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HYBRID DEVELOPMENT FOR RESISTANCE TO LATE BLIGHT AND ROOT KNOT NEMATODES IN TOMATO (*Solanum lycopersicum* L.)

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SUMMARY

Fifty-six accessions of tomato (10 lines, 4 tester, 40 F_1 hybrids, 1 standard check and 1 susceptible check) were evaluated for 10 attributes to ascertain the extent of standard heterosis; identify a few promising cross-combinations resistant to late blight and root knot nematode along with appropriate heterosis. The extent of of heterosis were reported from 4.55 to 47.17% for total fruit yield, -24.14 to 33.84% for pericarp thickness, 0.80 to 28.57% for dry matter, -368.75 to 29.58% for lycopene; over standard the check. Only one hybrid combination LBR-15 × EC-119197 (3.31%) exhibited standard heterosis for TSS. Out of 40 hybrids, 4 namely, LBR-19 × 8-2-1-2-5, LBR-12 × EC-119197, LBR-13 x 1-6-1-4 and LBR-6 × 1-6-1-4 were observed with high disease resistance to late blight and root knot nematodes vis-à-vis appropriate heterosis for desirable traits; particularly fruit yield, fruit weight, pericarp thickness, TSS and dry matter.

Key words: Tomato, heterosis, resistance, late blight, root knot nematodes

Key findings: The hybrids LBR-19 × 8-2-1-2-5, LBR-12 × EC-119197 and LBR-6 × 1-6-1-4 can be used for resistance to late blight and root knot nematodes with higher potential of desirable horticultural traits.

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INTRODUCTION

Cultivated tomato (*Solanum lycopersicum* L.) is one of the most important and a very popular Solanaceous vegetable crop in the world because of its wide adaptability, high yield potential and suitability for variety of uses in fresh as well as processed food industries (He *et al*., 2003; Solieman *et al*., 2013; Nwosu *et al*., 2014; Meena and Bahadur, 2015). As a cash crop, it has great demand in the international market (Hannan *et al*., 2007). It is prone to attack by several diseases that limit its successful cultivation. The disease, late blight, in the main season (November-April), particularly in northern plains of India causes grave problem; together with root knot nematodes infestation production is further limited. It has been assuming epidemic proportions frequently causing economic distress to the farmers. Hybrids in India are quite popular among farmer because of high yield, early and uniform maturity, high net return etc., despite relatively costly seeds. Heterosis breeding in tomato for biotic and abiotic resistance has been remained of pertinence and many breeding programs are inclined to this particular aspect. Heterosis in tomato is manifested in the form of the greater vigor, faster growth and development, earliness in maturity, increased productivity, and higher levels of resistance to biotic and abiotic stresses (Yordanov, 1983). Heterosis is defined as superiority of the hybrid over their parents in vegetative growth, adaptiveness and productivity (Shull, 1908). Heterotic plants are more vital, vigorous, well acclimatized than their parents, and heterosis in tomato reported by many investigators (Bhatt *et al*., 2001; Bai and Lindout, 2007; Garg *et al*., 2013; Solieman *et al*., 2013; Chauhan *et al*., 2014). It is important tool to enhance yield from 30 to 400% (Solieman *et al*., 2013) and exploitation of dominant monogenic resistance could be achieved in form of hybrids. A strong late blight resistance gene, *Ph-3*, which is a partially dominant (Chunwongse *et al*., 2002) and Mi, mongenically dominant gene, controlling resistance to root knot nematodes (Cap *et al*., 1991) has been exploited in form of F_1 hybrids.

Generating information about the relationships between desirable attributes along with inbuilt disease resistance could be better option to produce crop without application of harsh chemicals and could maximize net returns to famers, equally. The line × tester analyses have been commonly used for the analysis of combining ability with heterosis. The approach of line × tester analyses was proposed by Kempthorne (1957) based on estimates of combining ability variance and effects that helps in estimation of heterosis. This design has advantages compared to diallel and partial diallel crosses. It clearly indicates to the breeder about the choice of parents to develop hybrids or advance generation selection programs to realize promising improved genotypes in homozygous condition. Therefore, the main objective of this investigation was to identify F_1 hybrids having desirable traits along with inbuilt resistance to late blight and root knot nematodes.

MATERIALS AND METHODS

This study was carried out during the season 2012-13 and 2013-14 at Department of Vegetable Science, Punjab Agricultural University, Ludhiana, Punjab, India. The experimental material for this study consisted of ten late blight resistant lines namely, LBR-6, LBR-7, LBR-9, LBR-10, LBR-11, LBR-12, LBR-13, LBR-15, LBR-19 and LBR-21 (procured from AVRDC, Taiwan); 4 root knot nematodes resistant testers namely, 8-2-1-2-5; 1-6-1-4; PNR-7 (developed and widely used by PAU, Ludhiana in breeding programs) and EC-119197 (procured from NBPGR, New Delhi). These parents were crossed in a line × tester fashion and the resultant 40 F_1 hybrids along with their parents and one late blight and nematode susceptible check (Punjab Upma) and one standard check (TH-1) were evaluated for yield, its component characters and resistance to late blight and root knot nematode. The experiment was laid out in a randomized block design with 3 replications.

Observations recorded

The observation were recorded on 5 randomly selected plants per replication for each accessions on 10 quantitative and qualitative characters viz., (i) average fruit weight (g), (ii) total fruit yield (kg/plant), (iii) number of locules per fruit, (iv) pericarp thickness (mm), (v) Polar/Equatorial (P/E) ratio, (vi) dry matter (%), (vii) total soluble solids (^{o}Brix; by using a hand refractometer, Model: ATAGO, Tokyo, Japan), (viii) lycopene (mg/100 g of fresh weight; the estimation of lycopene was done as per the procedure given by Ranganna, 1976), (ix) titratable acidity (mg/100 ml of juice), (x) carotenoides (mg/100 g fresh weight; done as per procedure given by Sadasivam, 1987).

Statistical analysis

The combining ability analysis for different characters was done as per the model suggested by Kempthorne (1957). The analysis of variance was calculated by statistical software, SPAR1.

Estimation of heterosis

The magnitude of heterosis was estimated in relation to better parent as well as standard check values. Both were calculated as percentage increase or decrease of F_1s over the better parent (BP) and standard check (SC) values.

$$\text{Percent heterosis (better parent)} = \frac{(F_1\text{-BP})}{\text{BP}} \times 100$$

Where BP = performance of better parent.

$$\text{Percent heterosis (over check)} = \frac{(F_1\text{-Check})}{\text{Check}} \times 100$$

Where Check = performance of the standard check.

Screening for late blight

Screening of all the 56 genotypes under natural and artificially conditions was performed and data was recorded using the 0-5 scale described by Thind *et al*. (1989). Data was recorded in field using scale to derive percentage disease index (PDI) under natural screening.

