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Sowjanya BA
Department of Genetic and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

Sridevi O
Department of Genetic and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

Corresponding Author:
Sowjanya BA
Department of Genetic and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

Combining ability and heterosis studies in tomato (*Solanum lycopersicum* L.) under ToLCV disease stress condition

Sowjanya BA and Sridevi O

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Abstract
The present investigation was carried out by crossing 15 lines (susceptible to ToLCV) with 3 testers (resistant to ToLCV) in line × tester design, the resultant 45 hybrids along with parents were evaluated for combining ability at Botany Garden, Department of Genetics and Plant Breeding, College of Agriculture, Dharwad during *Rabi*, 2018-19 and also screened for ToLCV resistant. Analysis of variance revealed highly significant differences among all the F_1 hybrid means and their respective six parental values for all examined traits and revealed the predominance of non-additive gene action for all the traits. In respect of both gca and sca effects, the parents and hybrids differed significantly. Among the parents, L4, L5, L6, L7 and AVTO-1219 were the best general combiners for yield per plant and other characters under study, and these may be used as valuable donors in the hybridization programme. Among the crosses, L3 × T3, L8 × T1, L13 × T3 and L14 × T2 were the most valuable combiners for yield per plant and other characters under study could be utilized for heterosis breeding programmes. The crosses L3 × T3, L1 × T3 and L7 × T3 exhibited superior mid parent heterosis for yield per plant. Out of 45 hybrids evaluated for performance in leaf curl stress condition under natural condition, five hybrids L6 × T2, L7 × T3, L10 × T2, L12 × T3 and L13 × T3 exhibited moderate resistance reaction.

Keywords: Tomato, gene action, combining ability, heterosis, ToLCV

Introduction

Among the vegetable crops, tomato (*Solanum lycopersicum* L.) is one of the most popular and widely grown vegetable crop and is native of Peru, South America (Rick, 1969) [21]. It belongs to the family Solanaceae with chromosome number 2n=2x=24. It is mainly consumed as salad, juice, sauce, ketchup and whole canned fruit. It is rich source of antioxidants, vitamin A, vitamin C and minerals like Ca, P and Fe in diet. Tomato is grown majorly in tropical and subtropical areas. Because of its day neutral, self-pollinated nature it can be grown throughout the year.

Worldwide growth and spread of tomato as a vegetable crop is limited by the fact that it is affected by a number of diseases causing substantial yield loss and also affecting the quality of fruits. Besides fungal, bacterial and mycoplasmal infection, it is also affected by large number of viral diseases. Among the various diseases, in India tomato leaf curl virus (ToLCV) is a major viral disease which cause 90 to 100 per cent yield loss in the affected areas. In southern India it affects during summer season and in northern India in autumun season (Banerjee and Kalloo, 1987a) [5].

In the face of mounting pressure, sustainable advance in tomato productivity and production is perhaps salutary to realize nutritional security particularly when India is facing demographic watershed. To meet the ever-increasing demand for this vegetable, there is a need to develop superior, stable and resistant varieties and also hybrids with better yield and quality.

By the application of biometrical principles, genetic architecture of yield can be better understood. Several biometrical methods provide the information on the combining ability status of parental lines. One of the technique widely used is line × tester analysis developed by Kempthrone (1957) [14]. This method provides reliable information on magnitude of additive and non-additive components of the lines based on the general combining ability (GCA) effects of parents and their hybrid combinations. This helps to assess the nature of gene action and in identifying superior parental lines for their *per se* performance.

The most excellent combinations with high GCA of individual lines are useful to get more desirable recombination which enables for further improvement of crop.

Heterosis breeding is one of the method to improve the yield and quality. The importance of heterosis breeding has been recognized widely in most of the vegetable crops. Hedrick and Booth (1968) [11] were the first to observe heterosis in tomato for superior yield and for higher number of fruits per plant. Choudhary *et al.* (1965) [8] emphasized the extensive exploitation of heterosis to maximize tomato production. Manifestation of heterosis in tomato is in the form of higher vigour, faster growth and development, increased productivity, earliness in maturity, higher levels of resistance to biotic and abiotic stresses (Yordanov, 1983) [32]. The study of heterosis provides the basis for the utilization of valuable hybrid combinations in the breeding.

Development of hybrids is important to increase yield *per se* and enhance resistance for most of the diseases. Choosing of suitable parents is very important in any hybrid breeding programme to realize significant heterosis for the economic traits.

Materials and Methods

The present study was carried out at Botany garden, University of Agricultural Sciences, Dharwad during rabi season 2018. The study used F_1 population developed by crossing 15 lines (susceptible to ToLCV) of tomato which were developed in the University of Agricultural Sciences, Dharwad Department of Genetics and Plant Breeding with 3 testers (CLN2768A, CLN777H and AVTO-1219) which were obtained from AVRDC Taiwan resistant to ToLCV disease. Forty five crosses were made manually by hand emasculation and pollination. The experiment was laid out by following Randomized Complete Block Design (RCBD). The experiment was replicated two times. The crop grown according to the standard cultural recommendations for the area and thirty days old seedlings of the plants were transplanted into the experimental plot with a spacing of 60 × 60 cm.

