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Research Article

Heterosis and combining ability for tomato leaf curl virus (ToLCV) and Bacterial wilt disease in tomato (*Solanum lycopersicum* L.)

R. P. Jaiprakash Narayan[1]*, S. B. Mallesh[2], M. G. Patil[3] and Mallikarjun Dhotre[1]
*[1]Assistant Professor (Horticulture), AC, Bheemarayanagudi, UAS, Raichur
[2]Assistan Professor (Plant Pathology) AC, UAS, Raichur,
[3] Professor (Horticulture) AC, UAS, Raichur
***E-mail:** jphort@gmail.com

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Abstract

ToLCV (Gemini virus) and Bacterial wilt (*Ralstonia solanacearum*) are the important diseases affecting the tomato and cause more than 90 per cent yield loss especially during summer and rainy seasons. In the present experiment 63 genotypes were evaluated for the magnitude of resistance for ToLCV and bacterial wilt diseases. Among them, four were highly resistant and nine were resistant to ToLCV incidence and four were resistant and four were moderately resistant to bacterial wilt incidence. Only four genotypes *viz.*, TP25, TP29, TP40 and TP43 showed combined resistance to ToLCV and bacterial wilt incidence. Maximum heterosis over better parent and standard parent in desirable direction were -92.03 per cent (TP24 x TP40: TP45 x TP25) for per cent ToLCV incidence; -92.64 per cent (TP24 x TP40: TP45 x TP25) for per cent ToLCV coefficient of infection and 98.15 per cent (TP1 x TP29) and 70.56 per cent (TP5 x TP29) for total yield per plant respectively. 18 crosses exhibited non significant (desirable) heterosis over the standard parent (TP25) in the needful direction and 15 crosses exhibited negative and significant heterosis over better parent for bacterial wilt incidence. The cross TP26 x TP40 for ToLCV incidence and TP24 x TP40 for ToLCV coefficient of infection, bacterial wilt and total yield per plant were identified as good specific combiners. The parents TP46, TP44 and TP27 for ToLCV incidence and ToLCV coefficient of incidence; TP24 and TP27 for bacterial wilt and TP5 and TP44 for total yield per plant were identified as good general combiners.

Key words

Bacterial wilt, combining ability, Heterosis, ToLCV and tomato

Introduction

Tomato (*Solanum lycopersicum* L.), belonging to the family Solanaceae is an extremely popular and widely grown vegetable in the world. It occupies an area of 8.82 lakh hectares (9.4% of total vegetable area) with an annual production of 187.36 lakh metric tons (11.50 % of the total vegetable production) accounting to an average productivity of 21.2 tons per hectare .The Indian national average yield is 21.2 tons per hectare compared to the world average of 33.9 tons per hectare. The highest tomato average yield to the extent of 88.00 tons per hectare had been recorded in USA (NHB, 2015). It is evident from the fact that a huge gap is seen between the national average yield of India and that of the important tomato growing nations. Low productivity in India is attributed to lack of high yielding varieties or hybrids and presence of serious pests and diseases. Of all the diseases, the occurrence of ToLCV and bacterial wilt in tomato is a major constraint in cultivation of tomato during summer and rainy season in India. ToLCV is a monopartite, Gemini virus known to be transmitted by the vector white fly, *Bemisia tabaci* Genn. ToLCV is known to infect the crop at all the stages starting from nursery to fruit formation. Saikia and Muniyappa (1989) reported cent per cent infection and fruit yield losses up to 90 per cent. Bacterial wilt is caused by a soil borne bacterial pathogen, *Ralstonia solanacearum* (Smith). It occurs normally after the flowering period and can cause considerable yield losses by sudden wilting and death of whole plant. *R. solanacearum* is known to survive in soil up to 45 cm depth and hence it can be transmitted by infected plant material, irrigation water, soil and farm implements. The loss in yield due to bacterial wilt up to an extent of 90.62 per cent was reported by Ramkishun, 1987.

Host plant resistance is an important disease control strategy and environmentally safe, with low running costs. Therefore, screening tomato cultivars possessing inbuilt resistance is an appropriate approach for disease management. Hence, an attempt has been made in the present investigation for screening and development of F_1 hybrids resistance to ToLCV and bacterial wilt disease in tomato.

