The Pharma Innovation Journal 2022; 11(12): 3896-3901

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(12): 3896-3901

www.thepharmajournal.com
Received: 19-09-2022
Accepted: 27-10-2022

Mahmadshafi
Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

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

Eshwar
Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

Corresponding Author:
Mahmadshafi
Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad, Karnataka, India

Heterosis for yield and yield related traits in Tomato

Mahmadshafi, O Sridevi and Eshwar

Abstract
In the present study 55 hybrids were developed by crossing 11 parents in half diallel fashion. 55 hybrids along with 11 parents and 2 checks were evaluated for yield and yield related components and screened against tomato leaf curl virus disease during summer 2022. Significant differences among genotypes were obtained for all the traits. Positive and negative high significant heterosis was found for many of the traits over the mid parent and commercial checks respectively. The highest number of fruits per plant in parent and hybrid was reported in AVTO-1424 (33.30) and AVTO-1424 × DMT-2 (41.80) respectively. The results revealed that the hybrid AVTO-1429 × DMT-3 exhibited significant positive standard heterosis for fruit yield per plant over both checks, and showed resistant to ToLCV. Out of 55 hybrids, 37, 13, 2 and 3 hybrids were exhibited resistant, moderate resistant, tolerance and susceptible reaction to tomato leaf curl virus. AVTO-1429 × DMT-3, was found to be significantly superior with respect to yield and yield contributing traits.

Keywords: Hybrids, heterosis, half diallel, ToLCV

Introduction
Tomato (*Solanum lycopersicum* L.) is the second most important vegetable crop after potato in the world. It is an important source of vitamins A and C. Lycopene that imparts red colour to the fruits is a powerful antioxidant. Tomato is believed to have originated in the mountainous regions of the Andes comprising Peru, Ecuador and Chile (Darwin *et al*., 2003) [3]. The phylogenetic classification of the family Solanaceae has been recently revised and the genus Lycopersicon has re-integrated into the genus *Solanum* (Peralta *et al*., 2008) [11]. The cultivated tomato and its wild relatives are diploid (2n = 24) with similar chromosome number and karyotype. It is an herbaceous annual plant with bisexual flowers and a major crop of the world economy and supplies essential nutrients in human diets.
The cultivated tomato has an estimated global production of over 193 million tonnes. It ranks third in priority after potato and onion. India ranks second after potato in the world. Major tomato producing countries are China, USA, India, Turkey, Egypt and Italy. India ranks second in the area as well as in the production of tomato next to China. In India, tomato occupies an area of 8.40 lakh ha, production of 20.35 mt and productivity of 24.19 t/ha. Karnataka ranks second next to Andhra Pradesh in both production and productivity with a production of 2.14 mt and productivity 30.02 t/ha from an area of 0.71 lakh ha (Ministry of Agriculture and Farmer welfare, Govt. of India, 2021-22).
Exploitation of hybrid vigour in Tomato (*Solanum lycopersicum* L.) is economical and easy for hybrid seed production because each fruit contains more seed compared to other vegetables as well as increased marketable fruit yield, component traits, and resistance to biotic and abiotic stresses. However, several major constraints including biotic (Bacterial, fungal and viral pathogens) and abiotic stresses greatly reduce the yield, fruit quality, nutritional content and shelf-life of tomato fruits (Hanson *et al*., 2016) [5]. In the past, commercial tomato growing areas have witnessed 100% yield losses worldwide due to tomato leaf curl virus (ToLCV) disease (Singh *et al*., 2014) [14]. The choice of suitable parents and the method used is important to breeding for improvement of traits in tomato. Hybrids usually have good quality characters and high yield.

Materials and methods
The experiment was conducted during rabi 2022 at the Botany Garden University of Agricultural Sciences Dharwad, Karnataka, India. Eleven parents were used in half diallel fashion to develop 55 hybrids the details of the parents used in the present study given in the (Table -1), 8 parents were confirmed for the presence of *Ty-2* and *Ty-3* genes by using linked genic markers P1-16 and SCAR-1 respectively. Seed of all hybrids, parents and 2 checks were sown in the portrays having 98 cavity and labelled.

The experiment was arranged in a randomized complete block design and replicated two times.

The field was prepared by one deep ploughing followed by clod breaking, hoeing, and levelling of the black soil. Fertilizers were applied at recommended quantity per hectare. Half of the nitrogen and all of the phosphorus and potassium were applied at soil preparation. Thirty days-old seedlings were carefully uprooted and transplanted by hand into field in the morning at a distance of 60 cm between rows and plants. The remaining nitrogen was top-dressed in two split doses at 20 and 30 days after sowing. Plants were irrigated immediately after transplanting. Weekly flood irrigation was given from transplanting to harvest. Weeds were controlled by two hand weedings at 1 and 2 weeks after transplanting of the seedlings. Plants were sprayed with Larvin (Chloropyripus) insectiside at 2.5 gm per liter of water at 15 day intervals after fruit initiation, for the control of fruit borer. Data were recorded from five randomly selected plants for days to fifty per cent flowering, plant height, number of primary branches per plant, number fruit per plant, average fruit weight, yield per plant and disease reaction of all parents, hybrids and checks were recorded and analyzed using Windostat (Ver. 9.2)

