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HETEROSIS AND COMBINING ABILITY STUDIES FOR FRUIT YIELD, COMPONENTS AND QUALITY TRAITS IN TOMATO (*SOLANUM LYCOPERSICUM* L.) UNDER MID HILL CONDITIONS OF HIMACHAL PRADESH INDIA

Shaina Sharma[1,2], Sanjay Chadha[1], Shivam Sharma[1,3]* and Sayed Hasibullah Sadat[1]

[1]Department of Vegetable Science, C.S.K. H.P.K.V. Palampur, Himachal Pradesh, India-176062

[2]International Rice Research Institute (IRRI) South Asia Hub Hyderabad, Telangana, India-502324

[3]Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India-144012

*Corresponding author Email: shivamsharma7154@gmail.com

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ABSTRACT

The present investigation was carried out at Vegetable Research Farm, CSK HPKV Palampur, Himachal Pradesh to assess the nature and magnitude of gene action on the basis of combining ability and heterosis in tomato. In order to identify the potential parents and cross-combinations, the 8 lines, 2 testers and 16 cross combinations along with standard check (Avtar) were evaluated in Randomized Complete Block Design replicated thrice during *kharif,* 2021. Analysis revealed the preponderance of non-additive gene effects for most of the traits viz., days to 50 per cent flowering, days to first harvest, duration of fruit harvest, plant height, fruit length, fruit width, fruit shape index, pericarp thickness, locules/fruit, total fruits/plant, marketable fruits/plant, total yield/plant, TSS, ascorbic acid content, titrable acidity, pH, carotenoid content, dry matter content, moisture content and TSS-AR ratio while additive gene effects for marketable yield per plant. Lines DPT 4 and DPT 1 were found to be good general combiners for most of the traits. The cross-combinations DPT 1×12-1, DPT 1× Palam Pride, DPT 4×12-1 and 2015/TOINVAR-4×12-1 exhibited high heterosis and SCA for majority of traits, therefore were rated as potential crosses. As a result, it would be helpful to exploit tomato hybrids, particularly those that showed high SCA in the current study for the development of hybrids.

Keywords: Gene action, Heterosis, Combining ability, Line × tester, Lycopene.

Introduction

Tomato (*Solanum lycopersicum* L., 2n=2x=24) belongs to the family Solanaceae and it is indigenous of Peru- Equador region (Rick, 1965). It is a major vegetable that is widely cultivated all over the world. Although tomatoes are mostly a day-neutral crop and a self-pollinating species, some cross pollination up to 5 % also occurs through insects (Ghadage *et al*., 2020). Growth habits of the plants are determinate, semi-determinate and indeterminate. Consumption of tomato has increased tremendously due to its numerous uses i.e. raw salads, as cooked vegetables and variety of processed products such as soup, ketchups, sauces, preserves, paste and puree (Tiwari *et al*., 1986).

Tomatoes are planted worldwide on an area of 5051983 ha with the production of 186821 thousand MT (Anonymous, 2020). In India, it is grown on an area of 789 thousand hactares with production of 19759 thousand MT (Anonymous, 2018). Whereas, in Himachal Pradesh, it is cultivated in about 13795 ha area with a production of 577004 MT (Anonymous, 2021). It is an important cash crop for small and marginal vegetable growers of the hilly areas. It is grown as an off-season crop in hilly regions which fetches premium prices in the markets of surrounding states like Punjab, Haryana and Delhi during rainy season (Dishri *et al*., 2017).

Hybrids are preferred over pure line varieties in tomato due to their superiority in marketable fruit yield, component characters and fruit quality (Kapur *et* *al*., 2013). The mechanism of reproduction and production of large number of seeds per fruit offer various opportunities for manifestation of heterosis in tomato (Singh and Singh, 1993). Knowledge of general combining ability (GCA) and specific combining ability (SCA) can be obtained by using the method given by Arunachalam (1974).