Artificial screening was performed through detached-leaf assay and whole-plant under epiphytotic conditions challenged by *P. infestans* inoculums and readings were taken on scale to derive PDI.

$$\text{PDI} = \frac{\sum[\text{number og plants with rating} \times \text{rating score}]}{\text{maximum rating score} \times \text{number of sample observed}} \times 100$$

Screening for root knot nematodes

Complete experimental materials were screened naturally, under field conditions and artificially, by challenging root knot nematodes inoculums (350 juveniles per 250 cc soil sample). The 7 to 8-week old seedlings were uprooted and graded on 0-5 scale (based on the number of galls) given by Taylor and Sasser (1978) under both the conditions.

RESULTS

Analysis of variance

The pooled analysis of variance (Table 1) revealed mean sum of squares due to replications were non-significant for all the characters except average fruit weight, total fruit yield and TSS whereas parents and hybrids were found to be significant for all the characters; which indicated the presence of considerable genotypic variation among parents and hybrids. Lines and testers were varied significantly for all the studied characters. Significant difference due to lines vs. testers was observed for all the characters except pericarp thickness which indicates differential response among lines and testers. Similarly, parents vs. hybrids were significant for all characters except TSS and titratable acidity.

Mean performance of parents and F_1 hybrids in relation to their heterosis

The results pertaining to mean performance of parents and checks are presented in Table 2 while of hybrids in Table 3. Heterosis (%) of top performing hybrids over better parent and standard check, TH-1, exhibited by F_1 hybrids for various characters are presented in Table 4.

The average fruit weight of F_1 hybrids varied from 52.00 to 130.00 g (mean 83.03 g) (Table 3) whereas that of parents from 55.00 to 145.33 g (mean 103.02 g) (Table 2). Among parental lines, the maximum average fruit was recorded by LBR-3 and minimum by tester 1-6-1-4 whereas cross combination LBR-9 × 8-2-1-2-5 and LBR-15 × 8-2-1-2-5 was recorded for maximum and minimum average fruit weight respectively. Of 40 hybrids, 4 and 23 showed significant positive heterosis over respective better parent and susceptible check respectively. Heterosis magnitude varied from -51.88 to 60.85% over better parent whereas -30.67 to 73.33% over the standard check. The promising hybrid combination LBR-11 × 8-2-1-2-5 (60.85%) exhibited maximum heterosis over respective better parent followed by LBR-11 × EC-119197 (21.49%), LBR-10 × EC-119197 (7.49%) and LBR-21 × 8-2-1-2-5 (7.10%) with mean fruit weight of 113.67 g, 81.00 g, 95.67 g and 110.67 g respectively. Cross combination, LBR-9 × 8-2-1-2-5 (73.33%) showed maximum significant heterosis over check, TH-1, followed by LBR-7 × 8-2-1-2-5 (56.89%), LBR-11 × 8-2-1-2-5 (51.56%), LBR-21 × 8-2-1-2-5 (47.56%) and LBR-9 × EC-119197 (44.44%) with mean fruit weight of 130.00 g, 117.67 g, 113.67 g, 110.67 g and 108.33 g respectively. Out of 40 hybrids, 28 revealed a considerable positive heterosis over the better parent and standard check both. Range of heterosis over better parent was found from 4.98 (LBR-6 × 8-2-1-2-5) to 55.25% (LBR-12 × EC-119197) and from 4.55 (LBR-15 × PNR-7) to 47.17 % (LBR-19 × 8-2-1-2-5) for standard check.

Table 1. Analysis of variance for experimental design for different characters.

Source of variation	d.f.	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P/E ratio	Dry matter (%)	Total soluble solids (°Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100 ml of juice)	Carotenoides (mg/100g fresh weight)
Lines	9	729.82**	0.74**	1.40**	4.95**	0.03**	1.00**	1.48**	3.41**	0.08**	3.15**
Testers	3	3,704.54**	0.12*	1.34**	6.87**	0.02**	3.66**	1.04**	46.01**	0.04**	39.10**
Lines×testers	27	632.09**	0.79**	1.00**	2.75**	0.02**	2.64**	1.12**	2.31**	0.03**	3.51**
Error	106	43.07	0.03	0.04	0.03	0.00	0.11	0.08	0.05	0.00	0.05
Components of genetic variance											
σ^2GCA		75.48	-0.02	0.02	0.15	0.00	-0.01	0.01	1.07	0.00	0.84
σ^2SCA		196.34	0.25	0.32	0.91	0.01	0.84	0.35	0.75	0.01	1.15
σ^2SCA/ σ^2GCA		2.60	-14.74	18.37	6.03	30.91	-57.14	51.82	0.71	5.31	1.38

Table 2. Mean performance of parents and checks for different characters.

Parents	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P / E ratio	Dry matter (%)	Total soluble solids (°Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100ml of juice)	Carotenoides (mg/100g fresh weight)
Lines										
LBR-6	123.67	0.81	3.33	3.94	0.74	5.61	3.67	1.93	0.87	3.01
LBR-7	127.67	2.43	3.00	4.48	0.74	5.28	3.27	2.20	0.69	1.85
LBR-9	137.00	0.89	4.20	4.24	0.79	5.26	4.40	1.33	0.64	0.88
LBR-10	89.00	0.75	3.93	4.31	0.80	4.85	4.00	3.76	0.92	3.57
LBR-11	63.00	0.66	2.47	5.43	0.89	6.25	2.20	3.49	0.76	1.98
LBR-12	142.00	1.14	4.13	4.13	0.69	4.74	4.20	1.84	0.98	1.31
LBR-13	145.33	0.90	4.53	4.04	0.67	4.94	2.53	2.26	0.65	2.36
LBR-15	105.00	1.60	3.33	4.35	0.98	5.16	3.40	1.52	0.73	4.49
LBR-19	127.33	0.77	3.20	6.16	0.84	4.79	3.07	2.70	0.67	2.72
LBR-21	103.33	1.11	3.87	4.89	0.85	5.85	3.80	1.85	0.59	1.46

(continued)

Parents	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P / E ratio	Dry matter (%)	Total soluble solids (^{o}Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100ml of juice)	Carotenoides (mg/100g fresh weight)
Testers										
PNR-7	86.67	1.31	4.07	3.65	0.81	5.61	4.53	6.58	0.66	3.19
8-2-1-2-5	70.67	2.10	2.00	4.98	1.56	5.27	4.13	3.80	0.74	5.04
EC-119197	66.67	1.32	4.50	3.83	1.17	4.05	4.33	2.02	0.44	9.65
1-6-1-4	55.00	1.41	3.00	5.91	0.76	4.91	3.53	2.51	0.66	1.46
Check										
Punjab Upma	49.33	0.89	3.13	5.00	0.77	4.72	3.53	4.38	0.73	1.24
TH-1	75.00	1.68	2.60	4.88	0.87	4.58	4.96	3.02	0.68	1.48
Grand Mean	97.92	1.26	3.46	4.64	0.87	5.12	3.72	2.82	0.71	2.56
CD at 5%	10.5	0.29	0.32	0.28	0.03	0.53	0.45	0.36	0.06	0.36
CD at 1%	13.8	0.38	0.42	0.36	0.04	0.70	0.59	0.47	0.08	0.47

Table 3. Mean performance of hybrids for different characters.