Material and Methods

The experiment was conducted during 2013-14 and the study comprised of 63 genotypes collected from Division of Horticulture, University of Agricultural Sciences, Bangalore, NBPGR, New Delhi, Indian Institute of Horticultural Research, Hesaraghatta, Bangalore and AVRDC, Taiwan. After screening for disease, quality and yield parameters 14 lines as female parents and 3 testers as male parents were selected and crossed in all possible combinations to obtain 42 F_1 hybrids. The parental genotypes and 42 F_1 hybrids were grown in randomized block design with three replications and other agronomic practices were followed as per package of practices given by University of Horticultural Sciences, Bagalkot

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(Anon., 2013). The incidence of ToLCV infection was recorded 30 days after transplanting at weekly interval. The number of plants infected in each genotype was recorded and computed by using the formula,

$$\text{Per cent ToLCV Incidence} = \frac{\text{Total number of plan infected with ToLCV}}{\text{Total number of plants observed}} \times 100$$

Coefficient of infection is the parameter with combined amount of infection and severity. (Banerjee and Kalloo, 1989). Coefficient of infection was calculated by multiplying the per cent infection with response value and categorized into different groups as given in the following table.

Symptom	**Symptom severity grade**	**Response value**	**Coefficient of infection**	**Reaction**
Symptom absent	0	0	0-4	Highly resistant
Very mild curling Upton 25% leaves	1	0.25	5-9	Resistant
Curling, puckering of 26-50% leaves	2	0.50	10-19	Moderately resistant
Curling, puckering of 51-75 % leaves	3	0.75	20-39	Moderately susceptible
Severe curling, puckering of >75% of leaves	4	1.00	40-69 70-100	Highly Susceptible

The traditional sick plots maintained for screening to bacterial wilt were used for experimental study. Bacterial wilt incidence is the number of plants infected out of the total number of plants that were planted and the observations were recorded at every two weeks interval after transplanting. The values obtained were expressed in per cent wilt incidence.

The ToLCV per cent incidence, coefficient of infection and per cent wilt incidence values were converted to arcsine values to obtain normal distribution and analysis was done for arcsine values. Data were recorded in thirty randomly selected plants in each F_1s and parents for different parameters. The observations were subjected to line x tester analysis. In practical plant breeding, superiority of the F_1 over mid parent is of little value, since it does not offer any advantage. However, the commercial usefulness of a hybrid would primarily depend on its performance in comparison to the best existing commercial variety or hybrids. Hence, heterosis over better parent and the standard parent was worked out in the present investigation for identification of superior hybrids. The genotype TP25 was selected as the standard parent, since it is resistant to both ToLCV and bacterial wilt incidence and was recorded with highest yield and maximum number of fruits per plant. The systematic study in relation to general and specific combining ability is necessary to assess the genetic potentialities of the parents in hybrid combinations (Griffing, 1956). Line x tester (l x t) method developed by Kempthorne (1957) has been used in the present study for estimating combining ability (GCA and SCA) and other genetic parameters.

Results and Discussion

Per cent ToLCV incidence and coefficient of infection ranged from 2.22 (TP29 and TP40) to 97.77 (TP35) and 1.67 (TP29 and TP40) to 97.77 (TP41), respectively (Table 1). Out of 63 genotypes, four were highly resistant, nine were resistant, three were moderately resistant, seventeen were moderately susceptible, eighteen were susceptible and twelve were highly susceptible to ToLCV incidence. The above findings are in agreement with the results obtained by Ho (1990), Chellimi *et al*. (1994) and Bhattarai (1998). The resistant genotypes *viz.*, TP13, TP25, TP29, TP40, TP3, TP22, TP33, TP43, TP44, TP47, TP53, TP56 and TP61 can be utilized in future breeding programme. Per cent bacterial wilt incidence ranged from 0.00 (TP29) to 91.11 per cent (TP17) (Table 13). Among 63 genotypes, four were resistant, four were moderately resistant, six were moderately susceptible, thirteen were susceptible and thirty-six were highly susceptible to bacterial wilt incidence. Similar reports were also reported by Kalloo and Banerjee (1990) and Kalloo and Banerjee (2000). The resistant genotypes *viz.*, TP25, TP29, TP40, TP45, TP46, TP41, TP42, TP43 and TP47 can be utilized in future breeding programme.

Only four genotypes *viz.*, TP25, TP29, TP40 and TP43 showed combined resistance to ToLCV and bacterial wilt incidence. Similar results were also reported by Sadashiva *et al*. (2002). Hence these genotypes can be utilized for future breeding programme. Maximum number of fruits per plant was observed in TP 35 (125.44) followed by TP 52 (105.15), TP 10 (98.48), TP 28 (89.62) and TP 7 (80.43) and minimum was observed in TP 54 (21.00). Number of fruits per plant ranged from 21.00 to 125.44 with an average mean of 40.21. Total yield per plant (kg) was maximum in TP 31 and TP 44 (2.95 kg) followed by TP 31 (2.82 kg), TP 18 (2.69 kg), TP 19 (2.63 kg) and TP 5 (2.58 kg) and minimum (0.84 kg) was observed in TP 14. Total yield per plant ranged from 0.84 kg to 2.95 with an average mean of 1.98 kg.