The plant growth measurements include days to 50 per cent flowering (DFF), plant height (PH), number branches per plant (NBPP), number of cluster per plant (NCPP), number of fruits per cluster (NFPC), number of fruits per plant (NFPP), polar length of fruit (PLF), equatorial length of fruit (ELF), fruit shape index (FSI), pericarp thickness of fruit (PTF), number of locules per fruit (NLPF), total soluble solids (TSS), average fruit weight (AFW) and yield per plant (YPP).

Screening of F_1's for ToLCV disease resistance

All forty five hybrids developed by crossing 15 lines with 3 testers along with parents were naturally screened for ToLCV disease resistance in summer 2019 by transplanting twenty five days old artificially inoculated seedlings to field condition and Plants were examined visually for disease symptoms at 30, 60 and 90 days after transplanting and observations recorded.

Per cent ToLCV disease incidence

The incidence of ToLCV was recorded at 30, 45 and 60 days after transplanting. The number of plants infected in each entry was recorded and computed by using the following formula.

$$\text{Per cent disease incidence (\%)} = \frac{\text{Total number of plants infected with ToLCV}}{\text{Total number of plants}} \times 100$$

3.1.8 ToLCV disease symptom severity

An arbitrary scale was employed for scoring the disease severity as described by Lapidot and Friedmann (2002) (Table 1).

Data analysis

Data were recorded on five randomly selected plants from each replication of parents, hybrids and two checks and analyzed by analysis of variance (ANOVA) at 5% levels of significance. Combining ability analysis was done using line × tester method (Kempthorne, 1957) [14]. The heterosis (%) over better parent by using the formula proposed by Falconer (1981) [9].

Table 1: ToLCV disease symptom severity scale used for screening the disease in tomato

Class	Category	Incidence	Score	Symptom severity
Resistant	R	0	0	No symptom
Moderately Resistant	MR	Upto 25%	1	Light yellowing along the leaf margins and mild vein clearing
Tolerant	T	26-50%	2	Yellowing of leaves and slight curling, growth, flowering and yield not greatly affected.
Susceptible	S	51-75%	3	Pronounced leaf curling, yellowing, stunting and reduced fruiting.
Highly susceptible	HS	>75%	4	Very severe curling, puckering, stunting and reduction in leaf size and no fruit formation.

Results and Discussion

Data in table 2 reflected that the analysis of variances due to genotypes and its components (parents, crosses and parents vs. crosses) were highly significant for all the traits studied except number of fruits per cluster. These results indicated wide between the parental materials used in this study. It also indicated that the variance due to lines was highly significant for all the traits studied except for fruits per cluster and fruit shape index and variance due to testers were significant for all the traits except for days to 50 per cent flowering, number of clusters per plant, number of fruits per cluster, equatorial length of fruit, fruit shape index, fruit shape index, pericarp thickness and number of locules. The variances due to line x tester interactions, representing specific combining ability, were also highly significant for all the traits, which suggested manifestation of parental genetic variability in their crosses.

In present study, *gca* variances was found to be significant for all the traits studied except number of fruits per cluster, number of fruits per plant, fruit shape index, number of locules per fruit and TSS and sca variance was found to be significant for all the traits studied except days to 50 per cent flowering (Table 2). This suggested that both additive and non-additive variances were important in the inheritance of these characters. Significant of both variances have been reported by Singh *et al.* (2010) [28] for days to 50% flowering; Asati *et al.* (2007) [4] and Singh *et al.* (2010) [28] for plant height at final harvest; Premalakshme *et al.* (2006) [20], Singh *et al.* (2010) [28] and Asati *et al.* (2007) [4] for number of fruits per plant, Singh *et al.* (2008) [27] for average fruit weight; Bhatt *et al.* (2000) [6] and Singh *et al*. (2010) [28] for fruit yield per plant; Himanshu *et al.* (2008) [12] for pericarp thickness; Singh *et al.* (2005) [26] and Joshi and Kohli (2006) [13] for total soluble solids;

The ratio of GCA to SCA variance was less than unity for all the characters including fruit yield per plant indicating predominance of non-additive gene action and hence, improvement in the yield can be achieved through heterosis breeding program (Table 3). These findings are in agreement with Ahmad *et al.* (2009) [2], Farzane *et al.* (2012) [10] and Mali and Patel (2014) [17] for plant height at final harvest; Angadi *et al.* (2012) [3] for number of clusters per plant; Angadi *et al.* (2012) [3] and Yadav *et al*. (2013) [30] for number of fruits per plant; Yadav *et al.* (2013) [30], Saleem *et al.* (2013) [22] and Agarwal *et al.* (2014) [1] for average fruit weight;