Hybrids	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P / E ratio	Dry matter (%)	Total soluble solids (^{o}Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100 ml of juice)	Carotenoides (mg/100g fresh weight)
LBR-6 x PNR-7	92.33	1.63	3.27	4.28	0.91	5.96	3.47	3.49	0.77	1.98
LBR-6 x 8-2-1-2-5	79.00	2.21	2.93	5.08	0.79	4.99	3.53	3.96	0.73	2.80
LBR-6 x EC-119197	88.33	1.80	3.53	4.25	0.90	6.05	3.73	1.68	0.64	4.62
LBR-6 x 1-6-1-4	80.67	1.96	3.33	6.08	0.84	5.71	3.73	3.02	0.77	**1.50**
LBR-7 x PNR-7	85.67	2.15	3.47	3.89	0.81	5.92	3.27	4.09	0.83	2.15
LBR-7 x 8-2-1-2-5	117.67	1.92	2.80	4.35	0.89	6.10	2.80	4.90	0.58	3.52
LBR-7 x EC-119197	71.00	0.98	4.07	3.55	0.67	5.66	3.93	1.39	0.61	5.90
LBR-7 x 1-6-1-4	72.33	1.90	3.93	5.68	0.81	5.75	3.53	2.07	0.61	1.36
LBR-9 x PNR-7	66.67	1.85	3.73	4.53	0.72	3.69	3.73	4.96	0.58	2.21
LBR-9 x 8-2-1-2-5	130.00	2.29	3.87	5.45	0.80	5.33	4.47	4.07	0.53	2.06
LBR-9 x EC-119197	108.33	2.51	5.20	3.28	0.85	6.51	5.13	1.86	0.55	4.52
LBR-9 x 1-6-1-4	82.33	1.35	5.00	4.35	0.65	6.27	4.93	2.15	0.64	5.01
LBR-10 x PNR-7	82.67	2.08	4.20	4.44	0.63	6.73	4.47	2.92	0.82	1.92
LBR-10 x 8-2-1-2-5	61.67	2.49	3.47	6.65	0.65	6.40	3.40	2.88	0.84	4.85
LBR-10 x EC-119197	95.67	2.07	3.00	6.01	0.83	4.66	3.20	1.49	0.78	4.03

(continued)

Hybrids	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P / E ratio	Dry matter (%)	Total soluble solids (°Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100 ml of juice)	Carotenoides (mg/100g fresh weight)
LBR-10 x 1-6-1-4	76.67	1.66	3.40	7.10	0.86	3.10	3.53	2.35	0.89	1.12
LBR-11 x PNR-7	67.67	1.13	3.20	5.80	0.72	5.13	3.27	3.15	0.70	2.43
LBR-11 x 8-2-1-2-5	113.67	1.47	3.33	4.06	0.76	5.97	3.73	3.83	0.63	1.85
LBR-11 x EC-119197	81.00	1.69	3.47	2.75	0.68	6.13	4.00	2.12	0.62	4.16
LBR-11 x 1-6-1-4	62.33	1.62	4.20	6.25	0.84	5.38	4.27	3.15	0.68	1.06
LBR-12 x PNR-7	71.67	2.34	3.87	5.73	0.85	6.05	3.47	5.90	0.71	1.56
LBR-12 x 8-2-1-2-5	88.33	1.89	3.60	5.15	0.68	5.97	3.80	4.26	0.81	3.24
LBR-12 x EC-119197	89.00	2.95	4.07	5.05	0.91	5.89	4.47	2.46	0.65	3.48
LBR-12 x 1-6-1-4	68.33	1.85	4.20	6.02	0.89	4.96	4.53	2.96	0.63	2.51
LBR-13 x PNR-7	74.33	1.60	4.13	4.46	0.68	6.13	4.33	4.78	0.78	3.71
LBR-13 x 8-2-1-2-5	85.00	2.04	3.93	5.28	0.77	4.92	3.60	4.64	0.91	2.41
LBR-13 x EC-119197	103.33	1.95	3.27	6.90	0.90	6.77	3.07	2.28	0.93	5.78
LBR-13 x 1-6-1-4	83.33	2.06	3.13	5.11	0.87	5.07	3.00	4.09	0.72	3.23
LBR-15 x PNR-7	62.33	1.76	3.40	6.32	0.83	5.46	3.60	4.95	0.86	2.91
LBR-15 x 8-2-1-2-5	62.67	1.90	3.00	5.30	0.86	4.90	3.07	3.59	0.53	4.09
LBR-15 x EC-119197	87.67	1.29	4.87	4.82	0.86	5.30	5.13	2.19	0.91	6.66
LBR-15 x 1-6-1-4	52.00	2.73	2.33	6.37	0.96	3.90	2.4	1.61	0.56	2.02
LBR-19 x PNR-7	75.00	2.03	4.47	4.74	0.85	6.93	4.53	6.39	0.85	3.13
LBR-19 x 8-2-1-2-5	81.67	3.18	3.00	4.70	0.83	6.05	3.00	4.42	0.73	1.50
LBR-19 x EC-119197	106.67	2.60	3.07	4.11	0.70	5.12	3.27	0.96	0.81	3.30
LBR-19 x 1-6-1-4	69.00	1.61	2.87	6.99	0.84	4.44	3.13	3.76	0.65	2.88
LBR-21 x PNR-7	74.67	2.44	3.53	4.26	0.82	6.71	4.00	5.72	0.68	3.02
LBR-21 x 8-2-1-2-5	110.67	1.05	3.53	4.30	0.78	5.37	3.80	1.25	0.68	1.01
LBR-21 x EC-119197	90.00	2.10	3.87	4.87	0.82	3.81	3.53	1.58	0.69	5.11
LBR-21 x 1-6-1-4	70.00	2.66	3.73	2.92	0.83	5.80	3.47	1.85	0.64	2.03
CD at 5%	10.50	0.29	0.32	0.28	0.03	0.53	0.45	0.36	0.06	0.36
CD at 1%	13.80	0.38	0.42	0.36	0.04	0.70	0.59	0.47	0.08	0.47

Table 4. Top performing hybrids for various characters over better parent and check.