Though selection have played greater role in crop improvement, revolution in agriculture has been possible only because of development of F_1 hybrids for cultivation, in which heterosis refers to superiority of an F_1 over its parents is exploited. The F_1 hybrids derived from crossing of pure lines are uniform in growth and development and possess better adaptability to changing and adverse environmental conditions and give high, early as well as total yields (Riggs, 1988). In practical plant breeding, genetic diversity is prerequisite for getting high magnitude of heterosis. In the present investigation, variance due to genotypes was highly significant for all yield and disease parameters studied indicating large amount of diversity among the genotypes studied.

Magnitude of heterosis over better parent and standard parent was significant in both the directions for ToLCV coefficient of infection. The cross TP24 x TP40 and TP45 x TP25 exhibited significant maximum heterosis in the desirable direction (negative) over better parent (- 92.64% and - 92.78 %) followed by the cross TP48 x TP25 (- 90.01 %). Eighteen crosses exhibited non significant (desirable) heterosis over the standard parent (TP29) in the needful direction. Twenty crosses exhibited negative and significant heterosis over better parent for ToLCV coefficient of infection (Table 2). Among 15 lines, eight lines exhibited significant GCA effects in the desirable (negative) direction and four lines had positively significant GCA effects. Maximum negative and significant GCA effects was observed in TP46 (- 21.73) followed by TP44 (- 21.24) and TP27 (- 21.12). Among testers TP25 (- 4.27) and TP29 (5.62) had significant GCA effects (Table 3). Out of 42 crosses, 11 exhibited significant SCA effects in the desirable direction. The maximum SCA effects (Table 4) in the desirable direction was exhibited by TP24 x TP40 (-30.08) followed by TP26 x TP40 (-29.39) and TP19 x TP25 (-27.14). The GCA: SCA (Table 3) ratio is almost equal (1:1.10) indicates the involvement of both additive and non additive gene action which can be improved by simple selection and recurrent selection method of breeding in heterotic hybrids. Similar findings were also reported by Kulkarni (1999).

Magnitude of heterosis over better parent and standard parent was significant in both the directions for bacterial wilt incidence. The cross TP24 x TP40 exhibited significant maximum heterosis in the desirable direction (negative) over better parent (-99.04 %). Eighteen crosses exhibited non significant (desirable) heterosis over the standard parent (TP25) in the needful direction and 15 crosses exhibited negative and significant heterosis over better parent for bacterial wilt incidence. Among 15 lines, six lines exhibited significant GCA effects in the desirable (negative) direction and maximum negative and significant GCA effects was observed in TP5, TP24 and TP27 (- 32.31) followed by TP45 (- 30.71). Among testers TP40 (- 3.92) expressed negative and significant GCA effects. Out of 42 crosses, 7 exhibited significant SCA effects in the desirable direction and maximum SCA effects in the desirable direction was exhibited by TP50 x TP29 (- 17.50) followed by TP44 x TP40 (- 17.30) and TP44 x TP29 (-14.76). The GCA: SCA ratio is also high (1:32.15) indicates the predominance of non additive gene action contributing for heterosis as evidenced by Grimault (1995), Louw (1985) and Vidavsky *et al.* (1998).

Maximum positive and significant heterobeltiosis was exhibited by the cross TP1 x TP29 (98.15 %) followed by TP1 x TP29 (98.15 %), TP24 x TP40 (86.16 %) and TP5 x TP29 (81.39 %). The cross TP5 x TP29 exhibited maximum positive and significant heterosis over the standard parent (70.56 %) followed by TP1 x TP29 (69.74 %) and TP24 x TP40 (67.57 %). Majority of the crosses exhibited positive and significant heterosis over better parent (31 crosses) and standard parent (25 crosses) for total yield per plant. Four lines, *viz*., TP5 (0.52), TP44 (0.26), TP59 (0.25) and TP45 (0.21) and the testers, *viz*., TP40 (0.21) and TP29 (0.16) exhibited positively significant GCA effects. 12 crosses exhibited positive and significant SCA effects and the highest positive SCA effects was observed in the cross TP24 x TP40 (1.10) followed by TP46 x TP25 (1.01), TP1 x TP29 (0.96), TP45 x TP25 (0.93), TP51 x TP25 (0.93) and TP50 x TP25 (0.80). The GCA: SCA ratio for total yield (1:2.46) indicates little dominance of non additive gene action and involvement of additive gene action reveals that heterosis breeding can be exploited for improvement of yield in heterotic hybrids and at the same time transgressive segregants can be obtained by following reciprocal recurrent selection method of breeding. Similar findings were also reported by Padma *et al.* (20002) and Bhatt *et al.* (2001).