Nature and magnitude of combining ability effects provide guidelines for identifying parents and their utilization in hybridization programme. In the present study, significant *gca* effects were observed for most of the characters (Table 4). Among the parents L1, L5, L6, L7, L9, L10, L15 and AVTO-1219 (T3) were good general combiner for fruit yield per plant and some of its direct components. The females *viz.*, L2, L4, L8, L13 and L14 were found to be poor general combiner for fruit yield as well as yield attributing characters. Among males, CLN2777H (T2) was found to be poor general combiner for most of the traits followed by CLN2768A (T1). The estimates of *gca* effect further revealed that the parental lines showing high *gca* effects for fruit yield per plant also exhibited high to average *gca* effects for one or more yield components. Among parents, high *gca* effect for average fruit weight was found in L4, L5, L6, L7, L9, L10, L13 and AVTO-1219 (T3) which associated with positive and significant *gca* effects for average fruit weight. Almost identical result have been reported by Himanshu *et al.* (2008) [12], Ahmad *et al*. (2009) [2], Farzane *et al.* (2012) [10], Narasimhamurthy and Gowda (2013) [18].

Specific combining ability effects (SCA) is the manifestation of non-additive component of genetic variance and associated with interaction effects, which may be due to dominance and epistatic component of genetic variation that are non-fixable in nature. Such non-fixable components are potential parameters for heterosis breeding which is very much useful in tomato where commercial exploitation of heterosis is feasible. The estimation of sca effects (Table 5) show that, the crosses L3 × T3, L8 × T1, L13 × T3 and L14 × T2 had positive and significant values for yield per plant. The crosses L2 × T1, L10 × T3 and L1 × T3 exhibited positive and highly significant values for average fruit weight. The crosses L3 × T3, L8 × T1 and L14 × T1 had positive and significant or highly significant values for number of fruits per plant.

Heterosis

Significant efforts have been made for exploitation of heterosis in different yield contributing traits to find the feasible cross for the production of F_1 hybrids. The hybrids showing high heterosis have good chances to identify desirable lines in succeeding generations as compared to hybrids having low heterotic effects (Sharif *et al.*, 2001) [24]. All the crosses exhibited significant mid parent heterosis in majority of the traits indicating a predominance of non-additive gene action in the genetic control of these traits. The highest mid parent heterosis were exhibited by the hybrids *viz* L4 × T3 for plant height, L10 × T2, L3 × T1 and L6 × T2 for the trait number of branches per plant, L12 × T3, L10 × T2 and L6 × T2 hybrids exhibited for the trait number of clusters per plant. Highest mid parent heterosis for number of fruits per cluster hybrids exhibited by the crosses L5 × T1, L14 × T1, L3 × T3 and L4 × T2. The crosses L2 × T1, L2 × T3, L2 × T2 and L4 × T2 exhibited highest mid-parent value for the trait number of fruits per plant. Hybrids L1 × T3, L4 × T3, L13 × T2, L13 × T3, L10 × T3 and L6 × T3 exhibited highest mid parent heterosis for the trait average fruit weight. Highest mid parent heterosis for the trait polar length of fruit observed in the crosses L1 × T3, L4 × T3 and L6 ×. For th trait equatorial length of the fruit highest mid parent heterosis observed in the hybrids L1× T3, L4× T3 and L6× T3. The crosses L3 × T3 and L2 × T3exhibited highest mid parent heterosis for the trait fruit shape index. For pericarp thickness the crosses L13 × T3, L15 × T2 and L1 × T3 recorded highest significant value over mid-parent heterosis. The crosses L1 × T3, L11 × T2, L13 × T2 and L15 × T2 exhibited highest mid parent heterosis for the trait number of locules per fruit. Highest mid parent heterosis for TSS exhibited by the crosses L3 × T1, L10 × T1, L3 × T2, L14 × T2, L1 × T1 and L13 × T1. Highest mid parent heterosis for yield per plant obtained in the cross combination L4 × T3, L5 × T2, L7 × T2, L4 × T2 and L1 × T1. Assuming that epistasis is absent, the cause of heterosis can only be attributed to the dominant gene action. The results were in accordance with the findings of Makesh *et al*. (2003) [16], Bhatt *et al*. (2004) [7], Tiwari and Lal (2004) [29], Nitu *et al.* (2010) [19], Singh and Asati (2011) [25] and Shankar *et al*. (2013) [23].

Screening of hybrids for ToLCV disease resistance

The hybrids were evaluated based on 0 to 5 disease rating scale. The reaction of hybrids is presented in Table 1 and 2. Among 45 hybrids, five hybrids L6 × T2, L7 × T3, L10 × T2, L12 × T3 and L13 × T3 were moderately resistant, twenty-three were tolerant and remaining 15 were susceptible to ToLCV disease. Among 15 lines two lines 1602-15 and 1602-50 were tolerant, three lines 1601-36, 1602-03 and 1602-21 were highly susceptible remaining ten lines were susceptible and all the testers were resistant.