Average fruit weight (g)		Total fruit yield (kg/plant)		Number of locules per fruit		Pericarp thickness (mm)		P/E Ratio	
Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over	
Better parent	TH-1	Better parent	TH-1	Better parent	TH-1	Better parent	TH-1	Better parent	TH-1
LBR-11 x 8-2-1-2-5 (60.85**)	LBR-9 x 8-2-1-2-5 (73.33**)	LBR-12 x EC-119197 (55.25**)	LBR-19 x 8-2-1-2-5 (47.17**)	LBR-10 x EC-119197 (-50.00**)	LBR-15 x 1-6-1-4 (-11.59**)	LBR-13 x EC-119197 (70.79**)	LBR-10 x 1-6-1-4 (45.49**)	LBR-12 x 1-6-1-4 (14.61**)	LBR-6 x PNR-7 (4.40**)
LBR-11 x EC-119197 (21.49**)	LBR-7 x 8-2-1-2-5 (56.89**)	LBR-19 x EC-119197 (49.23**)	LBR-12 x EC-119197 (43.05**)	LBR-13 x 1-6-1-4 (-44.73**)		LBR-15 x PNR-7 (45.29**)	LBR-19 x 1-6-1-4 (43.24**)	LBR-13 x 1-6-1-4 (12.64**)	LBR-12 x EC-119197 (4.40**)
LBR-10 x EC-119197 (7.49**)	LBR-11 x 8-2-1-2-5 (51.56**)	LBR-9 x EC-119197 (47.41**)	LBR-15 x 1-6-1-4 (38.46**)	LBR-13 x EC-119197 (-38.53**)		LBR-10 x EC-119197 (39.44**)	LBR-13 x EC-119197 (41.39**)	LBR-6 x PNR-7 (10.99**)	LBR-6 x EC-119197 (3.33**)
LBR-21 x 8-2-1-2-5 (7.10**)	LBR-21 x 8-2-1-2-5 (47.56**)	LBR-21 x 1-6-1-4 (46.99**)	LBR-21 x 1-6-1-4 (36.84**)	LBR-11 x EC-119197 (-29.68**)		LBR-12 x PNR-7 (38.74**)	LBR-10 x 8-2-1-2-5 (36.27**)	LBR-6 x 1-6-1-4 (9.52**)	LBR-13 x EC-119197 (3.33**)
	LBR-9 x EC-119197 (44.44**)	LBR-21 x PNR-7 (46.31**)	LBR-19 x EC-119197 (35.38**)	LBR-6 x EC-119197 (-27.48**)		LBR-10 x 8-2-1-2-5 (33.53**)	LBR-15 x 1-6-1-4 (30.53**)	LBR-10 x 1-6-1-4 (6.98**)	LBR-7 x 8-2-1-2-5 (2.25**)
	LBR-19 x EC-119197 (42.23**)	LBR-12 x PNR-7 (44.02**)	LBR-9 x EC-119197 (33.07**)	LBR-11 x PNR-7 (-27.19**)		LBR-12 x EC-119197 (22.28**)	LBR-15 x PNR-7 (29.51**)	LBR-7 x 1-6-1-4 (6.17**)	LBR-12 x 1-6-1-4 (2.25**)
	LBR-13 x EC-119197 (37.77**)	LBR-15 x 1-6-1-4 (41.39**)	LBR-10 x 8-2-1-2-5 (32.53**)	LBR-6 x PNR-7 (-24.46**)		LBR-10 x 1-6-1-4 (20.14**)	LBR-11 x 1-6-1-4 (28.07**)	LBR-12 x PNR-7 (4.71**)	
	LBR-10 x EC-119197 (27.56**)	LBR-21 x EC-119197 (37.14**)	LBR-21 x PNR-7 (31.15**)	LBR-7 x PNR-7 (-17.29**)		LBR-15 x EC-119197 (10.80**)	LBR-6 x 1-6-1-4 (24.59 **)	LBR-19 x PNR-7 (1.18*)	
	LBR-6 x PNR-7 (23.11**)	LBR-10 x PNR-7 (37.02**)	LBR-9 x 8-2-1-2-5 (26.64**)	LBR-13 x 8-2-1-2-5 (-15.27**)		LBR-13 x PNR-7 (10.40**)	LBR-12 x 1-6-1-4 (23.36**)		
	LBR-12 x 8-2-1-2-5 (17.77**)	LBR-10 x EC-119197 (36.23**)	LBR-6 x 8-2-1-2-5 (23.98**)	LBR-12 x 8-2-1-2-5 (-14.72**)		LBR-9 x 8-2-1-2-5 (9.44**)	LBR-10 x EC-119197 (23.16**)		

(continued)

Dry matter (%)		Total soluble solids (°Brix)		Lycopene content (mg/100g fresh weight)		Titratable acidity (mg/100ml fruit juice)		Carotenoides (mg/100g fresh weight)	
Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over		Percentage increase / decrease over	
Better parent	TH-1	Better parent	TH-1	Better parent	TH-1	Better parent	TH-1	Better parent	TH-1
LBR-13 x EC-119197 (27.03**)	LBR-19 x PNR-7 (28.57**)	LBR-11 x 1-6-1-4 (17.33**)	LBR-9 x EC-119197 (3.31**)	LBR-13 x 1-6-1-4 (38.63**)	LBR-19 x PNR-7 (29.58**)	LBR-13 x EC-119197 (43.08**)	LBR-13 x EC-119197 (38.81**)	LBR-9 x 1-6-1-4 (70.86**)	LBR-15 x EC-119197 (58.56**)
LBR-12 x EC-119197 (19.52**)	LBR-13 x EC-119197 (26.88**)	LBR-15 x EC-119197 (15.59**)	LBR-15 x EC-119197 (3.31**)	LBR-19 x 1-6-1-4 (28.19**)	LBR-12 x PNR-7 (23.73**)	LBR-19 x PNR-7 (26.87**)	LBR-13 x 8-2-1-2-5 (35.82**)	LBR-12 x 1-6-1-4 (41.83**)	LBR-7 x EC-119197 (53.22**)
LBR-9 x EC-119197 (19.20**)	LBR-10 x PNR-7 (26.45**)	LBR-9 x EC-119197 (14.23**)		LBR-7 x 8-2-1-2-5 (22.45**)	LBR-21 x PNR-7 (21.33**)	LBR-15 x EC-119197 (24.66**)	LBR-15 x EC-119197 (35.82**)	LBR-21 x 1-6-1-4 (28.08**)	LBR-13 x EC-119197 (52.25**)
LBR-19 x PNR-7 (19.05**)	LBR-21 x PNR-7 (26.23**)	LBR-9 x 1-6-1-4 (10.75**)		LBR-13 x 8-2-1-2-5 (18.10**)	LBR-9 x PNR-7 (9.27**)	LBR-13 x 8-2-1-2-5 (22.97**)	LBR-10 x 1-6-1-4 (32.84**)	LBR-19 x 1-6-1-4 (5.56**)	LBR-21 x EC-119197 (45.99**)
LBR-10 x 8-2-1-2-5 (17.66**)	LBR-9 x EC-119197 (23.96**)	LBR-12 x 1-6-1-4 (7.28**)		LBR-12 x EC-119197 (17.89**)	LBR-15 x PNR-7 (9.09**)	LBR-19 x EC-119197 (20.90**)	LBR-15 x PNR-7 (28.36**)		LBR-9 x 1-6-1-4 (44.91**)
LBR-9 x 1-6-1-4 (16.11**)	LBR-10 x 8-2-1-2-5 (22.66**)	LBR-12 x EC-119197 (3.13**)		LBR-7 x 8-2-1-2-5 (22.45**)	LBR-7 x 8-2-1-2-5 (8.16**)	LBR-7 x PNR-7 (20.29**)	LBR-19 x PNR-7 (26.87**)		LBR-10 x 8-2-1-2-5 (43.09**)
LBR-10 x PNR-7 (16.64**)	LBR-13 x PNR-7 (19.25**)	LBR-9 x 8-2-1-2-5 (1.57**)		LBR-12 x 1-6-1-4 (15.20**)	LBR-13 x PNR-7 (5.86**)	LBR-15 x PNR-7 (17.81**)	LBR-10 x 8-2-1-2-5 (25.37**)		LBR-6 x EC-119197 (40.26**)
LBR-7 x 8-2-1-2-5 (13.44**)	LBR-7 x 8-2-1-2-5 (18.85**)			LBR-19 x 8-2-1-2-5 (14.03**)	LBR-13 x 8-2-1-2-5 (3.02**)	LBR-21 x EC-119197 (16.95**)	LBR-7 x PNR-7 (23.88**)		LBR-11 x EC-119197 (33.65**)
LBR-19 x 8-2-1-2-5 (12.89**)				LBR-12 x 8-2-1-2-5 (10.80**)		LBR-13 x 1-6-1-4 (9.09**)	LBR-10 x PNR-7 (22.39**)		LBR-15 x 8-2-1-2-5 (32.52**)
LBR-21 x PNR-7 (12.82**)				LBR-15 x EC-119197 (7.76**)					LBR-10 x EC-119197 (31.51**)