Table 1: Details of material used for half diallel analysis

Parents	Pedigree	Source	Tygenes
AVTO-1219	CLN3241-H-27	AVRDC, Taiwan	Ty-1/Ty-3, Ty-2
AVTO -1418	CLN3669A	AVRDC, Taiwan	Ty-2, Ty-3
AVTO -1424	CLN3682C	AVRDC, Taiwan	Ty-3, Ty-2
AVTO -1429	FMTT1733D	AVRDC, Taiwan	Ty-4
IIHR-2905	CLN0331A	IIHR, Bangalore	ty-5, Ty-6
IIHR -2619	CLN5512C	IIHR, Bangalore	Ty-1, Ty-3
IIHR -2896	CLN3552B	IIHR, Bangalore	Ty-1, Ty-2
IIHR -2852	CLN3125P	IIHR, Bangalore	Ty-1, ty-5
GPBT-08	-	UAS, Dharwad	-
DMT-2	-	UAS, Dharwad	-
DMT-3		UAS, Dharwad	-
Checks			
Abhilash	-	Seminis	-
Varun	-	Bayer	-

Result and Discussion

Estimates of mean squares for all the characters studied were highly significant indicating wide differences among the genotypes. Mean performance of parent and their disease reaction against ToLCV is given in the (Table-2).

The heterotic effect in F1 generation over standard checks and mid parents are presented in (Tables 3 and 4)

Table 2: Mean performance of parents for yield and yield related traits and disease reaction against ToLCV

Crosses	DFF	PH	NPB	NFPP	AFW	YPP	DR
GPBT-08	52.90	148.40	1.80	22.00	76.57	1.68	S
IIHR-2896	48.40	172.70	2.20	25.30	85.10	2.15	R
IIHR-2905	48.20	200.30	1.80	27.90	93.27	2.60	R
IIHR-2619	46.40	200.00	1.90	25.30	421.52	2.20	R
AVTO-1219	46.90	236.50	2.10	30.10	68.09	2.05	R
AVTO-1418	45.50	234.50	1.80	27.00	90.79	2.45	R
AVTO-1424	49.90	193.20	2.10	33.30	91.62	3.05	R
AVTO-1429	52.20	187.10	1.80	27.40	115.32	3.15	MR
DMT-2	49.60	148.30	1.30	23.70	102.59	2.35	S
IIHR-2852	50.90	230.30	1.90	24.80	122.98	3.05	R
DMT-3	48.50	129.30	2.10	27.40	104.01	2.85	S
Checks							
ABHILASH	51.30	222.80	1.90	32.80	102.33	3.35	R
VARUN	46.70	212.20	1.70	28.48	43.64	3.05	R

Days to 50 per cent flowering decides earliness of the genotype. Early genotypes are usually preferred as they are considered to be physiologically more efficient than late types. Parent AVTO-1418 (45.50) displayed earliness to flowering whereas GPBT-08 (52.90) observed late flowering followed by IIHR-2852 (50.90). The Cross IIHR-2905 × AVTO-1219 (42.50) recorded earliness while AVTO-1418 × AVTO-1424 (54.50) was late. Overall, hybrids were early compared to parents and checks.

Heterosis for this trait ranged from -15.32 (GPBT-08 × AVTO-1429) to 29.67 per cent (AVTO-1418 × IIHR-2852) over mid parent, -17.15 (IIHR-2905 × AVTO-1219) to 21.83 percent (AVTO-1418 × IIHR-2852) over commercial check Abhilash and -8.99 (IIHR-2905 × AVTO-1219) to 33.83 per cent (AVTO-1418 × IIHR-2852) over commercial check Varun. The negative heterotic performance for this trait was highest in the cross GPBT-08 × AVTO- 1429 over mid parent and IIHR-2905 × AVTO-1219 over commercial checks.

18 hybrids recorded negative significant heterosis over mid parent, 27 and 1 hybrids exhibited highly significant negative heterosis over commercial checks. Similar results obtained by Joshi (2015) [6] and Kumar *et al.* (2017) [8].

Plant height is one of the major concerns to plant breeding since it has positive correlation with yield per plant as

reported Gautam *et al.* (2018) [4] and Rehana *et al.* (2019) [12]. The *per se* performance of parents and hybrids revealed that, the parent had the plant height ranging from 129.30 cm (DMT-3) to 236.50 cm (AVTO-1219) and Hybrids it ranged from 173.80 cm (DMT-2 X DMT-3) to 348.22 cm (IIHR-2905 × AVTO-1429).

Hybrid performance with respect to mid-parent heterosis ranged from -11.35 (AVTO- 1219 × AVTO-1424) to 86.85 per cent (AVTO-1219 × DMT-3). 9 hybrids recorded highly significant positive heterosis over mid parent. Many hybrids recorded heterosis in positive direction over the standard checks. The range of standard heterosis over checks *viz.*, Abhilash and Varun was from -21.99 (DMT-2 × DMT-3) to 86.85 per cent (AVTO-1219 × DMT-3) and -17.86 (IIHR-2619 × DMT-3) to 98.18 per cent (AVTO-1219 × DMT-3) respectively.