The GCA is attributed to additive gene actions and additive × additive epistasis and is theoretically fixable. While, SCA is attributable to non-additive gene effect (dominance or epistasis or both) and is non-fixable. The presence of non-additive genetic variance is the primary indication for initiating the hybrid programme. Therefore, combining ability plays an important role in the development of breeding procedures and also in crop hybridization either to exploit heterosis or to combine the favourable fixable genes which may be used for selection programmes. Such investigations not only provide necessary information about the choice of parents but also simultaneously illustrate the nature and extent of gene action involved in the expression of desirable characters.

Materials and Method

Planting material and layout

Experimental material comprised of eight lines *viz.,* L1(DPT 1), L2 (DPT 3), L3 (DPT 4), L4 (DPT 5), L5 (DPT 6), L6 (DPT 7), L7 (DPT 8) and L8 (2015/TOINVAR-4) and two testers viz. T1 (12-1) and T2 (Palam Pride) were developed at CSK HPKV Palampur. The line × tester design during *kharif,* 2020 generated 16 cross combinations which were then evaluated along with standard check (Avtar) and parents in Randomized Complete Block Design with three replications during *kharif,* 2021. Row to row and plant to plant distances was maintained at 75×45 cm, with plot size 2.7×1.5 m, accommodating 12 plants in each entry per replication.

Experimental location

Experiment was carried out at Vegetable Research Farm of CSK HPKV Palampur, Himachal Pradesh which is situated at 32^o 6' N latitude, 76^o 3' E longitude and 1290.8 m altitude. Agro-climatically, the location falls under the mid hill zone (Zone-II) of Himachal Pradesh characterized by humid sub-temperate climate with high rainfall of 2500 mm per annum of which 80 % is received during June to September. The soil is acidic in nature with pH ranging from 5.0-5.6 with silt clay loam texture.

Cultural practices and plant protection measures

Farm yard manure @ 20 t/ha and chemical fertilizers (100 Kg N, 75 Kg P_2O_5, 50 Kg K_2O /ha) were applied as per the recommended package of practices. Half dose of N and full doses of P_2O_5 and K_2O were applied at the time of field preparation. The remaining half dose of N was top dressed in two equal amounts, first after four weeks of transplanting and second at the time of earthing up. The remaining intercultural operations were carried out in accordance with the recommended package of practice for vegetable crops. For the control of late blight and fruit rot diseases, two sprays of Mancozeb (0.25 %) + Bavistin (0.1 %) at an interval of seven days were given. Two sprays of Plethora (0.08 %) at seven days interval were given to control the infestation of fruit borer. Two sprays of Malathion (0.1 %) at an interval of seven days were given with the onset of monsoon during June-July to take care of fruit-fly infestation.

Quantitative and Biometric analysis

The observations were recorded on five competitive plants marked at random in each entry over the replications on different quantitative traits *viz.,* days to 50 per cent flowering, days to first harvest, average fruit weight (g), fruit shape index, pericarp thickness (mm), total fruits/plant, marketable fruits/plant, marketable yield/plant (kg), total yield/plant (kg), locules/fruit, plant height (cm), duration of fruit harvest (days). Biometrical analysis was done for the characters, TSS (ºBrix), ascorbic acid (mg/100g), lycopene content (mg/100g), titrable acidity (%), dry matter content (%), pH content, moisture content (%), carotenoid content (mg/100g) and TSS-AR ratio.

Statistical analysis

Recorded data were analysed with the program R software (RStudio Team 2020). Modified line × tester analysis was carried out as per the method given by Arunachalam (1974). Analysis of variance was carried out following model given by Panse and Sukhatme (1984). The model of Arunachalam (1974) was used for estimating the GCA and SCA effects in combining ability analysis. The estimates of heterosis were calculated as the deviation of F_1 mean from the better parent (BP) and standard check (SC) following the method of Turner (1953) and Hayes *et al*. (1956). The percent contribution of lines, testers, and their interaction towards total variability in each character was estimated following the method of Singh and Choudhory (1977).