Table 2: Analysis of variance (ANOVA) for combining ability for yield and yield component traits in tomato

Source of Variations	Degrees of freedom	Days to 50% flowering	Plant height (cm)	Number of branches per plant	Number of clusters per plant	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)
Replications	1	0.28	87.97	2.94	35.97*	0.0004	25.81	4.82
Crosses	44	15.74*	1030.14**	10.53**	131.38**	0.37**	800.03**	623.41**
Line Effect	14	31.64**	1522.72	13.26	158.40	0.31	1231.53	1167.18**
Tester Effect	2	1.81	339.39	34.47*	166.10	0.05	35.04	737.02
Line * Tester Effect	28	8.79	833.18**	7.46**	115.39**	0.42	638.91**	343.41**
Error	44	8.60	27.64	0.98	8.12	0.04**	17.87	12.26
Total	89	12.04	523.93	5.73	69.37	0.20	404.65	314.32

Source of Variations	Degrees of freedom	Polar length of fruit (mm)	Equatorial length of fruit (mm)	Fruit shape index	Pericarp thickness (mm)	No. of locules	TSS (% brix)	Fruit yield per plant (kg)
Replications	1	0.10	17.64	0.004	0.07	0.001	0.24	0.01
Crosses	44	57.57**	147.20**	0.023**	2.53**	1.72**	1.22**	0.83**
Line Effect	14	101.39**	266.96*	0.021	2.94	1.62	1.42	1.80**
Tester Effect	2	50.70	2.45	0.036	4.82	1.14	0.70	1.44*
Line * Tester Effect	28	36.15**	97.65**	0.023**	2.17**	1.82**	1.16**	0.30**
Error	44	5.98	5.06	0.005	0.10	0.17	0.06	0.04
Total	89	31.42	75.47	0.014	1.30	0.93	0.64	0.43

* - Significant at 5% level ** - Significant at 5% level

Table 3: Estimates of variance components as reference to the prevailing gene action for yield and yield attributing characters in tomato

Sl. No.	Traits	σ^2gca	σ^2sca	σ^2gca/σ^2sca
1	Days to 50% flowering	0.43**	-0.06	-7.17
2	Plant height (cm)	50.55*	406.07**	0.12
3	No. of primary branches per plant	0.09**	0.21**	0.43
4	No. of secondary branches per plant	1.28**	3.37**	0.38
5	No. of clusters per plant	8.61*	54.07**	0.16
6	No. of fruits per cluster	0.008	0.19**	0.04
7	No. of fruits per plant	34.29	311.41**	0.11
8	Average fruit weight (g)	52.34**	166.71**	0.31
9	Polar length of fruit (mm)	3.79**	14.17**	0.27
10	Equatorial length of fruit (mm)	7.13*	45.63**	0.16
11	Fruit shape index	0.001	0.006*	0.17
12	Pericarp thickness (mm)	0.06	0.80**	0.08
13	No. of locules per fruit	0.21*	1.02**	0.21
14	TSS (% brix)	0.055	0.54**	0.10
15	Fruit yield per plant (kg)	0.088**	0.13**	0.68

* - Significant at 5% level ** - Significant at 1% level

Table 4: Estimates of general combining ability effects of parents for yield and its attributing traits in tomato