With maximum heterosis over better parent, the cross combination, LBR-12 × EC-119197 showed maximum *per se* performance (2.95 kg/plant) followed by LBR-19 × EC-119197 (2.60 kg/plant) and LBR-9 × EC-119197 (2.51 kg/plant). The hybrids, LBR-19 × 8-2-1-2-5 (47.17%), LBR-12 × EC-119197 (43.05%) and LBR-15 × 1-6-1-4 (38.46%) exhibited heterosis over standard check in descending order with mean performance of 3.18 kg/plant, 2.95 kg/plant and 2.73 kg/plant subsequently.

Average number of locules of hybrids varied from 2.33 (LBR-15 × 1-6-1-4) to 5.20 (LBR-9 × EC-119197) with mean value of 3.63. 20 out of 40 hybrids showed heterosis ranged from -6.72 (LBR-12 × PNR-7) to -50.00% (LBR-10 × EC-119197) over better parent only and only LBR-7 × 8-2-1-2-5 (2.80) recorded minimum number of locules with required significant negative heterosis over the standard check. The pericarp thickness of parental lines and F_1 hybrids varied from 3.65 to 6.16 mm (Table 2) and 2.75 to 7.10 mm (Table 3) with an average of 4.60 and 2.75 mm respectively. Among the crosses, heterosis was recorded from -50.59 to 70.79% and from -43.65 to 45.49% over the better parent and check respectively. Out of 40 hybrids 24 and 20 exhibited required heterosis over better parent and standard check respectively. The cross combination, LBR-13 × EC-119197 (70.79% and 6.90 mm) exhibited maximum heterosis over better parent followed by LBR-15 × PNR-7 (45.29% and 6.32 mm), LBR-10 × EC-119197 (39.44% and 6.01 mm), LBR-12 × PNR-7 (38.74% and 5.73 mm) and LBR-10 × 8-2-1-2-5 (33.53% and 6.65 mm). The combination LBR-10 × 1-6-1-4 (45.49% and 7.10 mm) exhibited maximum heterosis over standard check followed by LBR-19 × 1-6-1-4 (43.24% and 6.99 mm) and LBR-13 × EC-119197 (41.39% and 6.90 mm). Polar/Equatorial ratio of parents varied from 0.67 (LBR-13) to 1.56 (8-2-1-2-5) with mean of 0.88 (Table 2). Of hybrids it did vary from 0.63 (LBR-15 × 1-6-1-4) to 0.96 (LBR-10 × PNR-7) with mean of 0.80 (Table 3). Out of 40 hybrids, 8 and 7 cross combinations were observed required heterosis with range of -140.00 to 14.61% and -38.10 to 9.38% over the better parent and check subsequently. Hybrid LBR-12 × 1-6-1-4 (14.61%) showed maximum positive significant heterosis over better parent followed by LBR-13 × 1-6-1-4 (12.64%) and LBR-6 × PNR-7 (10.99%). The cross combination LBR-15 × 1-6-1-4 (9.38%) showed maximum heterosis followed by LBR-12 × EC-119197 (4.40%), LBR-6 × PNR-7 (4.40%), LBR-6 × EC-119197 (3.33%) and LBR-13 × EC-119197 (3.33%) (Table 4).

The dry matter of parents and hybrids varied from 4.05 to 6.25% (Table 2) and 3.10 to 6.93% (Table 3) with average of 5.18% and 5.52% respectively. Heterosis varied 2.56 (LBR-13 × 1-6-1-4) to 27.03% (LBR-13 × EC-119197) and 0.80 (LBR-6 × 8-2-1-2-5) to 28.57% (LBR-19 × PNR-7) over better parent and standard check respectively. The cross combination LBR-13 × EC-119197 exhibited maximum heterosis over both the better parent and check. The 7 out of 40 hybrids revealed a significantly positive heterosis over better parent, ranged from 1.57 to 17.33%. Only LBR-15 × EC-119197 (3.31%) showed significant heterosis over the standard check. The cross combination LBR-11 × 1-6-1-4 (17.33% and 4.27o brix) showed maximum heterosis over better parent followed by LBR-15 × EC-119197 (15.59% and 5.13 ^{o}Brix), LBR-9 × EC-119197 (14.23% and 5.13 ^{o}Brix), LBR-9 × 1-6-1-4 (10.75% and 4.93 ^{o}Brix) and LBR-12 × 1-6-1-4 (7.28% and 4.53 ^{o}Brix). Line LBR-9 (1.33 mg) was recorded for minimum while and PNR-7 (4.53 mg) for maximum lycopene content (Table 2). In case of hybrids, LBR-15 × 1-6-1-4 (0.96 mg) possessed minimum and LBR-9 × EC-119197 (6.39 mg) possessed maximum lycopene content. Out of 40 hybrids, 12 and 8 were found with significant heterosis ranged from 4.04 to 38.63% and -368.75 to 29.58% over better parent and standard the check. The range of acidity varied from 0.44 to 0.98 mg (Table 2) and 0.53 to 0.93 mg (Table 3) in parents and hybrids respectively. Of the 40 hybrids, 11 and 21 exhibited appropriate heterosis varied from 3.03 to 43.08% and 2.99 to 38.81% (Table 3) over better parent and standard check respectively. The cross combination LBR-13 × EC-119197 (43.08%) exhibited maximum heterosis over better parent followed by LBR-19 × PNR-7 (26.87%), LBR-15 × EC-119197 (24.66%) and LBR-13 × 8-2-1-2-5 (22.97%) whereas LBR-13 × EC-119197 (38.81%) over the check, followed by LBR-13 × 8-2-1-2-5

(35.82%), LBR-15 × EC-119197 (35.82%) and LBR-10 × 1-6-1-4 (32.84%). Hybrid, LBR-13 × EC-119197 (0.93 mg) showed maximum *per se* performance followed by LBR-13 × 8-2-1-2-5 (0.91 mg), LBR-15 × EC-119197 (0.91 mg) and LBR-10 × 1-6-1-4 (0.89 mg).The carotenoides of parental lines and hybrids ranged from 0.88 (LBR-9) to 9.65 mg (EC-119197) (Table 2) and 1.01 (LBR-15 × 8-2-1-2-5) to 6.66 mg (LBR-15 × EC-119197) (Table 3). The range of heterosis fluctuated from -236.00 to 70.86% and -173.27 to 58.56% over the better and standard check. Of 40 hybrids, 5 and 21 showed appropriate heterosis over better parent and standard check respectively.