Parent AVTO-1424 exhibited maximum and GPBT-08 exhibited minimum number of branches per plant. The cross AVTO-1424 × IIHR-28521418 exhibited maximum *per se* values, followed by GPBT-08 × DMT-2 and IIHR-2619 × AVTO- and the crosses IIHR-2619 × IIHR-2852, AVTO-1219 × AVTO-1418 and AVTO-1219 × AVTO-1424 exhibited minimum *per se* values for the trait.

Heterosis over mid-parent of the cross GPBT-08 × DMT-2 recorded maximum and GPBT-08 × IIHR-2905 showed minimum for the trait. The cross GPBT-08 × DMT-2, exhibited highest positive significant heterosis over commercial checks followed by IIHR-2619 × AVTO-1418, AVTO-1424 × IIHR-2852 and AVTO-1424 × AVTO-1429 and the crosses GPBT-08 × IIHR-2619, GPBT-08 × AVTO-1219, AVTO-1429 × DMT-2, AVTO-1418 × DMT-2, and IIHR-2896 × IIHR-2619 exhibited zero heterosis over standard check. Similar trend of number of branches per plant were reported by Khan and Jindal (2016) [7] and Kumar *et al.* (2017) [8].

Number of fruits per plant is one of the major concerns to plant breeding since it has positive correlation with yield per plant, Liu *et al.* (2021) [9] also reported similar trends for number of fruits per plant in tomato. Number of fruits per plant in parents and hybrids ranged from 22.00 (GPBT-08) to 33.30 (AVTO-1424) and 20.10 (GPBT-08 × DMT-2) to 41.80 per cent (AVTO-1424 × DMT-2) respectively. Heterosis over mid parent ranged from -12.04 (GPBT-08 × DMT-2) to 46.67 (AVTO-1424 × DMT-2). 50 crosses exhibited positive heterosis over mid parent of which 37 crosses were recorded positive significant heterosis.

Magnitude of heterosis over standard checks, ranged -38.72 (GPBT-08 × DMT-2) to 27.44 (AVTO-1424 × DMT-2) and -34.53 (GPBT-08 × DMT-2) to 36.16 per cent (AVTO-1424 × DMT-2). The hybrid AVTO-1424 × DMT-2 exhibited maximum significant positive heterosis over commercial checks.

The average fruit weight of a plant directly contributes to yield and positively correlated to fruit yield per plant, so positive heterosis is desirable for the trait. Among the parents, maximum fruit weight was noticed in AVTO-1219 (68.05) and minimum was noticed in IIHR- 2619 (42.52) while, the hybrid AVTO-1429 × DMT-3 exhibited maximum fruit weight (118.84 g) and minimum was observed in IIHR-2896 × IIHR-2619(40.74 g) Out of 55 hybrids, 14 recorded positive values of which 4 hybrids were positive significant. The range values in the hybrids over mid-parent heterosis and standard heterosis ranged from -83.91 (IIHR-2896 × IIHR-2619) to 57.18 per cent (GPBT-08 × AVTO-1219), -60.19 (IIHR-2896 × IIHR-2619) to 16.14 (AVTO-1429 × DMT-3) and -59.05 (IIHR-2896 × IIHR-2619) to 19.46 per cent (AVTO-1429 × DMT-3) respectively. Similar results were reported by Syarifah *et al.* (2016) [16] and Aisyah *et al.* (2016) [1].

Among parents, AVTO-1418 recorded highest fruit yield and exhibited highest mean value for the trait followed by IIHR-2852, AVTO-1429 and DMT-3.

Hybrids AVTO-1429 × IIHR-2852 exhibited highest *per se* value for the trait followed by AVTO-1429 × DMT-3, DMT-2 × IIHR-2852, AVTO-1424 × AVTO-1429, AVTO-1424 × IIHR-2852 and AVTO-1424 × DMT-2.

Out of 55 crosses, 11 crosses *viz.*, GPBT-08 × AVTO-1219, GPBT-08 × IIHR-2905, AVTO-1219 × AVTO-1418, DMT-2 × IIHR-2852, AVTO-1429 × DMT-3, AVTO-1429 × DMT-2, AVTO-1429 × IIHR-2852, AVTO-1219 × AVTO-1424, IIHR-2619 × DMT-3, AVTO-1424 × DMT-2 and AVTO-1424 × DMT-3 exhibited maximum positive significant heterosis over mid-parent. 4 crosses AVTO-1429 × IIHR-2852, AVTO-1429 × DMT-3, DMT- 2 × IIHR-2852 and AVTO-1424 × DMT-2 reported highest positive significant heterosis over standard checks. The results were in accordance with the findings of Gautam *et al.* (2018) [4], Rehana *et al.* (2019) [12] and Liu *et al.* (2021) [9].

Phenotypic screening of hybrids and parents against ToLCV disease resistance under natural condition

Among 55 hybrids, 37 hybrids showed resistant reaction to ToLCV disease, 13 hybrids exhibited moderate resistance it may be due to expressivity, penetrance and background effect of the genotype, while 3 hybrids were tolerant and the remaining 2 were susceptible to ToLCV disease, under natural condition.