Results and Discussion

Analysis of variance

The analysis of variance for the line × tester design revealed significant differences among parents for all traits (Table 1), indicating the presence of a significant amount of genetic variability for exploitation via recombinant breeding. The variances of the parents were further partitioned into lines, testers and line vs tester, revealing significant differences among lines for all traits and among testers for most traits except days to first harvest, duration of fruit harvest, total fruits/plant, marketable fruits/plant, marketable yield/plant, and lycopene content. The testers differed from lines for most of the traits except days to 50 % flowering, days to first harvest, locules/fruit and carotenoid content. For all parameters except average fruit weight, pericarp thickness, fruit length, fruit form index, pH content, dry matter content and moisture content, the lines showed greater magnitude of mean squares than the testers indicating a wider genetic diversity of the lines than the testers. Hybrids showed significant differences for all the examined attributes except for days to first harvest, which exhibited substantial differences among the crosses for these characters. As a result, selection is possible to identify the most desirable segregants within the crosses. Also, mean squares due to parent ×hybrid interaction were found to be significant for all attributes, suggesting that parental lines as a whole varied from the crosses due to heterosis resulting from the dominant and complimentary genes (Gravois and McNew, 1993). These findings for yield and other attributes are closely aligned with Saleem *et al.* (2011) and Rehana *et al.* (2019).

The analysis of variance for combining ability revealed significant differences across crosses for all the attributes studied except days to first harvest (Table 2). Except for days to first harvest, mean squares due to lines were significant for majority of the characters. Mean squares due to testers and line × tester was found to be significant for most of the attributes except days to first harvest and duration of harvest indicating that the resulting crosses had significant variability and that both GCA and SCA were involved in the genetic expression of these factors. This demonstrated the suitability of the parents and crosses for combining ability studies. The significant variation in line × tester interactions suggested that SCA played a significant role in the expression of these attributes, emphasising the significance of non-additive variance for all of the characters (Sanghera and Hussain, 2012). The estimates of additive and dominance variances (Table 2) indicated that for all traits except marketable yield per plant, the relative magnitude of dominant gene action was higher. The degree of dominance was in the over-dominance range, except for marketable yield per plant, where the dominance component was higher than the additive component. The role of non-additive gene action in inheritance of various attributes following line ×tester mating design has also been noted by Kapur *et al.* (2013) for days to 50 % flowering; Acharyaa *et al*., (2018) for titrable acidity; Kumar *et al.* (2013) for ascorbic acid and lycopene content; Ghadage *et al.* (2020) for total number of fruits per plant, fruit length, fruit diameter and fruit weight; Akram *et al.* (2019).

Combining ability studies

The good general combiners with respect to different traits indicated that no single parent proved to be a good general combiner for all of the traits studied. L3 was found to be a good general combiner for most of the traits *viz.,* days to 50 per cent flowering, plant height, total fruits/plant, total yield/ plant, marketable fruits/plant, marketable yield /plant, average fruit weight, fruit width, TSS, titrable acidity, dry matter content, moisture content and TSS-AR ratio. On the basis of parents with good general combining ability estimates, it can be concluded that L3 appeared to be the most promising as they were good general combiners for 13 traits, L1 for 11 traits, L4, L5 and L7 for eight traits, L8 for seven traits, L2 for six traits and L6 for five traits. Similarly, among testers, T1 proved to be a good general combiner for 10 traits viz. days to 50 per cent flowering, plant height, total fruits/plant, total yield/ plant, marketable fruits/plant, marketable yield /plant, locules per fruit, ascorbic acid content, pH content and carotenoid content. T2 was found good general combiner for 10 traits *viz.,* average fruit weight, pericarp thickness, fruit length, fruit width, fruit shape index, TSS, titrable acidity, dry matter content, moisture content and TSS- AR ratio. The results for GCA were found in close agreement with the findings of Nezami *et al.* (2022), Nayana *et al.* (2021), Ghadage *et al.* (2020), Kumar *et al.* (2020), Madhavi *et al.* (2018) and Raj *et al.* (2017), Rajan *et al.* (2018), Bhandari *et al*, (2021) and Dufera *et al*, (2018)