Analysis of variance for combining ability

Analysis of variance for combining ability for all characters is presented in Table 1. The ratios of σ^2SCA/ σ^2GCA were observed more than unity for all the characters except dry matter which indicated the predominance of non-additive gene. For dry matter the ratio was observed less than unity; indicating the greater role of additive gene effects for the inheritance of this particular trait. The negative GCA variance was estimated for total fruit yield and dry matter; therefore, these could be considered indifferent from zero.

Screening of hybrids against late blight and root knot nematodes

Experimental materials was screened naturally under the field conditions and challenged artificially. Almost all the lines exhibited resistant to highly resistant response under both the conditions. Eight crosses viz. LBR-12 × EC-119197 (14.00% DI), LBR-6 × 1-6-1-4 (18.00% DI), LBR-10 × 8-2-1-2-5 (18.00% DI), LBR-12 × 1-6-1-4 (18.00% DI), LBR-13 × 1-6-1-4 (18.00% DI), LBR-21 × 8-2-1-2-5 (18.00% DI), LBR-21 × 1-6-1-4 (18.00% DI) and LBR-13 × EC-119197 (20.00% DI) were found resistant under Detached-leaf method and results were almost similar in Whole-plant assay (Table 5).

In case of root knot nematodes screening, tester 1-6-1-4 was found to be completely disease free under artificial screening with gall index of zero while testers, while PNR-7 and 8-2-1-2-5 were found to be highly resistant with gall index of 0.5 (1.2). Hybrids viz. LBR-9 × 1-6-1-4, LBR-10 × PNR-7, LBR-11 × 8-2-1-2-5, LBR-11 × EC-119197 and LBR-13 × PNR-7 were found to be resistant for root knot nematodes with good *per se* performance; under both natural and artificial conditions (Table 6).

DISCUSSION

There is great demand of F_1 hybrid tomato seeds in India because of high yield, high productivity, high fruit weight, good recovery rate, pigments richness, biotic and abiotic resistance, and high remuneration to farmers (Madhavi Reddy, 2010; Singh *et al*., 2014). Problem of late blight and root knot nematodes limits the tomato cultivation in many tracts of India particularly hilly and northern plains of country. The predominance of non-additive gene effects due to high SCA effects in most of traits (Table 1); monogenic and oligogenic nature of disease inheritance encouraged to conduct performed study.

Average fruit weight directly contributes the total yield and appropriate size encourages the consumer acceptance. The range of heterosis over better parent was found negative in almost all the cross combinations due to bulky fruit size of late blight resistant (LBR) lines (Table 2). The extent of heterosis varied from -51.88 to 60.85% and -30.67 to 73.33% over the better parent and standard check respectively. Solieman *et al*. (2013) observed heterosis ranged from -32.78 to 11.29% for average fruit weight whereas Chauhan *et al*. (2014) reported **heterosis** ranged from 9.96 to 14.79% over mid parent and 13.19 to 28.01% over standard parent. Fruit yield per plant holds great pertinence for any commercial breeding program. In our study, heterosis was ranged from 4.98 to 55.25% and 4.55 to 47.17 % over the better parent and standard check respectively. Heterosis range of F_1 hybrids varied from -6.72 to -50.00% over better parent for number of locules. Fruit firmness and acidity is indirectly proportional to locules hence less number of locule per fruit is suitable for processing cultivars. Garg and Cheema (2010) recorded heterosis magnitude varied from -34.12 to 33.95% for said character.

Table 5. Screening of tomato genotypes for late blight.