Among 11 parents, 7 parents *viz.*, IIHR-2896, IIHR-2905, IIHR-2619, AVTO-1219, AVTO-1418, AVTO-1424 and IIHR-2852 showed resistant, AVTO-1429 moderate resistant and 3 parents, *viz.*, GPBT-08, DMT-2 and DMT-3 were susceptible, 2 commercial checks *viz.*, ABHILASH, VARUN exhibited no ToLCV symptoms. (Table-2 and 3)

Table 3: Magnitude of heterosis (%) over mid parent and standard checks (Abhilash and Varun)

Hybrids	Mean		Days 50% flowering		Mean		Plant height (cm)		Mean	No. of primary branches		Disease reaction	
	Mid parent		Abhilash	Varun	Mid parent		Abhilash	Varun	Mid parent	Abhilash	Varun		
GPBT-08 × IIHR-2896	48.30	-4.64	-5.85	3.43	179.10	11.55	-19.61	-15.6	1.80	-10	-5.26	5.88	R
GPBT-08 × IIHR-2905	49.00	-3.07	-4.48	4.93	203.40	16.66	-8.71	-4.15	1.80	0	-5.26	5.88	MR
GPBT-08 × IIHR-2619	48.20	-2.92	-6.04	3.21	189.60	8.84	-14.9	-10.65	1.90	2.7	0.00	11.76	T
GPBT-08 × AVTO-1219	46.20	-7.41*	-9.94**	-1.07	248.80	29.28**	11.67	17.25	1.90	-2.56	0.00	11.76	R
GPBT-08 × AVTO-1418	46.60	-5.28	-9.16**	-0.21	236.30	23.43	6.06	11.36	1.70	-5.56	-10.53	0	MR
GPBT-08 × AVTO-1424	46.80	-8.95**	-8.77*	0.21	225.60	32.08	1.26	6.31	2.50	28.21	31.58	47.06	MR
GPBT-08 × AVTO-1429	44.50	-15.32**	-13.26**	-4.71	194.00	15.65	-12.93	-8.58	2.00	11.11	5.26	17.65	MR

GPBT-08 × DMT-2	48.20	-5.95*	-6.04	3.21	177.90	19.92	-20.15	-16.16	2.30	48.39**	21.05**	35.29	S
GPBT-08 × IIHR-2852	45.20	12.91**	-11.89**	-3.21	212.80	12.38	-4.49	0.28	2.00	8.11	5.26	17.65	R
GPBT-08 × DMT-3	44.60	-12.03**	-13.06**	-4.5	185.90	33.89**	-16.56	12.39	1.90	-2.56	0.00	11.76	S
IIHR-2896 × IIHR-2905	49.50	2.48	-3.51	6.00	238.90	28.1	7.23	12.58	2.10	5	10.53	23.53	R
IIHR-2896 × IIHR-2619	47.10	-0.63	-8.19*	0.86	213.90	14.78	-3.99	0.8	1.90	-7.32	0.00	11.76	R
IIHR-2896 × AVTO-1219	46.20	-3.04	-9.94**	-1.07	343.60	67.94*	54.22**	61.92	2.00	-6.98	5.26	17.65	R
IIHR-2896 × AVTO-1418	44.90	-4.37	-12.48**	-3.85	247.50	21.56	11.09	16.64	2.00	0.00	5.26	17.65	MR
IIHR-2896 × AVTO-1424	43.80	-10.89**	-14.62**	-6.21	236.00	29	5.92	11.22	2.20	2.33	15.79	29.41	R
IIHR-2896 × AVTO-1429	44.20	-12.13**	-13.84**	-5.35	235.90	31.13**	5.88	11.17	1.90	-5	0.00	11.76	R
IIHR-2896 × DMT-2	50.80	3.67	-0.97	8.78*	217.50	35.51**	-2.38	2.5	2.00	14.29	5.26	17.65	MR
IIHR-2896 × IIHR-2852	44.90	-9.57**	-12.48**	-3.85	238.30	18.26	6.96	12.3	1.70	-17.07	-10.53	0.00	R
IIHR-2896 × DMT-3	46.60	-3.82	-9.16**	-0.21	191.50	26.82	-14.05	-9.75	1.90	-11.63	0	11.76	MR
IIHR-2905 × IIHR-2619	46.60	-1.48	-9.16**	-0.21	209.50	4.67	-5.97	-1.27	2.20	18.92**	15.79	29.41	MR
IIHR-2905 × AVTO-1219	42.50	-10.62**	-17.15**	-8.99*	219.10	0.32	-1.66	3.25	2.00	2.56	5.26	17.65	R
IIHR-2905 × AVTO-1418	44.50	-5.02	-13.26**	-4.71	233.50	7.41	4.8	10.04	2.10	16.67	10.53	23.53	R
IIHR-2905 × AVTO-1424	43.80	-10.7**	-14.62**	-6.21	206.00	4.7	-7.54	-2.92	2.00	2.56	5.26	17.65	R
IIHR-2905 × AVTO-1429	45.10	-10.16**	-12.09**	-3.43	450.60	-10.20**	10.22**	11.25**	2.20	22.22	15.79	29.41	R
IIHR-2905 × DMT-2	50.00	2.25	-2.53	7.07	188.30	8.03	-15.48	-11.26	2.00	29.03**	5.26	17.65	MR
IIHR-2905 × IIHR-2852	45.20	-8.78**	-11.89**	-3.21	231.80	7.66	4.04	9.24	1.60	-13.51	-15.79	-5.88	MR
IIHR-2905 × DMT-3	45.00	-6.93*	-12.28**	-3.64	186.90	13.41	16.11	-11.92	1.80	-7.69	-5.26	5.88	MR
IIHR-2619 × AVTO-1219	46.00	-1.39	-10.33*	-1.5	215.40	-1.31	-3.32	1.51	1.90	-5	0.00	11.76	R
IIHR-2619 × AVTO-1418	47.10	2.5	-8.19	0.86	208.50	-4.03	-6.42	-1.74	2.30	24.32**	21.05**	35.29**	R

