0.01	0.02
	P9× P3 (32.14**)	0.62	P7× P8 (18.18**)	0.65	P7× P8 (51.16**)	0.65		
Ascorbic acid (mg/100g)	P6 × P5 (32.13**)	30.39	P9 × P3 (23.63**)	31.29	P9 × P3 (29.40**)	31.29	0.36	1.01
	P3 × P5 (30.38**)	27.38	P7 × P3 (21.31**)	30.70	P7 × P3 (26.98**)	30.70		
Lycopene (mg/100g)	P4× P3 (38.79**)	3.67	P8× P3 (67.33**)	4.75	P8× P3 (120.78**)	4.75	0.04	0.12
	P7× P3 (37.33**)	4.12	P5× P6 (62.51**)	4.61	P5× P6 (114.42**)	4.61		
Carotene (mg/100g)	P9× P5 (73.33**)	1.99	P9× P5 (27.78**)	1.99	NS	NS	0.02	0.07
	P6× P5 (63.48**)	1.88	P7× P3 (26.28**)	1.97	NS	NS		
Total sugars (mg/100g)	P2× P7 (20.83**)	2.42	P1 × P8 (23.49**)	1.78	P1 × P8 (4.70*) NS	1.78	0.03	0.09
	P1× P8 (19.40**)	1.78	P3 × P8 (22.35**)	2.50		NS		

**Significant at P ≤0.01 level and *Significant at P ≤0.05 level.

$P_7 \times P_3$ were heterotic over standard check for ascorbic acid content and $P_7 \times P_3$ were also heterotic over check hybrid NUN 5024 for carotene. The antioxidant lycopene comprises 90–95% of the total pigmentation in tomato fruit. The hybrids $P_8 \times P_3$ and $P_5 \times P_6$ were heterotic over standard check for lycopene content in fruit. None of the hybrid was heterotic over check COTH-3 for carotene in the fruit. Hybrids $P_7 \times P_3$, $P_9 \times P_3$, $P_8 \times P_3$ and $P_9 \times P_5$ were best performing for quality traits. These findings are in agreement with Mukesh *et al.* (2003) for ascorbic acid, Kumar *et al.* (2006) for acidity and Fei *et al.* (1998); Pandirana *et al.* (2015) for lycopene in tomato hybrids.

The present study revealed significant amount of heterosis along with per se values in oblong fruited tomato hybrids. The parental lines P_3, P_4, P_5, P_6, P_7 and P_8 were found to be most promising for exploiting heterosis in oblong fruited tomato for growth, yield and quality parameters. However, the hybrids which performed better for yield parameters were not heterotic considerably for quality parameters except $P_7 \times P_3$. Among the cross combinations, the promising F_1 hybrid combinations that out fielded their parents and check hybrids for maximum number of components were $P_6 \times P_4$, $P_6 \times P_5$, $P_7 \times P_3$, $P_9 \times P_3$, $P_8 \times P_6$ and $P_7 \times P_6$. The selective hybrids particularly $P_6 \times P_4$, $P_7 \times P_3$ and $P_9 \times P_3$ could be used for dual purpose (fresh market as well as processing), since they hold improved economic traits with oblong fruit shape and good fruit quality traits. Further, desirable pure lines could be obtained from the segregating generation of these potential hybrids.

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