Genotypes	Natural Screening			Artificial screening					
				Detached-leaf method			Whole-plant assay		
	% Incidence	% Disease index	Response	% Incidence	% Disease index	Response	% Incidence	% Disease index	Response
LBR-6	30.00	6.33	HR	60.00	18.00	R	33.66	13.33	R
LBR-7	20.00	7.00	HR	60.00	12.00	R	50.00	10.64	R
LBR-9	20.00	4.67	HR	50.00	10.00	HR	33.33	6.65	HR
LBR-10	23.33	7.33	HR	40.00	12.00	R	33.33	7.31	HR
LBR-11	20.00	3.33	HR	40.00	6.00	HR	26.66	3.12	HR
LBR-12	10.00	2.00	HR	33.33	8.00	HR	23.33	4.65	HR
LBR-13	16.66	2.66	HR	40.00	16.00	R	26.66	11.31	R
LBR-15	16.66	6.00	HR	40.00	12.00	R	26.26	8.64	HR
LBR-19	6.66	1.33	HR	30.00	12.00	R	13.13	8.64	HR
LBR-21	30.00	8.00	HR	30.00	22.00	MS	26.66	21.31	MS
PNR-7	30.00	10.00	HR	60.00	22.00	MS	50.00	19.97	R
8-2-1-2-5	50.00	18.66	R	70.00	42.00	S	76.60	36.57	MS
EC-119197	36.66	23.33	MS	70.00	50.00	S	79.80	41.66	S
1-6-1-4	70.00	28.33	MS	90.00	56.00	S	100.00	48.54	S
LBR-6 x PNR-7	40.00	12.66	R	70.00	56.00	S	66.66	52.56	S
LBR-6 x 8-2-1-2-5	50.00	16.00	R	80.00	60.00	S	73.33	53.20	S
LBR-6 x EC-119197	36.66	17.66	R	70.00	32.00	MS	66.66	30.55	MS
LBR-6 x 1-6-1-4	26.66	12.00	R	40.00	18.00	R	73.33	16.66	R
LBR-7 x PNR-7	36.66	12.33	R	70.00	46.00	S	49.98	40.56	S
LBR-7 x 8-2-1-2-5	46.66	20.00	R	60.00	36.00	MS	63.31	25.27	MS
LBR-7 x EC-119197	10.33	4.66	HR	40.00	8.33	HR	30.66	6.33	HR
LBR-7 x 1-6-1-4	33.33	22.33	MS	80.00	50.00	S	69.98	46.55	S
LBR-9 x PNR-7	40.00	24.00	MS	60.00	48.00	S	66.66	42.56	S
LBR-9 x 8-2-1-2-5	53.33	25.66	MS	70.00	50.00	S	46.66	43.22	S
LBR-9 x EC-119197	36.66	18.33	R	60.00	36.00	MS	56.33	30.59	MS
LBR-9 x 1-6-1-4	56.66	17.33	R	90.00	50.00	S	66.66	45.88	S
LBR-10 x PNR-7	36.66	21.00	MS	80.00	36.00	MS	73.33	31.92	MS
LBR-10 x 8-2-1-2-5	30.00	13.00	R	50.00	18.00	R	46.66	15.33	R
LBR-10 x EC-119197	46.66	17.66	R	70.00	36.00	MS	50.00	30.59	MS
LBR-10 x 1-6-1-4	33.33	20.33	MS	50.00	38.00	MS	43.33	31.20	MS
LBR-11 x PNR-7	56.66	26.33	MS	80.00	52.00	S	69.98	49.21	S
LBR-11 x 8-2-1-2-5	53.33	27.33	MS	80.00	66.00	HS	50.00	60.18	HS
LBR-11 x EC-119197	53.33	24.33	MS	70.00	72.00	HS	69.98	59.85	S
LBR-11 x 1-6-1-4	60.00	23.66	MS	70.00	52.00	S	93.33	43.86	S
LBR-12 x PNR-7	56.66	20.66	MS	80.00	42.00	S	79.98	39.23	MS
LBR-12 x 8-2-1-2-5	36.66	21.00	MS	70.00	38.00	MS	66.65	37.58	MS
LBR-12 x EC-119197	36.66	7.33	HR	70.00	14.00	R	59.98	12.63	R
LBR-12 x 1-6-1-4	40.00	8.66	HR	60.00	18.00	R	49.98	16.60	R
LBR-13 x PNR-7	43.33	12.66	R	70.00	40.00	MS	69.98	29.26	MS
LBR-13 x 8-2-1-2-5	26.66	6.66	HR	80.00	32.00	MS	49.98	31.25	MS
LBR-13 x EC-119197	23.33	8.33	HR	60.00	20.00	R	63.33	16.66	R
LBR-13 x 1-6-1-4	40.00	6.00	HR	50.00	18.00	R	46.50	17.66	R
LBR-15 xPNR-7	56.66	27.66	MS	90.00	62.00	HS	83.33	53.20	S
LBR-15 x 8-2-1-2-5	50.00	18.66	R	70.00	40.00	MS	73.00	28.96	MS
LBR-15 x EC-119197	60.00	28.00	MS	70.00	42.00	S	69.80	36.56	MS
LBR-15 x 1-6-1-4	53.33	26.33	MS	60.00	50.00	S	56.33	40.56	S
LBR-19 x PNR-7	60.00	19.00	R	70.00	36.00	MS	69.98	27.93	MS
LBR-19 x 8-2-1-2-5	46.66	18.66	R	40.00	16.00	R	33.33	14.53	R
LBR-19 x EC-119197	43.33	17.66	R	60.00	38.00	MS	43.16	34.60	MS
LBR-19 x 1-6-1-4	53.33	22.66	MS	60.00	48.00	S	73.00	46.57	S
LBR-21 x PNR-7	53.33	23.33	MS	100.00	82.00	HS	96.65	66.52	S
LBR-21 x 8-2-1-2-5	40.00	7.33	HR	70.00	18.00	R	66.66	19.28	R
LBR-21 x EC-119197	33.33	17.33	R	80.00	62.00	HS	86.66	55.36	S
LBR-21 x 1-6-1-4	43.33	19.66	R	40.00	18.00	R	33.33	16.87	R
Punjab Upma (Susceptible check)	80.00	49.33	S	100.00	98.00	HS	100.00	89.25	HS
TH-1 (Standard check)	50.00	38.00	S	60.00	36.00	MS	56.66	32.50	MS

Response is based on Percentage disease index (PDI), Highly resistant (HR) >0-10 PDI; Resistant (R) >10-20 PDI; Moderately susceptible (MS) >20-40 PDI; Susceptible (S) >40-60 PDI; Highly Susceptible (HS) >60 PDI (In natural and artificial screening)

Table 6. Screening of tomato lines, testers, hybrids and checks for root knot nematodes (Figures in parentheses are $\sqrt{n+1}$).

Genotypes	Natural screening		Artificial screening	
	Gall index	Response	Gall index	Response
LBR-6	0.3(1.1)	HR	4(2.2)	S
LBR-7	3.3(2.07)	S	2.5(1.9)	MR
LBR-9	1.3(1.5)	R	4.5(2.3)	HS
LBR-10	3(2)	MR	4(2.2)	S
LBR-11	4.3(2.3)	HS	3.5(2.1)	S
LBR-12	2.3(1.8)	MR	3.5(2.7)	S
LBR-13	2.7(1.9)	MR	4(2.2)	S
LBR-15	1(1.4)	HR	2.5(1.9)	MR
LBR-19	1.3(1.5)	R	4(2.2)	S
LBR-21	1.7(1.6)	R	3.5(2.1)	S
PNR-7	0(1)	I	0.5(1.2)	HR
8-2-1-2-5	0(1)	I	0.5(1.2)	HR
EC-119197	0(1)	I	1.5(1.6)	HR
1-6-1-4	0(1)	I	0(1)	I
LBR-6 x PNR-7	3(2)	MR	3(2)	MR
LBR-6 x 8-2-1-2-5	2.7(1.9)	MR	3.5(2.1)	S
LBR-6 x EC-119197	2(1.7)	R	4(2.2)	S
LBR-6 x 1-6-1-4	1.7(1.6)	R	2(1.7)	R
LBR-7 x PNR-7	3.3(2.1)	S	4(2.2)	S
LBR-7 x 8-2-1-2-5	4(2.2)	S	4(2.3)	S
LBR-7 x EC-119197	3.3(2.1)	S	3.5(2.1)	MR
LBR-7 x 1-6-1-4	3.7(2.1)	S	4.5(2.3)	HS
LBR-9 x PNR-7	2.3(1.8)	MR	2.5(1.9)	MR
LBR-9 x 8-2-1-2-5	4(2.2)	S	4(2.2)	S
LBR-9 x EC-119197	0.3(1.1)	HR	1.5(1.6)	R
LBR-9 x 1-6-1-4	0(1)	I	1(1.4)	HR
LBR-10 x PNR-7	0(1)	I	1(1.4)	HR
LBR-10 x 8-2-1-2-5	0(1)	I	4(2.2)	S
LBR-10 x EC-119197	0(1)	I	2.5(1.9)	MR
LBR-10 x 1-6-1-4	2.7(1.9)	MR	1.5(1.6)	R
LBR-11 x PNR-7	1.3(1.5)	R	1.5(1.6)	R
LBR-11 x 8-2-1-2-5	0(1)	I	1(1.4)	HR
LBR-11 x EC-119197	0(1)	I	1(1.4)	HR
LBR-11 x 1-6-1-4	0(1)	I	4(2.2)	S
LBR-12 x PNR-7	0(1)	I	2(1.7)	R
LBR-12 x 8-2-1-2-5	3.3(2.1)	S	4(2.2)	S
LBR-12 x EC-119197	1.3(1.5)	R	1.5(1.6)	R
LBR-12 x 1-6-1-4	2 (1.7)	R	2(1.7)	R
LBR-13 x PNR-7	0.3(1.1)	HR	1(1.4)	HR
LBR-13 x 8-2-1-2-5	2.3(1.8)	MR	3.5(2.1)	S
LBR-13 x EC-119197	2.3(1.8)	MR	4(2.2)	S
LBR-13 x 1-6-1-4	0(1)	I	2(1.7)	R
LBR-15 x PNR-7	0.3(1.1)	HR	4.5(2.3)	HS
LBR-15 x 8-2-1-2-5	2.7(1.9)	MR	4(2.2)	S
LBR-15 x EC-119197	0(1)	I	2(1.7)	R
LBR-15 x 1-6-1-4	0(1)	I	4(2.2)	S
LBR-19 x PNR-7	0(1)	I	4(2.2)	S
LBR-19 x 8-2-1-2-5	1.3(1.5)	R	2(1.7)	R
LBR-19 x EC-119197	0.7(1.2)	HR	4.5(2.3)	HS
LBR-19 x 1-6-1-4	0(1)	I	1(1.4)	HR
LBR-21 x PNR-7	0(1)	I	2(1.7)	R
LBR-21 x 8-2-1-2-5	1(1.4)	R	1.5(1.6)	R
LBR-21 x EC-119197	0.7(1.3)	HR	4(2.2)	S
LBR-21 x 1-6-1-4	0(1)	I	1.5(1.6)	R
Punjab Upma (Susceptible check)	4.3(2.3)	HS	4.5(2.3)	HS
TH-1 (Standard check)	3.3(2.07)	S	2.5(1.9)	MR
CD (5%)	0.3		0.3	