Hybrids	Mean		Days 50% flowering		Mean		Plant height (cm)		Mean	*No. of primary branches*			Disease reaction
	Mid parent		Abhilash	Varun	Mid parent		Abhilash	Varun		Mid parent	Abhilash	Varun	
IIHR-2619 × AVTO-1424	50.50	4.88	-1.56	8.14*	243.20	23.7	9.16	14.61	2.00	0.00	5.26	17.65	R
IIHR-2619 × AVTO-1429	48.60	-1.42	-5.26	4.07	186.90	-3.44	-16.11	-11.92	1.90	2.7	0.00	11.76	MR
IIHR-2619 × DMT-2	47.30	-1.46	-7.80*	1.28	206.40	18.52	-7.36	-2.73	1.70	6.25	-10.53	0.00	T
IIHR-2619 × IIHR-2852	49.40	1.54	-3.7	5.78	226.40	5.23	1.62	6.69	1.50	-21.05	-21.05	-11.76	R
IIHR-2619 × DMT-3	50.30	6.01	-1.95	7.71*	174.30	5.86	-21.77	-17.86	1.90	-5	0	11.76	R
AVTO-1219 × AVTO-1418	51.70	11.90**	-0.78	10.71**	243.70	3.48	9.38	14.84	1.50	-23.08	-21.05	-11.76	R
AVTO-1219 × AVTO-1424	51.20	5.79	-0.19	9.64*	190.48	-11.35	-14.51	-10.24	1.80	-14.29	-5.26	5.88	R
AVTO-1219 × AVTO-1429	51.80	4.54	0.97	10.92**	229.80	8.5	3.14	8.29	2.00	2.56	5.26	17.65	R
AVTO-1219 × DMT-2	49.40	2.38	-3.7	5.78	217.60	13.1	-2.33	2.54	2.10	23.53	10.53	23.53	R
AVTO-1219 × IIHR-2852	52.00	6.34*	1.36	11.35**	246.60	5.66**	10.68**	16.21	1.70	-15	-10.53	0	R
AVTO-1219 × DMT-3	46.50	-2.52	-9.36**	-0.43	416.30	12.76**	86.85**	96.18**	1.90	-9.52	0	11.76	MR
AVTO-1418 × AVTO-1424	54.50	14.26**	6.24	16.70**	230.10	7.6	3.28	8.44	2.10	7.69	10.53	23.53	R
AVTO-1418 × AVTO-1429	47.60	-2.56	-7.21*	1.93	194.10	-7.92	-12.88	-8.53	1.80	0.00	-5.26	5.88	R
AVTO-1418 × DMT-2	46.70	-1.79	-8.97**	0	214.60	12.12	-3.68	1.13	1.90	22.58*	0	11.76	R
AVTO-1418 × IIHR-2852	62.50	29.67**	21.83**	33.83**	206.60	-11.1	-7.27	-2.64	2.00	8.11	5.26	17.65	R
AVTO-1418 × DMT-3	46.80	-0.43	8.77*	0.21	220.30	21.11	1.12	3.82	2.00	2.56	5.26	17.65	R
AVTO-1424 × AVTO-1429	47.90	-6.17	-6.63	2.57	212.70	11.86	-4.53	0.24	2.40	23.08	26.32**	41.18**	R
AVTO-1424 × DMT-2	50.00	0.5	-2.53	7.07	218.60	28.02	-1.89	3.02	2.40	41.18**	26.32	41.18**	R
AVTO-1424 × IIHR-2852	47.90	-4.96	-6.63	2.57	192.90	-8.9	-13.42	-9.1	2.70	35	42.11**	58.82	R
AVTO-1424 × DMT-3	52.20	6.10*	1.75	11.78**	216.20	34.08**	-2.96	1.89	2.10	0.00	10.53	23.53	R
AVTO-1429 × DMT-2	44.60	-12.38**	-13.06**	-4.5	215.50	28.5	-3.28	1.56	1.90	22.58	0.00	11.76	R
AVTO-1429 × IIHR-2852	49.00	-4.95	-4.48	4.93	234.03	12.13	5.04	10.29	2.10	13.51	10.53	23.53	R
AVTO-1429 × DMT-3	49.00	-2.68	-4.48	4.93	227.70	43.93**	2.2	7.3	2.10	7.69	10.53	23.53	R
DMT-2 × IIHR-2852	47.10	-6.27*	-8.19*	0.86	218.20	15.27	-2.06	2.83	1.90	18.75**	0.00	11.76	R
DMT-2 × DMT-3	49.50	0.92	-3.51	6.00	173.80	25.22	-21.99	-18.1	1.70	0.00	-10.53	0.00	S
IIHR-2852 × DMT-3	47.90	-3.62	-6.63	2.57	209.50	16.52	-5.97	-1.27	2.20	10	15.79	29.41**	R