Parents	Days to 50% flowering	Plant height (cm)	No. of branches per plant	No. of clusters	No. of fruits per cluster	Total no. of fruits	Average fruit weight (g)	Polar length of fruit (mm)	Equatorial length of fruit (mm)	Fruit shape index	Pericarp thickness (mm)	No. of locules	TSS (% brix)	Yield per plant (kg)
Lines														
L1	-1.09	0.963	-0.53	-1.39	0.44 **	18.48**	-2.08	1.11	0.03	0.01	-0.02	0.27	0.46**	0.58**
L2	-0.42	-10.25**	-0.03	0.59	-0.13	-3.78*	-5.25**	-2.08	-4.67**	0.05	0.12	-0.22	0.19	-0.79**
L3	6.08**	-26.83**	2.31**	-5.38**	-0.13	-24.19**	-17.99**	-2.99*	-4.82**	0.06	0.15	1.34**	1.14**	0.0001
L4	-0.76	-19.60**	-2.19**	-1.66	0.09	-1.88	12.07**	4.84**	4.42**	0.01	0.13	-0.37	-0.77**	-0.26**
L5	1.08	4.45*	-1.04**	1.95	-0.07	9.47**	8.54**	1.97	2.27*	-0.01	0.60**	0.21	-0.15	0.48**
L6	-0.089	10.84**	0.59	0.89	-0.24**	-4.83 **	15.05**	4.40**	7.16 **	-0.05	0.57**	-0.04	-0.42**	0.212**
L7	-1.09	-6.95**	-0.11	-2.29*	0.14	1.05	8.41**	1.36	2.32*	-0.02	0.38*	-0.51*	-0.04	0.70**
L8	1.41	-12.55**	-0.76*	-4.85**	0.37**	-21.53**	-12.86**	-3.11**	-5.05**	0.01	-0.75**	-0.54**	-0.32**	-0.52**
L9	-2.25	21.74**	1.30**	6.86**	-0.19*	21.40**	18.93**	1.40	5.65**	-0.08	0.33*	0.52**	0.27*	0.51**
L10	-3.75**	9.18**	2.64**	3.73**	-0.33**	11.92**	4.97**	0.87	-0.10	0.03	-0.23	-0.09	-0.12	0.29**
L11	-2.09	16.25**	-0.17	-4.12**	-0.27**	-2.55	0.38	-1.11	4.04**	-0.08	-0.83**	0.56**	-0.46 **	0.128
L12	-0.42	22.41**	-0.03	3.62**	0.17*	5.87**	1.58	1.95	4.12**	-0.04	0.78**	-0.21	-0.20	0.13
L13	2.08	-18.08**	-2.28**	-7.98**	-0.002	-23.29 **	5.76**	1.03	3.49 **	-0.05	0.66**	-0.13	0.05	-0.95**
L14	1.58	16.73**	1.65**	11.98**	0.15	12.88 **	-35.54**	-12.19**	-19.81**	0.14**	-1.87**	-0.66**	0.65**	-0.85**
L15	-0.25	-8.30**	-1.36**	-1.94	-0.03	0.98	-1.98	2.53*	0.93	0.02	-0.04	-0.14	-0.27*	0.33**
SEm+	1.22	1.87	0.34	1.09	0.10	1.64	1.29	1.14	1.03	0.04	0.14	0.19	0.11	0.07
CD at 5% female	2.46	3.77	0.69	2.21	0.16	3.30	2.60	2.29	2.08	0.09	0.29	0.38	0.23	0.15
CD at 1% female	3.28	5.04	0.93	2.96	0.22	4.41	3.48	3.07	2.78	0.12	0.39	0.51	0.30	0.19
Testers														
CLN2768A	-0.09	-0.95	0.88 **	-1.09*	0.02	0.78	-4.01 **	-1.49 **	0.18	-0.04*	-0.44**	0.05	-0.05	-0.03
CLN2777H	0.28	3.73 **	0.31*	2.70**	0.03	-1.23	-1.54*	0.67	-0.33	0.02	0.10	0.16	0.17 **	-0.20**
AVTO1219	-0.19	-2.78 **	-1.19**	-1.60**	-0.05	0.46	5.54**	0.83	0.15	0.02	0.33**	-0.22 *	-0.12 *	0.23**
SEm+	1.19	0.84	0.15	0.49	0.03	0.73	0.58	0.51	0.46	0.02	0.06	0.08	0.05	0.03
CD at 5% male	2.41	1.69	0.31	0.99	0.07	1.47	1.16	1.02	0.93	0.04	0.13	0.17	0.10	0.06
CD at 1% male	3.22	2.25	0.42	1.32	0.09	1.97	1.55	1.37	1.24	0.05	0.17	0.23	0.14	0.09

* - Significant at 5% level ** - Significant at 5% level

Table 5: Estimates of specific combining ability effects of F_1 hybrids for yield and its attributing traits in tomato