From the experiment it was found that, Out of 63 genotypes evaluated four genotypes *viz.*, TP25, TP29, TP40 and TP43 showed combined resistance to ToLCV and bacterial wilt diseases. However, four genotypes were highly resistant, nine were resistant and three were moderately resistant to ToLCV incidence. Similarly, four genotypes were resistant and four were moderately resistant to bacterial wilt incidence. The highest heterosis (-92.03 %) over better parent and standard parent in desirable direction was recorded in TP24 x TP40 and TP45 x TP25 for per cent ToLCV incidence. The cross TP1 x TP29 (98.15 %) exhibited the highest heterosis for total yield per plant. Eighteen crosses exhibited non significant (desirable) heterosis over the standard parent (TP25) in the needful direction for bacterial wilt incidence. The cross TP26 x TP40 for ToLCV incidence and TP24 x TP40 for ToLCV coefficient of infection, bacterial wilt and total yield per plant were identified as good specific combiners. The parents TP46, TP44 and TP27 for ToLCV incidence and coefficient of infection, TP24 and TP27 for bacterial wilt and TP5 and TP44 for total yield per plant were identified as good general combiners.

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Table 1. Reaction of sixty three genotypes for ToLCV incidence, coefficient of infection and bacterial wilt incidence in tomato

Sl. No.	Genotype	Per cent ToLCV incidence	ToLCV coefficient of infection	Disease reaction	Bacterial wilt incidence (%)	Disease reaction	No. of fruits/ plant	Total yield/ plant (kg)
1.	TP1	68.88	58.32	S	82.22	HS	35.57	2.40
2.	TP2	64.44	41.66	S	82.22	HS	26.24	2.31
3.	TP3	8.88	4.99	R	73.33	HS	31.61	2.07
4.	TP4	42.22	28.18	MS	68.88	HS	45.80	2.07
5.	TP5	84.44	63.32	S	77.77	HS	44.27	2.58
6.	TP6	57.77	31.66	MS	37.77	MS	24.88	1.56
7.	TP7	51.11	41.11	S	46.66	S	80.43	1.49
8.	TP8	68.88	51.66	S	53.33	S	31.38	0.98
9.	TP9	17.77	12.21	MR	60.00	S	30.54	1.62
10.	TP10	59.99	46.66	S	91.10	HS	98.48	1.62
11.	TP11	19.99	10.5	MR	60.00	S	31.73	2.27
12.	TP12	44.44	27.77	MS	57.77	S	34.82	2.55
13.	TP13	8.88	3.88	HR	59.99	S	50.47	2.54
14.	TP14	64.44	52.77	S	73.33	HS	32.12	0.84
15.	TP15	71.11	35.55	MS	77.77	HS	50.53	2.44
16.	TP16	88.88	88.88	HS	66.66	HS	24.76	1.98
17.	TP17	84.44	63.33	S	91.11	HS	43.65	1.70
18.	TP18	66.66	66.66	S	73.33	HS	49.37	2.69
19.	TP19	44.44	27.22	MS	86.66	HS	48.69	2.63
20.	TP20	44.44	32.77	MS	68.88	HS	32.52	1.65
21.	TP21	73.33	68.33	HS	76.66	HS	35.43	0.97
22.	TP22	13.33	8.88	R	61.10	HS	30.32	2.13
23.	TP23	75.55	61.66	S	65.55	HS	30.31	1.52
24.	TP24	82.22	61.66	S	73.33	HS	38.73	2.11
25.	TP25	4.44	2.22	HR	3.33	R	41.35	2.55
26.	TP26	35.55	21.66	MS	82.21	HS	35.77	2.02
27.	TP27	82.22	61.65	S	86.66	HS	41.50	1.76
28.	TP28	86.66	72.77	HS	73.33	HS	89.62	1.61
29.	TP29	2.22	1.67	HR	0.01	R	38.84	2.39
30.	TP30	95.35	79.44	HS	75.55	HS	31.07	2.95
31.	TP31	88.88	66.66	S	77.77	HS	32.01	2.82
32.	TP32	66.66	33.33	MS	77.77	HS	37.74	1.70
33.	TP33	13.33	6.66	R	33.33	MS	30.35	1.92
34.	TP34	84.44	63.33	S	39.99	MS	35.66	1.71
35.	TP35	97.77	73.33	HS	28.88	MS	125.44	1.60
36.	TP36	84.44	77.77	HS	75.55	HS	33.59	2.50
37.	TP37	82.22	67.77	S	53.33	S	43.38	2.20
38.	TP38	91.11	68.33	HS	62.22	HS	35.76	2.07
39.	TP39	86.66	78.88	HS	22.22	MS	41.47	2.16
40.	TP40	2.22	1.65	HR	2.22	R	35.08	2.13
41.	TP41	97.77	97.77	HS	15.55	MR	31.72	2.07
42.	TP42	84.44	48.33	S	13.33	MR	27.54	1.44
43.	TP43	13.33	6.66	R	17.77	MR	26.34	1.94
44.	TP44	17.77	8.88	R	65.55	HS	31.73	2.95
45.	TP45	84.44	63.33	S	2.22	R	48.29	2.32
46.	TP46	75.55	62.77	S	2.22	R	40.69	2.45
47.	TP47	15.55	7.77	R	59.99	S	29.70	1.92
48.	TP48	48.88	31.11	MS	53.33	S	40.03	2.56
49.	TP49	91.11	91.11	HS	84.44	HS	28.66	1.24
50.	TP50	46.66	25.55	MS	75.55	HS	30.69	1.48
51.	TP51	33.33	13.88	MR	59.99	S	30.58	1.67
52.	TP52	86.66	86.66	HS	22.21	MS	105.15	1.72
53.	TP53	8.88	5.54	R	48.88	S	23.33	1.84
54.	TP54	75.55	69.44	HS	51.11	S	21.00	1.53
55.	TP55	55.55	38.33	MS	77.77	HS	47.07	1.94