Table 4: Magnitude of heterosis (%) over mid parent and standard checks (Abhilash and Varun)

Hybrids	Mean		No. fruits per plant		Mean	Average fruit weight (gm)			Mean		Yield per plant (Kg)	
	Mid parent		Abhilash	Varun	Mid parent		Abhilash	Varun	Mid parent		Abhilash	Varun
GPBT-08 × IIHR-2896	30.10	27.27**	-8.23	-1.95	68.12	-15.74	-33.43	-31.53	2.05	7.04	-38.81**	-32.79**
GPBT-08 × IIHR-2905	29.70	19.04**	-9.45	-3.26	101.10	19.05*	-1.2	1.62	3.00	40.09**	-10.45	-1.64
GPBT-08 × IIHR-2619	28.40	20.08**	-13.41*	-7.49	82.86	-66.73**	-19.02	-16.71	2.35	21.04	-29.85**	-22.95*
GPBT-08 × AVTO-1219	29.40	12.86*	-10.37	-4.23	113.69	57.18*	11.11	14.28	3.34	79.16**	-0.18	9.64
GPBT-08 × AVTO-1418	29.20	19.18**	-10.98	-4.89	75.44	-9.84	-26.27	-24.16	2.20	6.46	-34.33**	-27.87**
GPBT-08 × AVTO-1424	35.00	26.58**	6.71	14.01*	64.70	-23.07	-36.77	-34.97	2.25	-4.92	-32.84**	-26.23**
GPBT-08 × AVTO-1429	30.10	21.86**	-8.23	-1.95	68.88	-28.2	-32.68	-30.76	2.07	-14.55	-38.36**	-32.30**
GPBT-08 × DMT-2	20.10	-12.04	-38.72**	-34.53**	95.05	6.1	-7.11	-4.46	1.90	-5.78	-43.28**	-37.70**
GPBT-08 × IIHR-2852	24.80	5.98	-24.39**	-19.22**	66.54	-33.31	-34.97	-33.12	1.65	-30.28**	-50.75**	-45.90*
GPBT-08 × DMT-3	21.90	-11.34	-33.23**	-28.66**	86.06	-4.68	-15.89*	13.49	1.85	-18.38	-44.78**	-39.34**
IIHR-2896 × IIHR-2905	26.90	1.13	-17.99**	-12.38*	65.08	-27.03	-36.4	-34.58	1.75	-26.32*	-47.76**	-42.62**
IIHR-2896 × IIHR-2619	28.30	11.86	-13.72*	-7.82	40.74	-83.92**	-60.19	-59.05	1.15	-47.13**	-65.67**	-62.30**
IIHR-2896 × AVTO-1219	31.40	13.36*	-4.27	2.28	86.40	12.8	-15.56	-13.15	2.75	30.95*	-17.91*	-9.84
IIHR-2896 × AVTO-1418	28.50	8.99	-13.11*	-7.17	87.81	-0.16	-14.19	-11.74**	2.50	8.7	-25.37**	-18.03

IIHR-2896 × AVTO-1424	28.20	-3.75	-14.02*	-8.14	99.47	12.57	-2.79	-0.02	2.80	7.69	-16.42	-8.2
IIHR-2896 × AVTO-1429	30.60	16.13**	-6.71	-0.33	52.31	-47.8	-48.88	-47.42	1.60	-39.62**	-52.24**	-47.54**
IIHR-2896 × DMT-2	25.20	2.86	-23.17**	-17.92**	97.28	3.65	-4.94	-2.22	2.45	8.89	-26.87**	-19.67*
IIHR-2896 × IIHR-2852	29.40	17.37**	-10.37	-4.23	93.53	-10.1	-8.6	-5.99	2.75	5.77	-17.91*	-9.84
IIHR-2896 × DMT-3	26.50	0.57	-19.21**	-13.68*	71.85	-24.01	-29.78**	-27.78	1.90	-24.00*	-43.28**	-37.70*
IIHR-2905 × IIHR-2619	30.90	16.17**	-5.79	0.65	46.91	-81.77**	-54.15	-52.84	1.45	-39.58**	-56.72**	-52.46**
IIHR-2905 × AVTO-1219	28.30	-2.41	-13.72*	-7.82	51.10	-36.66	-50.06	-48.64	1.45	-37.63**	-56.72**	-52.46**
IIHR-2905 × AVTO-1418	27.90	1.64	-14.94**	-9.12	87.74	-4.66	-14.25	-11.81	2.45	-2.97	-26.87**	-19.67*
IIHR-2905 × AVTO-1424	32.30	5.56	-1.52	5.21	94.47	2.19	-7.68	-5.04	3.05	7.96	-8.96	0
IIHR-2905 × AVTO-1429	32.20	16.46**	-1.83	4.89	53.00	-49.18**	-48.2	-46.73**	1.70	-40.87**	-49.25**	-44.26**
IIHR-2905 × DMT-2	29.00	12.40*	-11.59*	-5.54	55.30	-43.53	-45.96	-44.41	1.60	-35.35**	-52.24**	-47.54**
IIHR-2905 × IIHR-2852	29.80	13.09*	-9.15	-2.93	43.58	-59.69	-57.41	-56.19	1.30	-53.98**	-61.19**	-57.38**
IIHR-2905 × DMT-3	29.40	6.33	-10.37	-4.23	76.45	-22.5	-25.29	-23.15	2.25	-17.43	-32.84**	-26.23**
IIHR-2619 × AVTO-1219	33.90	22.38**	3.35	10.42	72.21	-70.50**	-29.43	-27.42	2.45	15.29	-26.87**	-19.67*
IIHR-2619 × AVTO-1418	35.10	34.23**	7.01	14.33*	44.15	-82.76**	-56.85	-55.62	1.55	-33.33**	-53.73**	-49.18**