Experimental hybrids	Days to 50% flowering	Plant height (cm)	No. of primary branches	No. of secondary branches	No. of clusters	No. of fruits per cluster	Total no. of fruits	Average fruit weight (g)	Polar length of fruit (mm)	Equatorial length of fruit (mm)	Fruit shape index	Pericarp thicknes (mm)	No. of locules	TSS (% brix)	Yield per plant (kg)
L1 x T1	-1.58	7.35 *	0.05	-1.21 *	-0.18	-0.02	1.06	-5.17*	3.22	-1.31	0.092	-0.11	-0.15	0.83**	-0.03
L1 x T2	1.06	0.96	0.34 *	0.35	0.58	-0.03	1.57	-14.16**	-8.19 **	-7.56**	-0.03	-0.78**	-0.48	0.29	-0.10
L1 x T3	0.52	-8.32 *	-0.38 **	0.86	-0.39	0.05	-2.63	19.33**	4.97*	8.87**	-0.06	0.90**	0.63	-1.11**	0.132
L2 x T1	0.76	26.22**	-0.10	2.78**	3.33	-0.65**	0.52	22.00**	7.93**	9.63 **	-0.03	1.33**	0.46	-0.98**	0.26*
L2 x T2	-0.61	1.73	-0.22	-3.15**	-5.78**	0.04	-6.27*	5.89*	1.14	6.63**	-0.12	0.84**	0.80*	0.20	0.25
L2 x T3	-0.14	-27.95 **	0.32 *	0.36	2.45	0.61**	5.74*	-27.89**	-9.08**	-16.26 **	0.15	-2.17**	-1.27**	0.78**	-0.51**
L3 x T1	1.26	-5.55	-0.48 **	1.01	-3.05	-0.15	-11.86**	5.54*	0.43	6.10**	-0.14	-0.08	1.29**	0.75**	-0.61**
L3 x T2	-1.61	-7.09 *	-0.35 *	0.72	-5.99 **	-0.46**	-16.49**	-7.23**	-0.96	7.59 **	-0.19 *	-0.68**	1.04**	0.19	-0.27*
L3 x T3	0.36	12.63**	0.83**	-1.72**	9.04**	0.61**	28.36**	1.69	0.53	-13.69 **	0.33**	0.753 **	-2.33**	-0.96**	0.88 **
L4 x T1	0.59	-9.98 **	0.01	-0.55	-0.42	-0.47**	-6.08*	-3.37	-5.29 *	-3.704 *	-0.03	-1.34**	0.61	0.05	-0.26*
L4 x T2	-2.28	10.78 **	-0.27	-0.98	-4.87*	0.32*	0.34	-3.16	0.57	-4.41*	0.09	0.86**	-0.496	-0.62 **	-0.03
L4 x T3	1.69	-0.794	0.26	1.53*	5.29**	0.17	5.741 *	6.52**	4.72*	8.16**	-0.06	0.48	-0.117	0.58**	0.29*
L5 x T1	1.256	-33.18 **	-0.50 **	-0.69	-9.58**	0.49**	-21.38**	-6.71**	-1.38	-4.07*	0.049	0.53*	-1.22 **	-0.58**	-0.33*
L5 x T2	-2.61	10.83**	0.23	-1.13	1.95	0.15	8.73**	11.09**	2.59	2.03	0.02	-0.33	-0.58	-0.35	0.19
L5 x T3	1.36	22.35**	0.27	1.83**	7.63**	-0.64**	12.64**	-4.38	-1.21	2.05	-0.07	-0.20	1.79**	0.93**	0.14
L6 x T1	-1.08	-17.13**	-0.44**	-2.67**	1.28	-0.04	0.07	-8.08**	-0.44	-4.68*	0.08	-0.12	-0.72*	-0.50*	-0.07
L6 x T2	-0.44	0.43	0.88**	2.93**	-1.27	-0.14	-4.67	-3.56	-2.60	-2.93	-0.02	-1.14**	0.17	0.08	0.04
L6 x T3	1.52	16.70**	-0.44**	-0.26	-0.01	0.18	4.59	11.65**	3.04	7.62**	-0.06	1.26**	0.55	0.43*	0.03
L7 x T1	-0.08	-4.49	-0.52 **	-0.88	-7.64**	-0.02	-6.01*	4.90*	-0.21	2.41	-0.03	0.99**	0.01	0.34	-0.09
L7 x T2	0.06	17.39**	0.37*	1.19	10.42**	-0.13	-0.75	-12.32**	-1.44	-2.86	0.02	-0.23	-0.36	0.09	0.08
L7x T3	0.02	-12.91 **	0.15	-0.31	-2.78	0.15	6.76*	7.42**	1.64	0.46	0.01	-0.76**	0.35	-0.43*	0.01
L8 x T1	-1.58	32.52**	0.47**	3.32**	10.18**	0.05	28.22**	-7.24**	-3.30	-4.79*	0.02	0.27	0.28	0.51*	0.79**
L8 x T2	2.06	-24.17**	-0.59**	-3.41**	-5.57**	-0.16	-16.89**	6.63**	5.36**	1.42	0.10	-0.03	-0.33	-0.23	-0.34 *
L8 x T3	-0.48	-8.35*	0.13	0.09	-4.61*	0.11	-11.41**	0.61	-2.06	3.37	-0.11	-0.25	0.05	-0.28	-0.46 **
L9 x T1	-0.91	1.22	-0.03	-1.79**	-9.94**	0.21	-29.11**	1.46	0.50	-0.04	0.03	0.75**	-0.03	0.16	-0.01
L9 x T2	-0.28	-6.97*	-0.21	0.77	1.37	-0.59**	12.40**	-0.30	-3.52	-4.03*	0.01	-0.17	-0.14	-0.78 **	0.05
L9 x T3	1.19	5.75	0.24	1.03	8.57**	0.39**	16.71**	-1.16	3.02	4.07*	-0.03	-0.58*	0.17	0.62 **	-0.04
L10 x T1	2.09	-9.21**	0.01	-1.38*	2.18	-0.45**	-1.77	-19.58**	-4.20*	-3.63*	-0.04	-0.63 *	-0.67*	1.29**	0.03
L10 x T2	-0.78	-3.90	-0.27	1.69**	-0.61	0.74**	3.56	-1.73	2.36	-4.11*	0.13	-0.45	0.32	-0.29	-0.09
L10 x T3	-1.31	13.12**	0.26	-0.31	-1.58	-0.29*	5.34	21.31**	1.84	7.75**	-0.08	1.08**	0.35	-1.01**	0.06
L11 x T1	-0.08	-0.37	0.27	0.35	-1.26	0.45**	7.34*	0.22	-0.66	0.66	0.00	-0.69**	-0.82 *	-0.47*	0.17

Table 4: Contd…..