It was observed that no single cross could reveal significant SCA effects for all the traits. The promising hybrids/crosses exhibiting significant desirable SCA effects for most of the traits were L4×T2, L1×T1, L2×T1 and L7×T1 (Table 3). The hybrid L4×T2 was exceptionally good with desirable SCA effects, involving parents with Good (G) ×Poor (P) general combining ability for plant height, carotenoid content, G ×G for pericarp thickness, fruit length, fruit width, titrable acidity, TSS-AR ratio, P ×G for average fruit weight, P×P for ascorbic acid content, A×G for lycopene content, A×P for pH. The hybrid L1×T1 exhibited significant desirable SCA effects for plant height, total yield/ plant, average fruit weight, pericarp thickness, fruit width, titrable acidity, carotenoid content, lycopene content, dry matter content and moisture content. However, the parents involved in this hybrid are G×G for plant height, total yield/ plant, G×P for average fruit weight, titrable acidity, P×P for pericarp thickness, fruit width, P×G for carotenoid content, lycopene content, A×P for dry matter content and moisture content suggesting that poor and average parental combinations could also be of use in the production of hybrids due to the complementation of favourable genes. Similarly other hybrids revealed significant SCA effects were L2×T1, L7×T1 for eight traits, L3×T2, L8×T1 for seven traits, L7×T2 for six traits, L2×T2, L5×T1, L5×T2 for five traits, L4×T1, L8×T2 for four traits and L6×T1, L6×T2 for three traits. The results obtained were found in close conformity with the findings of Nezami *et al*. (2022), Soresa *et al*. (2021), Reddy *et al*. (2020), Dharva *et al*. (2018), Kumar *et al*. (2018) and Alam *et al*. (2017)

Estimates of proportional contribution

The proportional contribution of lines ranged from 18.64 (pH content) to 79.21 (pericarp thickness). The proportional percent contribution of testers ranged from 0.95 (plant height) to 53.27 (fruit length). The proportional contribution of line × tester interactions ranged from 6.81 (marketable yield per plant) to 72.95 (lycopene content). Further, it was noticed that the percent contribution of lines was higher than the corresponding testers and their interaction for most of the traits except for days to 50 per cent flowering, total fruits per plant, marketable fruits per plant, fruit length, ascorbic acid content, lycopene content and pH. Therefore, it can be concluded that lines played a significant role in the expression of different characters in various cross-combinations.

Estimation of heterosis

For days to 50 % flowering, 9 crosses exhibited negative significant heterosis over BP and seven over SC (Table 4). Regarding days to first harvest, four crosses showed significant negative heterosis over BP. For duration of fruit harvest, L8×T1 and L3×T1 exhibited higher significant positive heterosis over BP and SC respectively. L1×T1 showed higher significant heterosis over BP and SC for plant height. Regarding total fruits per plant, L2×T1 and L5×T1 exhibited higher significant heterosis over BP and SC respectively. L3×T1 and L1×T1 showed higher significant heterosis over BP and SC respectively for total yield per plant. For marketable fruits per plant, L8×T1 showed higher significant BPH and L5×T1 showed higher significant SCH. L1×T1 showed higher significant BPH and SCH for marketable yield per plant and average fruit weight. Regarding locules per plant, L1×T2 exhibited significant negative BPH and SCH. L4×T2 exhibited higher significant positive heterosis over BP and SC for pericarp thickness. Regarding fruit length, 10 crosses exhibited significant heterosis over BP and six over SC. For fruit width, L4×T2 and L6×T2 showed higher significant BPH and SCH respectively. For fruit shape index, L8×T2 showed higher significant SCH.