Hybrids	Mean		No. fruits per plant		Mean	Average fruit weight (gm)			Mean	Yield per plant (Kg)		
	Mid parent		Abhilash	Varun		Mid parent	Abhilash	Varun		Mid parent	Abhilash	Varun
IIHR-2619 × AVTO-1424	32.50	10.92*	-0.91	5.86	92.42	-63.98**	-9.68	-7.11	3.00	14.29	-10.45	-1.64
IIHR-2619 × AVTO-1429	30.20	14.61*	-7.93	-1.63	56.25	-79.05**	-45.03	-43.46	1.70	-36.45**	-49.25**	-44.26**
IIHR-2619 × DMT-2	35.20	43.67**	7.32	14.66*	51.43	-80.37**	-49.74	-48.3*	1.80	-20.88	-46.27**	-40.98**
IIHR-2619 × IIHR-2852	34.00	35.73**	3.66	10.75	73.53	-72.99**	-28.14	-26.09	2.50	-4.76	-25.37**	-18.03
IIHR-2619 × DMT-3	28.10	6.64	-14.33*	-8.47	110.29	-58.03**	7.79	10.87	3.10	22.77*	-7.46	1.64
AVTO-1219 × AVTO-1418	33.20	16.29**	1.22	8.14	104.74	31.85*	2.36	5.28	3.47	54.36**	3.67	13.87
AVTO-1219 × AVTO-1424	33.80	6.62	3.05	10.1	93.43	17.01**	-8.69	-6.08	3.15	23.53*	-5.97	3.28
AVTO-1219 × AVTO-1429	30.30	5.39	-7.62	-1.3	92.36	0.72	-9.74	-7.16	2.80	7.69	-16.42	-8.2
AVTO-1219 × DMT-2	31.40	16.73**	-4.27	2.28	83.18	-2.53	-18.71	-16.39	2.60	18.18	-22.39*	-14.75
AVTO-1219 × IIHR-2852	32.60	18.74**	-0.61	6.19	105.83	10.77	3.42	6.37	3.45	35.29**	2.99	13.11
AVTO-1219 × DMT-3	30.20	5.04	-7.93	-1.63	73.09	-15.06	-28.57	-26.53	2.20	-10.2	-34.33**	-27.87**
AVTO-1418 × AVTO-1424	27.60	-8.46	-15.85**	-10.1	74.34	-18.49	-27.35	-25.28	2.05	-25.45**	-38.81**	-32.79**
AVTO-1418 × AVTO-1429	32.70	20.22**	-0.3	6.51	72.73	-29.42	-28.92	-26.89	2.35	-16.07	-29.85**	-22.95*
AVTO-1418 × DMT-2	28.60	12.82*	-12.80*	-6.84	66.43	-31.29**	-35.08	-33.23	1.90	-20.83*	-43.28**	-37.70**
AVTO-1418 × IIHR-2852	32.10	23.94**	-2.13	4.56	96.69	-9.54	-5.51	-2.81	3.10	12.73	-7.46	1.64
AVTO-1418 × DMT-3	35.10	29.04**	7.01	14.33*	98.10	0.72	4.13	-1.39	3.45	30.19**	2.9	13.11
AVTO-1424 × AVTO-1429	35.20	15.98**	7.32	14.66**	96.05	-7.16	-6.13	-3.45	3.38	8.94	0.81	10.72
AVTO-1424 × DMT-2	41.80	46.67**	27.44**	36.16**	94.95	-2.21	-7.2	-4.55	3.96	46.67**	18.21**	29.84**
AVTO-1424 × IIHR-2852	35.50	22.20**	8.23	15.64*	86.67	-19.22	-15.29**	-12.88	3.07	0.72	-8.3	0.72
AVTO-1424 × DMT-3	36.10	18.95**	10.06	17.59**	95.84	-2.01	-6.33	-3.66	3.45	16.95*	2.99	13.11
AVTO-1429 × DMT-2	36.30	42.07**	10.67	18.24**	99.65	-8.54	-2.61	0.17	3.60	30.91**	7.46	18.03
AVTO-1429 × IIHR-2852	35.30	35.25**	7.62	14.98*	113.89	-4.41	11.3	14.47	4.00	29.03**	19.40*	31.15**
AVTO-1429 × DMT-3	34.10	24.45**	3.96	11.07	118.84	8.37	16.14	19.46	4.05	35.00**	20.90*	32.79**
DMT-2 × IIHR-2852	34.90	43.92**	6.4	13.68*	114.61	1.62	12.01	15.21	4.00	48.15**	19.40*	31.15**
DMT-2 × DMT-3	35.40	38.55**	7.93	15.31*	73.48	-28.87	-28.19	-26.14	2.60	0	-22.39*	-14.75
IIHR-2852 × DMT-3	33.10	26.82**	0.91	7.82	55.88	-50.76	-45.38	-43.83	1.85	-37.29**	-44.78**	-39.34**