Experimental hybrids	Days to 50% flowering	Plant height (cm)	No. of primary branches	No. of secondary branches	No. of clusters	No. of fruits per cluster	Total no. of fruits	Average fruit weight (g)	Polar length of fruit (mm)	Equatorial length of fruit (mm)	Fruit shape index	Pericarp thickness (mm)	No. of locules	TSS (% brix)	Yield per plant (kg)
L11 x T2	-0.44	21.52 **	0.101	-0.50	6.29**	-0.41**	12.35**	4.48	1.97	2.51	-0.01	0.65*	0.87*	0.46*	0.12
L11 x T3	0.52	-21.16 **	-0.368*	0.15	-5.04*	-0.04	-19.69**	-4.71*	-1.31	-3.17	0.00	0.04	-0.05	0.01	-0.29*
L12 x T1	-2.74	-15.25 **	-0.09	-1.21*	-2.46	-0.29*	-1.68	16.14**	3.03	4.86**	-0.01	1.29**	-0.05	-0.38	-0.21
L12 x T2	1.89	-3.13	0.18	0.85	-0.35	0.24	-2.07	0.75	1.95	2.31	0.00	-0.48	0.34	0.80**	0.02
L12 x T3	0.86	18.38**	-0.09	0.36	2.81	0.06	3.74	-16.88**	-4.98 *	-7.18**	0.01	-0.82**	-0.29	-0.43*	0.19
L13 x T1	2.26	39.62**	0.60**	2.27**	4.67*	0.18	11.09**	-8.26**	0.06	-4.22*	0.08	-0.77**	-0.63	0.22	0.04
L13 x T2	2.89	-23.85**	-0.57**	-1.89**	-4.09*	0.04	-8.49**	2.57	-2.79	1.64	-0.07	-0.02	0.29	-0.79**	-0.45**
L13 x T3	-5.14 *	-15.76 **	-0.04	-0.38	-0.58	-0.21	-2.59	5.69*	2.74	2.58	-0.01	0.79**	0.34	0.58**	0.41**
L14 x T1	0.76	-21.91**	0.53**	0.55	14.14**	0.27	25.76**	5.17*	1.65	2.01	-0.03	-0.06	0.05	-1.03**	0.23
L14 x T2	2.39	12.55**	0.26	1.38*	4.81*	-0.03	21.42**	-2.26	0.25	-1.57	0.08	0.14	-0.21	0.55**	0.36**
L14 x T3	-3.14	9.37**	-0.79**	-1.93**	-18.95**	-0.24	-47.18**	-2.91	-1.90	-0.44	-0.05	-0.07	0.17	0.48*	-0.59**
L15 x T1	-0.91	10.12**	0.23	0.12	-1.26	0.45**	3.81	2.97	-1.34	0.78	-0.03	-1.38**	1.58**	-0.20	0.10
L15 x T2	-1.28	-7.00*	0.12	1.19	3.12	0.44**	2.32	13.32**	3.30	3.34	0.01	1.82**	-1.23**	0.38	0.16
L15 x T3	2.19	-3.05	-0.35 *	-1.31*	-1.86	-0.89**	-6.17*	-16.29**	-1.97	-4.13*	0.03	-0.44	-0.35	-0.18	-0.26*
SEm+	2.11	3.24	0.14	0.59	1.90	0.14	2.83	2.23	1.97	1.78	0.07	0.25	0.33	0.19	0.12
CD at 5%	4.26	6.54	0.29	1.21	3.84	0.28	5.72	4.51	3.99	3.60	0.15	0.50	0.67	0.39	0.25
CD at 1%	5.68	8.73	0.38	1.61	5.12	0.30	7.63	6.02	5.31	4.81	0.20	0.67	0.89	0.52	0.34

* - Significant at 5% level ** - Significant at 5% level

Table 6: Promising crosses of tomato on the basis of mid parent heterosis.

Characters	Best crosses for MP heterosis (percent)
Days to 50% flowering	L3 x T1
Plant height (cm)	L4 x T3 (35.26)
Number of branches per plant	L10 × T2 (60.53)
Number of clusters per plant	L10 x T2 (80.01)
Number of fruits per cluster	L5 x T1 (40.56) L14 x T1 (40.56)
Total number of fruits per plant	L2 x T1 (77.28)
Average fruit weight(g)	L1 x T3 (49.66)
Polar length of fruit (mm)	L1 x T3 (17.85)
Equatorial length of fruit (mm)	L1 x T3 (37.28)
Fruit shape index	L3 x T3 (35.82)
Pericarp thickness (mm)	L13 x T3 (48.34)
Number of locules	L1 x T3 (50.43)
TSS (% brix)	L3 x T1 (23.24)
Fruit yield per plant (kg)	L4 x T3 (35.26)

Table 7: Mean of per cent disease incidence taken at 30, 60 and 90 DAT and disease reaction of the F_1 hybrids developed by crossing 15 lines with 3 testers screened under natural condition for ToLCV disease during summer 2019