Significant positive heterosis was observed in two cross combinations over BP and SC for TSS. L3×T2 exhibited significant negative heterosis over BP and SC for titrable acidity. For ascorbic acid, L6×T1 showed higher significant BPH and SCH. L5×T2 and L8×T1 exhibited significant heterosis over BP and SC for lycopene content. L4×T2 and L7×T1 showed significant negative BPH and SCH respectively for pH content. Regarding carotenoid content, L4×T2 exhibited higher significant heterosis over BP and SC. For dry matter content, significant positive heterosis was observed in six cross-combinations over SC. Significant negative heterosis was observed in six crosses over SC for moisture content. L3×T2 exhibited higher significant heterosis over BP and SC for TSS-AR ratio. The hybrid L1×T1 recorded a significantly higher yield potential of 1.30 kg/plant with significantly higher standard heterosis over standard check Avtar (177.86 %). The estimation of heterosis in our study has shown different crosses showing BPH and SCH for all the traits under study given hint for exploiting heterosis for fruit yield and related traits in tomato. These results were in agreement with the results obtained by Aisyah *et al*. (2016), Rehana *et al*. (2019) and Nezami *et al*. (2022).

Conclusion

The most promising cross-combinations identified on the basis of standard heterosis for marketable yield per plant were DPT 1×12^{-1}, DPT 1× Palam Pride, DPT 4×12^{-1}, DPT 6×12^{-1} and 2015/TOINVAR-4×12^{-1}. DPT 1×12^{-1}, DPT 1 × Palam Pride, DPT 4×12^{-1} and 2015/TOINVAR-4×12^{-1}, were outstanding cross-combinations which exhibited high heterosis and SCA for yield and related traits, envisaging thereby the development of better hybrids possessing high marketable yield and good quality traits in tomato. These promising hybrids can be grown for commercialization after testing at preliminary yield trials and multi-location trials.

Table 1 : Analysis of variance for parents and hybrids (line × tester) for tomato fruit yield, component and quality traits

Source of variation	Replication	Parent	Line	Tester	Line vs Tester	Hybrid	Parent vs Hybrid	Error
Traits df	2	9	7	1	1	15	1	50
Days to 50 % flowering	5.397	14.774*	16.833*	13.500*	1.633	57.194*	284.411*	1.424
Days to first harvest	22.397	81.422*	100.660*	20.166	8.008	14.527	478.616*	14.304
Duration of fruit harvest	10.885	82.652*	92.000*	2.667	97.200*	34.221*	509.654*	10.618
Plant height (cm)	45.308	340.297*	317.930*	181.500*	655.669*	353.702*	21331.078*	6.408
Total fruits/Plant	5.640	25.559*	25.677*	1.739	48.552*	135.263*	546.268*	6.404
Total yield/ Plant (Kg)	0.000	0.155*	0.159*	0.123*	0.153*	0.600*	4.855*	0.014
Marketable fruits/Plant	2.272	31.314*	31.249*	1.893	61.190*	100.660*	701.653*	1.522
Marketable yield /plant (Kg)	0.006	0.051*	0.050*	0.004	0.105*	0.223*	2.056*	0.007
Average fruit weight (g)	32.673	264.317*	290.224*	303.028*	44.250*	330.704*	2769.141*	9.990
Locules per fruit	0.081	0.512*	0.646*	0.066*	0.014	0.812*	0.803*	0.009
Pericarp thickness (mm)	0.046	2.855*	2.218*	5.802*	4.370*	4.149*	0.345*	0.023
Fruit length (cm)	0.109	1.657*	1.490*	2.587*	1.892*	0.981*	1.352*	0.019
Fruit width (cm)	0.176	1.124*	1.313*	0.077*	0.850*	0.480*	7.765*	0.013
Fruit shape index	0.003	0.026*	0.017*	0.101*	0.015*	0.024*	0.080*	0.002
TSS(^{0}Brix)	0.001	0.312*	0.336*	0.094*	0.357*	1.511*	6.660*	0.012
Titrable acidity	0.001	0.436*	0.266*	0.228*	1.835*	0.258*	0.161*	0.001
Ascorbic acid content (mg/100g)	1.344	32.614*	35.098*	21.736*	26.096*	46.106*	417.730*	1.398
Lycopene content (mg/100g)	0.085	1.820*	1.981*	0.304	2.209*	2.090*	10.014*	0.163
pH content	0.047	0.056*	0.023*	0.308*	0.034*	0.048*	0.295*	0.004
Carotenoid content (mg/100g)	0.001	0.018*	0.022*	0.005*	0.001	0.018*	0.005*	0.001
Dry matter content	0.412	27.113*	2.539*	110.940*	115.307*	10.841*	32.352*	0.269
Moisture content	0.412	27.113*	2.539*	110.940*	115.307*	10.841*	32.352*	0.269
TSS-AR ratio	0.282	47.453*	39.379*	2.996*	148.430*	54.844*	68.643*	0.360