56.	TP56	11.10	8.88	R	77.66	HS	27.57	2.02
57.	TP57	55.55	31.11	MS	13.33	MR	40.39	1.81
58.	TP58	35.55	26.66	MS	51.11	S	34.40	1.52
59.	TP59	59.99	34.33	MS	77.77	HS	31.39	2.07
60.	TP60	46.66	23.33	MS	77.77	HS	30.42	1.48
61.	TP61	8.88	6.66	R	77.77	HS	23.02	1.28
62.	TP62	46.66	23.33	MS	84.33	HS	39.40	2.32
63.	TP63	44.44	22.22	MS	79.99	HS	33.50	1.66
						S.Em±	**3.69**	**0.202**
						C.D at 5%	**10.33**	**0.560**
						C.D at 1%	**13.65**	**0.747**

R - Resistant, MR - Moderately resistant, HR - Highly resistant,
S – Susceptible, MS - Moderately susceptible, HS – Highly susceptible

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Table 2: Heterosis (%) over better parent and standard parent for ToLCV , bacterial wilt and yield in tomato hybrids

Sl. No.	Cross	Per cent ToLCV incidence		ToLCV coefficient of infection		Per cent bacterial wilt incidence		Total yield/ plant (kg)	
		BP	SP	BP	SP	BP	SP	BP	SP
1.	TP1 x TP40	19.66	1157.89**	0.19	937.79**	-0.98	1113.91**	6.99	8.01
2.	TP1 x TP29	-19.11	750.31**	-25.58*	670.89**	2.61	1157.89**	98.15**	69.74**
3.	TP1 x TP25	-38.01**	551.61**	-50.96**	407.97**	-3.27	1085.84**	-6.18	-5.29
4.	TP5 x TP40	-7.79	1059.88**	-1.36	1033.24**	-91.32**	-0.00	60.57**	44.23**
5.	TP5 x TP29	-84.94**	89.38	-85.14**	70.75	-91.32**	-0.00	81.39**	70.56**
6.	TP5 x TP25	-68.92**	290.93*	-70.65**	237.15*	-91.32**	-0.00	34.06**	34.06**
7.	TP15x TP40	-34.89**	600.06**	-23.33	499.15**	11.58	1185.96**	47.95**	51.56**
8.	TP15 x TP29	2.29	999.81**	30.92*	922.21**	6.37	1125.90**	21.99**	24.97**
9.	TP15 x TP25	10.29	1085.84**	48.95**	1062.99**	2.89	1085.84**	-7.95	-5.70
10.	TP19 x TP40	73.56**	1125.90**	51.96**	1096.23**	-8.64	1085.84**	-12.58	6.51
11.	TP19 x TP29	37.42*	870.62**	24.67	881.42**	-3.09	1157.89**	-8.24	11.80
12.	TP19 x TP25	-85.84**	-0.00	-89.47**	-17.08	-4.01	1145.90**	-30.85**	-15.74
13.	TP24 x TP40	-92.03**	-0.00	-92.64**	-17.08	-99.04**	-89.38	86.56**	67.57**
14.	TP24 x TP29	-5.43	1085.84**	11.21	1153.10**	-82.84**	89.38	19.62*	12.48
15.	TP24 x TP25	-26.41**	822.86**	-17.76	826.69**	-91.63**	-0.00	-36.64**	-36.64**
16.	TP26 x TP40	-85.78**	-0.00	-88.97**	-17.08	-10.72	999.81**	61.63**	45.18**
17.	TP26 x TP29	49.15**	949.25**	39.83**	950.75**	-3.74	1085.84**	23.38*	16.01
18.	TP26 x TP25	68.57**	1085.84**	44.30**	984.34**	-0.49	1125.90**	-18.86*	-18.86*
19.	TP27 x TP40	-85.27**	89.38	-86.61**	53.67	-92.22**	-0.00	69.49**	52.24**