The magnitude of heterosis was improved compared to parental material. This was exemplified as occurring because the best performing hybrids AVTO-1429 × DMT-3, AVTO-1429 × IIHR- 2852 and DMT-2 × IIHR-2852 which had heterosis values of 20.90, 19.40,19.40 and 32.79, 31.15 and 31.15 respectively, over both commercial checks and showed resistance to ToLCV disease. These hybrids performed better than the commercial checks for yield per plant, hence these hybrids further evaluated for yield potential in multi-location trails to check their yield stability.

References

1. Aisyah SI, Wahyuni S, Syukur M, Witono JR. The estimation of combining ability and heterosis effect for yield and yield components in tomato (*Solanum lycopersicum* Mill.) at lowland. Ekin Journal of Crop Breeding Genetics. 2016;2(1):23-29.
2. Choudhary B, Punia RS, Sangha HS. Manifestation of hybrid vigour in F1 and its correlation in F2 generation of tomato (*Lycopersicon esculentum* Mill). Indian Journal of Horticulture. 1965;22:52-59.
3. Darwin SC, Knapp S, Peralta IE. Taxonomy of tomatoes in the Galápagos Islands: native and introduced species of Solanum section *Lycopersicon* (*Solanaceae*). Systematics and Biodiversity. 2003;1(1):29-53.
4. Gautam N, Kumar M, Kumar D, Kumar S, Vikram A, Dogra RK, *et al*. Combining ability and gene action studies for important quality traits in tomato (*Solanum lycopersicum* L.). International Journal of Chemical Studies. 2018;6(2):1992-6.
5. Hanson P, Lu SF, Wang JF, Chen W, Kenyon L, Tan CW, *et al*. Conventional and molecular marker-assisted selection and pyramiding of genes for multiple disease resistance in tomato. Scientia Horticulturae, 2016;201:346-354.
6. Joshi V. Genetic studies in the segregating populations of tomato (*Solanum lycopersicum*). M.Sc. (Agri.) Thesis University Agricultural Science Dharwad Karnataka (India); c2015.
7. Khan A and Jindal S K, Exploiting yield potential in tomato (*Solanum lycopersicum* L.) through heterosis breeding. Plant Gene and Trait. 2016;7(8):1-7.
8. Kumar P, Singh N and Singh PK. A study on heterosis in tomato (*Solanum lycopersicum* L.) for yield and its component traits. International Journal of Current Microbiology Applied Science. 2017;6:1318-1325.

9. Liu Z, Jiang J, Ren A, Xu X, Zhang H, Zhao T, *et al*. Heterosis and combining ability analysis of fruit yield, early maturity, and quality in tomato. Journal of Agronomy. 2021;11:807.
10. Ministry of Agriculture and Farmer welfare, Govt. of India; c2021-22.
11. Peralta IE, Spooner DM, Knapps S. Taxonomy of wild tomatoes and their relatives. Systematic Botany Monograph. 2008;84:186.
12. Rehana S, Ullah MZ, Zeba N, Narzis N, Husna A, Siddique AB. Estimation of heterosis for yield and yield attributing traits in tomato, crossed in line and tester method. *Progressive Agriculture*, 2019, 30 (2): 179-185.
13. Shankar A, Reddy R V, Sujatha M and Pratap M, Genetic variability studies in F1 generation of tomato (*Solanum lycopersicon* L.). IOSR Journal of Agriculture and Veterinary Science. 2013;4(5):31-34.
14. Singh K, Evaluation of tomato genotypes and its reaction against ToLCV causing leaf curl disease in tomato (*Solanum lycopersicum* L.). Journal of Experiment Biology Agriculture Science. 2014;2(1S):120-125.
15. Soresa D N, Nayagam G, Bacha N and Jaleta Z. Heterosis in tomato (*Solanum lycopersicum* L.) for yield and yield component traits. Advanced Resources. 2020;21(9):141-152.
16. Syarifah, Wahyuni S, Syukur M and Witono J R, The estimation of combining ability and heterosis effect for yield and yield components in tomato (*Lycopersicon esculentum* Mill.) at lowland. Ekin Journal of Crop Breeding and Genetics. 2016;2(1):23-9.