Table 2 : Analysis of variance for combining ability and estimates of genetic parameters for tomato fruit yield, component and quality traits

Source of variation	Replication	Crosses	Lines	Testers	Line × Tester	Error	Estimates of genetic parameters			
Traits df	**2**	**15**	**7**	**1**	**7**	**30**	**σ^2A**	**σ^2D**	**$(H/D)^{1/2}$**	**h^2ns**
Days to 50 % flowering	5.083	57.194*	43.702*	225.333*	46.667*	1.261	0.598	15.135	5.031	92.075
Days to first harvest	4.937	14.528	15.845	10.083	13.845	9.982	0.039	1.288	5.747	49.365
Duration of fruit harvest (days)	28.896	34.221*	48.021*	15.187	23.140	11.362	0.630	3.926	2.496	64.658
Plant height (cm)	26.241	353.702*	501.352*	50.430*	249.375*	4.482	5.928	81.631	3.711	98.347
Total fruits/Plant	2.038	135.263*	97.040*	1067.193*	40.352*	6.617	5.393	11.245	1.444	84.598
Total yield/ Plant (kg)	0.012	0.600*	0.902*	1.896*	0.113*	0.017	0.028	0.032	1.069	93.327
Marketable fruits/Plant	2.060	100.661*	92.860*	735.080*	17.830*	1.365	4.706	5.488	1.080	95.514
Marketable yield /plant (kg)	0.003	0.223*	0.240*	1.435*	0.032*	0.009	0.011	0.008	0.853	91.149
Average fruit weight (g)	10.059	330.704*	437.074*	169.877*	247.309*	13.256	4.738	78.018	4.058	92.587
Locules per fruit	0.056	0.812*	0.841*	2.471*	0.546*	0.011	0.015	0.178	3.445	95.824
Pericarp thickness (mm)	0.006	4.149*	7.043*	1.841*	1.586*	0.028	0.146	0.519	1.885	98.083
Fruit length (cm)	0.058	0.981*	0.681*	7.841*	0.302*	0.012	0.039	0.096	1.569	95.488
Fruit width (cm)	0.169	0.480*	0.525*	1.188*	0.334*	0.005	0.008	0.110	3.708	95.968
Fruit shape index	0.000	0.024*	0.028*	0.131*	0.006*	0.001	0.001	0.002	1.414	82.312
TSS (^{0}Brix)	0.005	1.511*	2.188*	0.867*	0.926*	0.014	0.033	0.304	3.035	97.26
Titrable acidity (%)	0.000	0.258*	0.274*	1.274*	0.097*	0.001	0.009	0.032	1.886	99.364
Ascorbic acid content (mg/100g)	0.100	46.106*	30.153*	45.923*	62.085*	1.332	-	20.251	-	92.888
Lycopene content (mg/100g)	0.122	2.090*	1.128*	0.585*	3.268*	0.106	-	1.054	-	81.423
pH content	0.045	0.048*	0.019*	0.080*	0.073*	0.004	-	0.023	-	83.815
Carotenoid content (mg/100g)	0.001	0.018*	0.018*	0.036*	0.015*	0.001	-	0.005	-	83.543
Dry matter content (%)	0.937	10.841*	11.585*	9.144*	10.341*	0.283	0.028	3.353	10.943	95.514
Moisture content (%)	0.937	10.841*	11.585*	9.144*	10.341*	0.283	0.028	3.353	10.943	95.514
TSS- AR ratio	0.488	54.844*	58.036*	193.122*	31.899*	0.206	1.304	10.564	2.846	97.995