20.	TP27 x TP29	-85.27**	89.38	-86.61**	53.67	-92.22**	-0.00	72.01**	61.74**
21.	TP27 x TP25	-85.27**	89.38	-86.61**	53.67	-92.22**	-0.00	-19.13*	-19.13*
22.	TP44 x TP40	-55.23*	89.38	-45.03	85.34	-81.30**	89.38	39.91**	62.29**
23.	TP44 x TP29	-55.23*	89.38	-45.03	85.34	-72.47**	178.76	33.61**	55.36**
24.	TP44 x TP25	-76.36**	-0.00	-75.41*	-17.08	14.02	1185.96**	-14.82	-0.95
25.	TP45 x TP40	-31.79**	777.14**	-37.93**	612.46**	-0.00	-0.00	50.30**	35.01**
26.	TP45 x TP29	-85.27**	89.38	-86.64**	53.38	-0.00	-0.00	23.95*	16.55
27.	TP45x TP25	-92.22**	-0.00	-92.78**	-17.08	-83.21**	89.38	60.11**	60.11**
28.	TP46 x TP40	-83.18**	89.38	-86.30**	53.67	89.38	89.38	26.47**	22.52*
29.	TP46 x TP29	-83.18**	89.38	-86.30**	53.67	89.38	89.38	20.87*	17.10
30.	TP46 x TP25	-91.12**	-0.00	-89.78**	14.59	-91.13**	-0.00	58.89**	58.89**
31.	TP48 x TP40	15.24	824.91**	18.27	881.21**	33.15*	921.18**	28.85**	18.18*
32.	TP48 x TP29	44.51**	1059.88**	47.56**	1124.20**	43.40**	999.81**	67.24**	57.26**
33.	TP48 x TP25	-87.54**	-0.00	-90.01**	-17.08	-9.15	924.66**	1.09	1.09
34.	TP50 x TP40	40.01*	921.18**	3.29	646.98**	-83.49**	89.38	57.55**	41.52**
35.	TP50 x TP29	59.02**	1059.88**	47.11**	963.91**	-91.28**	-0.00	20.06*	12.89
36.	TP50 x TP25	-68.54**	129.44	-74.37**	85.34	-5.75	981.24**	53.32**	53.32**
37.	TP51 x TP40	-62.09**	129.44	-61.08**	85.34	16.18	999.81**	37.46**	23.47**
38.	TP51 x TP29	65.34**	900.68**	84.14**	776.94**	18.92	10.25.78**	23.38*	16.01
39.	TP51 x TP25	112.48**	1185.96**	141.03**	1047.83**	-2.49	999.81**	54.27**	54.27**
40.	TP59 x TP40	12.00	798.94**	-6.46	709.18**	-13.12	921.18**	54.90**	39.35**
41.	TP59 x TP29	28.01	927.45**	25.69*	987.26**	0.89	1085.84**	56.85**	47.49**
42.	TP59 x TP25	60.22**	1185.96**	43.11**	1137.94**	15.54	1258.01**	29.72**	29.72**
	S.Em±	**6.16**	**6.16**	**5.10**	**5.10**	**5.51**	**5.51**	**0.217**	**0.217**
	C.D. at 5%	**17.08**	**17.08**	**14.15**	**14.15**	**15.29**	**15.29**	**0.600**	**0.600**
	C.D. at 1%	**22.48**	**22.48**	**18.63**	**18.63**	**20.12**	**20.12**	**0.790**	**0.790**

* and ** indicate significance of values at p=0.05 and p=0.01 respectively.

BP – Heterosis over better parent SP – Heterosis over the standard parent (TP25)

Table 3. Mean, arcsine value and gca effects for ToLCV incidence, coefficient of infection and bacterial wilt incidence in tomato parents