I-Immune, HR- Highly resistant, R- Resistant, MR- Moderately resistant, S- Susceptible, HS- Highly Susceptible (In natural and artificial screening)

Heterosis was recorded from -50.59 to 70.79% and from -43.65 to 45.49% over the better parent and standard check respectively for pericarp thickness. Garg and Cheema (2010) and Garg *et al*. (2010) assessed heterotic range of -30.26 to 70.61% and -24.14 to 33.84% for pericarp thickness respectively. Solieman *et al*. (2013) reported heterosis ranged from -9.22 to 25.88% for this trait. Most of hybrids showed their mean value less than one for P/E ratio, which indicated that the most of the hybrids were oblate or flat in shape. Here, heterosis was calculated from -140.00 to 14.61% and -38.10 to 9.38% over the better parent and standard check subsequently. Susic (1998) reported only 4.62 % of heterosis for fruit shape. Solieman *et al*. (2013) reported heterosis ranged from -34.72 to 15.18% for this trait.

Dry matter directly contributesfor final product. Heterosis was varied 2.56 to 27.03% and 0.80 to 28.57% over better parent and standard check subsequently. Due to predominance of GCA effects (Table 1) true breeding lines are successful rather hybrids. Garg and Cheema (2010) reported varied range of dry matter, 3.99 to 7.04% for studied F_1 hybrids. For processing purpose, TSS content should be more than 4.5 per cent. An increase in 1% of solids resulted in 20 per cent increase in recovery of processed product of tomato (Berry and Uddin, 1991). Here, heterosis over better parent, ranged from 1.57 to 17.33% whereas only LBR-15 × EC-119197 (3.31%) reflected significant positive heterosis over standard check. Most of the hybrids showed negative heterosis for TSS in present study. But larger effects of SCA (Table 1) encourage development of hybrids for relevant trait. Garg and Cheema (2010) reported heterosis range of -30.43 to 76.62% while from -11.46 to 25.50% by Solieman el al. (2013), for TSS. Lycopene imparts dark red color to the tomato, which appeal to consumers and provide immense nutritional value and anti-cancerous in nature. Heterosis ranging from 20.74 to 134.69% has been observed by Garg and Cheema (2010) for lycopene. In our study most of the hybrids exhibited negative heterosis for lycopene due to pronounced effect of GCA variance (Table 1). Heterosis was varied from 4.04 to 38.63% and -368.75 to 29.58% (Table 3) over better parent and standard check subsequently. So, hybrid development seems to be not encouraging for enhancement of lycopene content. Heterosis for titratable acidity oscillated in range of 3.03 to 43.08% and 2.99 to 38.81% over better 1 parent and check respectively. Garg *et al*. (2013) observed heterosis of 40.98 and 45.10% for titratable acidity in main and late-season, respectively over susceptible check, TH-1. Cross combinations involving one parent as orange colored EC-119197 were reported with high heterosis for carotenoids. Here, Heterosis is varied from -236.00 to 70.86% and -173.27 to 58.56% over the better and check parent respectively in both the directions. Mondal *et al*. (2009) recorded heterosis up to 311.29% while 99.72% has been observed by Mulge *et al*. (2012).

This study well illustrated that development of hybrid combinations having desirable traits along with multi-disease resistance is quite tedious. However the development of 4 hybrids namely, LBR-19 × 8-2-1-2-5, LBR-12 × EC-119197, LBR-13 x 1-6-1-4 and LBR-6 × 1-6-1-4 for combined resistance for late blight and root knot nematodes vis-à-vis desirable horticultural traits particularly fruit yield, fruit weight, pericarp thickness, TSS and dry matter is achievable task (Table 7).

CONCLUSION

Breeding programs for hybrid development to multi-disease resistance with standard heterosis for all required traits have not been developed. However, the results indicated that cross combinations namely, LBR-19 × 8-2-1-2-5, LBR-12 × EC-119197, LBR-13 x 1-6-1-4 and LBR-6 × 1-6-1-4 were to have combined resistance for late blight and root knot nematodes vis-à-vis desirable traits particularly fruit yield, fruit weight, pericarp thickness, TSS and dry matter with appropriate heterosis. Multi-year and multi-location trials are required prior to commercialization of these hybrids.

Table 7. Crosses possessing resistance to late blight and root knot nematodes with desirable horticultural traits.

Crosses possessing combined resistance	Average fruit weight (g)	Total fruit yield (kg/plant)	Number of locules per fruit	Pericarp thickness (mm)	P / E ratio	Dry matter (%)	Total soluble solids (°Brix)	Lycopene content (mg/100g fresh weight)	Titratable acidity (mg/100 ml of juice)	Carotenoides (mg/100g fresh weight)
LBR-19×8-2-1-2-5	81.67	3.18	3.00	4.70	0.83	6.05	3.00	4.42	0.73	1.50
LBR-12 x EC-119197	89.00	2.95	4.07	5.05	0.91	5.89	4.47	2.46	0.65	3.48
LBR-13 x 1-6-1-4	83.3	2.0	3.1	5.1	0.87	5.07	3.00	4.09	0.72	3.23
LBR-6 x 1-6-1-4	80.7	2.0	3.3	6.1	0.84	5.71	3.73	3.02	0.77	1.5

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