Table 3 : List of cross combinations showing good specific combining ability effects for horticultural traits in tomato

Traits	Cross combinations
Days to 50 % flowering	$L_4 \times T_1$(P×G), $L_3 \times T_2$(G×P), $L_1 \times T_2$(P×P), $L_7 \times T_1$(G×G) and $L_5 \times T_1$(G×G)
Plant height (cm)	$L_5 \times T_1$(P×G), $L_6 \times T_2$(A×P), $L_1 \times T_1$(G×G), $L_8 \times T_2$(P×P), $L_4 \times T_2$ (G×P) and $L_2 \times T_2$(G×P)
Total fruits/Plant	$L_2 \times T_1$(A×G) and $L_1 \times T_2$(G×P)
Total yield/ Plant	$L_1 \times T_1$(G×G) and $L_3 \times T_2$(G×P)
Marketable fruits/Plant	$L_8 \times T_1$(P×G), $L_1 \times T_2$(G×P), $L_7 \times T_1$(P×G) and $L_3 \times T_2$(G×P)
Marketable yield /plant	$L_1 \times T_2$(G×P)
Average fruit weight	$L_1 \times T_1$(G×P), $L_7 \times T_2$(G×G) and $L_4 \times T_2$(P×G)
Locules / fruit	$L_1 \times T_2$(G×P), $L_4 \times T_1$(P×G), $L_2 \times T_2$(P×P), $L_5 \times T_2$(A×P), $L_7 \times T_1$(G×G), $L_6 \times T_1$ (A×G) and $L_8 \times T_1$(A×G)
Pericarp thickness	$L_4 \times T_2$(G×G), $L_8 \times T_1$(G×P), $L_3 \times T_2$(P×G), $L_1 \times T_1$(P×P), $L_5 \times T_1$ (G×P) and $L_7 \times T_2$(G×G)
Fruit length	$L_2 \times T_1$(P×P), $L_4 \times T_2$ (G×G) and $L_7 \times T_2$(G×G)
Fruit width	$L_4 \times T_2$(G×G), $L_2 \times T_1$(P×P), $L_3 \times T_2$(G×G), $L_6 \times T_2$(G×G), $L_1 \times T_1$(P×P), $L_5 \times T_1$(P×P) and $L_7 \times T_1$(G×P)
Fruit shape index	$L_7 \times T_2$(A×G) and $L_2 \times T_1$(P×P)
TSS	$L_2 \times T_2$(G×G), $L_7 \times T_1$(P×P), $L_3 \times T_1$(G×P), $L_1 \times T_2$(G×G) and $L_8 \times T_1$(G×P)
Titrable acidity	$L_2 \times T_1$(P×P), $L_3 \times T_2$(G×G), $L_4 \times T_2$(G×G), $L_8 \times T_1$(G×P), $L_6 \times T_2$(P×G) and $L_1 \times T_1$(G×P)
Ascorbic acid content	$L_6 \times T_1$(G×G), $L_4 \times T_2$(P×P), $L_2 \times T_1$(A×G), $L_1 \times T_2$(G×P), $L_5 \times T_2$ (P×P) and $L_3 \times T_1$(A×G)
Lycopene content	$L_8 \times T_1$(G×G), $L_5 \times T_2$(A×G), $L_4 \times T_2$(A×G), $L_1 \times T_1$(P×G) and $L_2 \times T_1$(A×G)
pH content	$L_7 \times T_1$(G×G), $L_8 \times T_2$(A×P), $L_5 \times T_2$(A×P), $L_4 \times T_2$ (A×P) and $L_3 \times T_1$(P×G)
Carotenoid content	$L_1 \times T_1$(P×G) and $L_4 \times T_2$(G×P)
Dry matter content	$L_4 \times T_1$(A×P), $L_1 \times T_1$(A×P), $L_8 \times T_2$(P×G), $L_2 \times T_2$(G×G) and $L_7 \times T_2$(A×G)
Moisture content	$L_4 \times T_1$(A×P), $L_1 \times T_1$(A×P), $L_8 \times T_2$(P×G), $L_2 \times T_2$(G×G) and $L_7 \times T_2$(A×G)
TSS- AR ratio	$L_3 \times T_2$(G×G), $L_4 \times T_2$(G×G), $L_7 \times T_1$(P×P), $L_8 \times T_1$(G×P), $L_2 \times T_1$(P×P), $L_6 \times T_1$ (P×P) and $L_5 \times T_1$(P×P)