Sl. No.	Lines	Per cent ToLCV incidence			ToLCV coefficient of infection			Per cent bacterial wilt incidence			Total yield/ plant(kg)
		Mean	Arcsine value	GCA effects	Mean	Arcsine value	GCA effects	Mean	Arcsine value	GCA effects	GCA effects
1	TP1	68.88	56.42	14.43**	57.77	48.51	7.84**	82.22	65.79	27.76**	-0.11
2	TP5	84.44	67.51	-3.81	64.99	53.81	-2.70	77.77	61.85	-32.31**	0.52**
3	TP15	71.11	57.70	18.47**	35.55	36.57	15.15**	77.77	61.85	28.47**	-0.12
4	TP19	37.77	37.91	6.15*	36.11	36.87	6.97**	86.66	69.66	28.33**	-0.68**
5	TP24	84.44	67.30	4.57	63.33	52.77	7.00**	73.33	59.21	-32.31**	-0.34**
6	TP26	27.77	37.75	6.84*	63.33	35.19	6.30**	82.21	66.11	25.15**	-0.35**
7	TP27	86.66	69.01	-24.77**	64.99	53.76	-21.12**	86.66	69.01	-32.31**	0.08
8	TP44	15.55	22.70	-26.37**	7.77	15.79	-21.24**	65.55	54.34	-6.30**	0.26*
9	TP45	86.66	69.01	-14.07**	64.99	53.76	-13.51**	2.22	5.37	-30.71**	0.21*
10	TP46	75.55	60.42	-26.37**	62.77	52.51	-21.73**	2.22	5.37	-29.11**	0.11
11	TP48	46.66	43.07	4.15	39.99	38.85	7.40**	46.66	41.16	18.60**	-0.07
12	TP50	39.99	39.14	8.18	31.10	33.87	2.84	75.55	61.57	-13.16**	0.18
13	TP51	28.88	32.48	10.07**	14.44	22.30	6.18**	59.99	50.80	21.81**	0.07
14	TP59	46.66	43.07	22.53**	42.2	40.51	20.61**	77.77	63.08	26.10**	0.25*
	S.Em.±		**4.36**	**2.66**		**3.61**	**2.23**		**3.90**	**2.13**	**0.099**
	CD at 5%		**12.08**	**7.45**		**10.00**	**6.24**		**10.81**	**5.98**	**0.277**
	CD at 1%		**15.89**	**9.89**		**13.17**	**8.29**		**14.23**	**7.94**	**0.368**
	Testers										
1	TP40	2.22	5.37	-0.19	1.68	4.68	-1.36	2.22	5.37	-3.92**	0.21**
2	TP29	2.22	5.37	5.12**	1.67	4.68	5.62**	2.22	5.37	-1.66	0.16**
3	TP25	4.44	10.16	-4.93**	2.22	7.20	-4.27**	2.22	5.37	-5.57**	-0.37**
	S.Em.±		4.36	1.23		3.61	1.03		3.90	0.99	0.046
	CD at 5%		**12.08**	**3.45**		**10.00**	**2.89**		**10.81**	**2.77**	**0.128**
	CD at 1%		**15.89**	**4.58**		**13.17**	**3.84**		**14.23**	**3.67**	**0.170**
	GCA:SCA			**1:1.10**			**1:1.10**			**1:32.15**	**1:2.46**

NS = Non-significant * and ** indicates significance of values at P=0.05 and P=0.01 respectively.

Table 4. Mean, Arcsine value and specific combining ability (sca) effects for ToLCV incidence, coefficient of infection and bacterial wilt incidence in tomato hybrids