Crosses	30 DAT	60 DAT	90 DAT	Mean of per cent disease incidence	Disease reaction
L1 x T1	0.00	40.00	60.00	33.33	T
L1 x T2	20.00	60.00	80.00	53.33	S
L1 x T3	40.00	60.00	80.00	60.00	S
L2 x T1	0.00	40.00	60.00	33.33	T
L2 x T2	0.00	40.00	60.00	33.33	T
L2 x T3	40.00	60.00	80.00	60.00	S
L3 x T1	20.00	40.00	60.00	40.00	T
L3 x T2	20.00	60.00	80.00	53.33	S
L3 x T3	0.00	40.00	60.00	33.33	T
L4 x T1	20.00	40.00	40.00	33.33	S
L4 x T2	40.00	60.00	80.00	60.00	S
L4 x T3	0.00	40.00	60.00	33.33	T
L5 x T1	0.00	60.00	80.00	46.67	T
L5 x T2	40.00	20.00	60.00	40.00	T
L5 x T3	20.00	60.00	80.00	53.33	S
L6 x T1	20.00	60.00	60.00	46.67	T
L6 x T2	0.00	20.00	40.00	20.00	MR
L6 x T3	0.00	40.00	60.00	33.33	T
L7 x T1	40.00	60.00	100.00	66.67	S
L7 x T2	40.00	40.00	60.00	46.67	T
L7x T3	0.00	40.00	60.00	33.33	T
L8 x T1	0.00	20.00	40.00	20.00	MR
L8 x T2	40.00	60.00	60.00	53.33	S
L8 x T3	20.00	40.00	60.00	40.00	T
L9 x T1	40.00	60.00	60.00	53.33	S
L9 x T2	40.00	60.00	80.00	60.00	S
L9 x T3	20.00	40.00	60.00	40.00	T
L10 x T1	0.00	40.00	60.00	33.33	T
L10 x T2	0.00	20.00	40.00	20.00	MR
L10 x T3	40.00	60.00	80.00	60.00	S
L11 x T1	0.00	40.00	60.00	33.33	T
L11 x T2	0.00	20.00	60.00	26.67	T
L11 x T3	40.00	60.00	80.00	60.00	S
L12 x T1	20.00	40.00	60.00	40.00	T
L12 x T2	20.00	40.00	60.00	40.00	T
L12 x T3	0.00	20.00	40.00	20.00	MR
L13 x T1	0.00	40.00	60.00	33.33	T
L13 x T2	40.00	60.00	80.00	60.00	S
L13 x T3	0.00	20.00	40.00	20.00	MR
L14 x T1	0.00	40.00	60.00	33.33	T
L14 x T2	40.00	60.00	80.00	60.00	S
L14 x T3	20.00	40.00	60.00	40.00	T
L15 x T1	20.00	40.00	60.00	40.00	T
L15 x T2	0.00	40.00	60.00	33.33	T
L15 x T3	0.00	40.00	60.00	33.33	T
1601-01	40.00	60.00	80.00	60.00	S

1601-10	40.00	80.00	80.00	66.67	S
1601-14	20.00	60.00	80.00	53.33	S
1601-22	40.00	60.00	100.00	66.67	S
1601-24	40.00	60.00	80.00	60.00	S
1601-36	60.00	100.00	100.00	86.67	HS
1601-37	40.00	60.00	80.00	60.00	S
1601-47	40.00	60.00	100.00	66.67	S
1602-03	60.00	80.00	100.00	80.00	HS
1602-06	0.00	60.00	100.00	53.33	S
1602-09	40.00	60.00	80.00	60.00	S
1602-11	60.00	60.00	80.00	66.67	S
1602-15	40.00	40.00	60.00	46.67	T
1602-21	60.00	100.00	100.00	86.67	HS
1602-50	0.00	60.00	80.00	46.67	T
CLN2768A	0.00	20.00	20.00	0.00	R
CLN2777H	0.00	0.00	0.00	0.00	R
AVTO-1219	0.00	0.00	0.00	0.00	R

DAT: days after transplanting; R: resistant; MR: moderately resistance; T: tolerant; S: susceptible; HS: highly Susceptibl

Table 8: Crosses having high heterosis for yield per plant and its resistance reaction in tomato

Crosses	Per see performance yield per plant	Resistance reaction
L3 × T3	3.84	T
L1 × T3	3.69	MR
L5 × T3	3.59	T
L10 × T3	3.32	T
L7× T2	3.32	T
L7 × T1	3.31	T
L12 × T3	3.28	T
L1× T1	3.26	T
L6 × T3	3.21	T
L9 × T1	3.20	MR
L5× T2	3.20	T
L15 × T1	3.13	MR
L9 × T2	3.09	MR
L15× T3	3.04	T

Conclusion

It could be concluded from the present study that out of 15 lines seven lines *viz.*, Seven lines L1, L5, L6, L7, L9, L10, L14 and L15 and the tester AVTO-1219 identified as a good combiners for most of the traits studied. Similarly four crosses *viz.*, L3 × T3, L8 × T1, L13 × T3 and L14 × T4 are identified as the good specific combiner and highest *per se* performance for yield per plant. Similarly Crosses L3 × T3, L1 × T3 and L7 × T3 exhibited superior performance for yield compared to mid parent. Out of 45 hybrids evaluated for ToLCV disease resistance, five hybrids L6 × T2, L7 × T3, L10 × T2, L12 × T3 and L13 × T3 exhibited moderate resistance reaction. From this study, it may be concluded that the cross combinations L3 × T3, L1 × T3 and L5 × T3 could be included for further testing for exploitation of hybrid vigour in tomato in ToLCV affected areas.

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