Sl. No.	Cross	Per cent ToLCV incidence			ToLCV coefficient of infection			Per cent bacterial wilt incidence			Total yield/ plant (kg)
		Mean	Arcsine value	SCA effects	Mean	Arcsine value	SCA effects	Mean	Arcsine value	SCA effects	SCA effects
1.	TP1 x TP40	84.44	67.51	18.33**	56.10	48.60	13.79**	82.22	65.15	3.63	-0.61**
2.	TP1 x TP29	51.10	45.63	-8.86	35.54	36.10	-5.69	84.44	67.51	3.73	0.96**
3.	TP1 x TP25	33.33	34.97	-9.47*	16.64	23.79	-8.11*	79.95	63.64	-7.36*	-0.35*
4.	TP5 x TP40	77.77	62.25	31.31**	63.88	53.07	28.81**	2.22	5.37	3.92	-0.34*
5.	TP5 x TP29	4.44	10.16	-26.09**	2.77	8.00	-23.25**	2.22	5.37	1.66	0.32*
6.	TP5 x TP25	13.33	20.98	-5.22	7.77	15.79	-5.56	2.22	5.37	-5.57	-0.01
7.	TP15x TP40	37.77	37.57	-15.65**	23.33	28.08	-14.04**	86.66	69.01	6.78	0.48**
8.	TP15 x TP29	73.33	59.02	0.49	54.99	47.87	-1.22	82.22	65.79	1.30	-0.13
9.	TP15 x TP25	79.99	63.64	15.16**	66.10	54.47	15.26**	79.99	63.64	-8.08*	-0.35*
10.	TP19 x TP40	82.22	65.79	24.90**	68.32	56.02	22.09**	79.99	63.64	1.55	-0.07
11.	TP19 x TP29	55.55	52.09	5.88	51.66	45.96	5.05	79.99	67.51	3.16	0.11
12.	TP19 x TP25	2.22	5.37	-30.79**	1.11	3.88	-27.14**	84.44	66.86	-4.71	-0.04
13.	TP24 x TP40	2.22	5.37	-33.95**	1.11	3.88	-30.08**	0.01	0.57	-0.88	1.10**
14.	TP24 x TP29	79.99	63.64	19.01**	72.77	58.69	17.74**	6.66	10.16	6.45	-0.21
15.	TP24 x TP25	57.77	49.53	14.95**	47.21	43.40	12.34**	4.44	5.37	-5.57	-0.89**
16.	TP26 x TP40	8.88	5.37	-36.21**	4.44	3.88	-29.39**	73.33	59.02	0.12	0.55**
17.	TP26 x TP29	68.88	56.31	9.41*	43.33	49.21	8.96*	79.99	63.64	2.48	-0.11
18.	TP26 x TP25	79.99	63.64	26.80**	59.99	50.78	20.43**	82.22	65.79	-2.60	-0.44**
19.	TP27 x TP40	8.88	10.16	0.19	4.44	7.20	1.36	2.22	5.37	3.92	0.30
20.	TP27 x TP29	6.66	10.16	-5.12	3.33	7.20	-5.62	2.22	5.37	1.66	0.58**
21.	TP27 x TP25	6.66	10.16	4.93	3.33	7.20	4.27	2.22	5.37	-5.57	-0.88**
22.	TP44 x TP40	6.66	10.16	1.79	3.33	8.68	2.96	4.44	10.16	-17.30**	0.37*
23.	TP44 x TP29	8.88	10.16	-3.52	3.33	8.68	-4.03	6.66	14.96	-14.76**	0.24
24.	TP44 x TP25	6.66	5.37	1.73	3.33	3.88	1.07	86.66	69.01	32.06**	-0.61**
25.	TP45 x TP40	53.33	47.07	26.40**	30.55	33.37	19.91**	2.22	5.37	2.32	-0.26
26.	TP45 x TP29	8.88	10.16	-15.83**	4.44	7.18	-13.25**	2.22	5.37	0.06	-0.67**
27.	TP45x TP25	6.66	5.37	-10.57*	3.33	3.88	-6.66	4.44	10.16	-2.38	0.93**
28.	TP46 x TP40	8.88	10.16	1.79	3.33	7.20	1.97	4.44	10.16	5.52	-0.46**
29.	TP46 x TP29	4.44	10.16	-3.52	2.22	7.20	-5.01	4.44	10.16	3.26	-0.55**
30.	TP46 x TP25	2.22	5.37	1.73	2.22	5.37	3.05	2.22	5.37	-8.77*	1.01**
31.	TP48 x TP40	57.77	49.64	10.75**	51.66	45.95	11.59**	66.66	54.80	2.45	-0.39*
32.	TP48 x TP29	77.71	62.25	18.04**	70.61	57.33	15.99**	73.33	59.02	4.41	0.62**
33.	TP48 x TP25	6.64	5.37	-28.79**	3.33	3.88	-25.57**	66.66	54.99	-6.86	-0.23
34.	TP50 x TP40	66.66	54.80	11.88*	55.55	34.98	5.18	4.44	10.16	-10.44**	-0.07
35.	TP50 x TP29	77.77	62.25	14.00**	58.32	49.83	13.04**	2.22	5.37	-17.50**	-0.73**
36.	TP50 x TP25	8.88	12.31	-25.88**	4.44	8.68	-18.22**	71.60	58.03	27.93**	0.80**
37.	TP51 x TP40	6.66	12.31	-32.50**	3.33	8.68	-24.47**	73.33	59.02	3.45	-0.40*
38.	TP51 x TP29	64.44	53.70	3.57	43.33	41.07	0.94	75.55	60.42	2.58	-0.53**
39.	TP51 x TP25	86.66	69.01	28.93**	64.99	53.76	23.52**	73.33	59.02	-6.04	0.93**
40.	TP59 x TP40	55.55	48.24	-9.03	38.33	37.90	-9.68*	66.66	54.80	-5.05	-0.20
41.	TP59 x TP29	66.66	55.14	-7.45	59.99	50.92	-3.64	79.98	63.64	1.52	0.05
42.	TP59 x TP25	86.66	69.01	16.48**	71.66	57.98	13.31**	91.10	72.88	3.53	0.14
	S.Em±		**4.36**	**4.61**		**3.61**	**3.86**		**3.90**	**3.70**	**0.171**
	C.D. at 5%		**12.08**	**12.91**		**10.00**	**10.81**		**10.81**	**10.35**	**0.479**
	C.D. at 1%		**15.89**	**17.14**		**13.17**	**14.36**		**14.23**	**13.75**	**0.637**

* and ** indicate significance of values at p=0.05 and p=0.01, respectively.