(G) Good, (A) Average, (P) Poor

$L_1 \times T_1$ = DPT 1×12^{-1}, $L_1 \times T_2$ = DPT 1× Palam Pride, $L_2 \times T_1$ = DPT 3×12^{-1}, $L_2 \times T_2$ = DPT 3 × Palam Pride,
$L_3 \times T_1$ = DPT 4×12^{-1}, $L_3 \times T_2$ = DPT 4 × Palam Pride, $L_4 \times T_1$ = DPT 5×12^{-1}, $L_4 \times T_2$ = DPT 5× Palam Pride,
$L_5 \times T_1$ = DPT 6×12^{-1}, $L_5 \times T_2$ = DPT 6 × Palam Pride, $L_6 \times T_1$ = DPT 7×12^{-1}, $L_6 \times T_2$ = DPT 7×Palam Pride,
$L_7 \times T_1$ = DPT 8×12^{-1}, $L_7 \times T_2$ = DPT 8 × Palam Pride, $L_8 \times T_1$ = 2015/TOINVAR-4×12^{-1},
$L_8 \times T_2$ = 2015/TOINVAR-4 × Palam Pride

Table 4 : Heterosis (%) over better parent (BP) and standard check (SC) for fruit yield, component and quality traits in tomato

S. No.	Hybrids	Days to 50 % flowering		Days to first harvest		Duration of fruit harvest		Plant height (cm)		Total fruits/Plant		Total yield/ Plant (kg)		Marketable fruits/Plant	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	$L_1 \times T_1$	0.00	-0.87	9.13*	5.29	3.70	6.87	60.48*	56.08*	54.54*	84.56*	209.72*	195.37*	93.45*	145.03*
2	$L_1 \times T_2$	-9.76*	-3.48	-0.91	-4.41	13.33*	16.79*	28.40*	41.49*	41.83*	69.39*	98.38*	89.19*	72.23*	118.16*
3	$L_2 \times T_1$	-2.63	-3.48	-4.66	-0.80	8.40	8.4	39.68*	35.84*	95.92*	88.23*	89.26*	76.83*	93.29*	93.95*
4	$L_2 \times T_2$	-4.88*	1.74	-8.10*	0.00	12.98*	12.98*	27.44*	40.43*	-17.90	-15.97	5.71	0.00	5.15	5.51
5	$L_3 \times T_1$	-3.51	-4.35	-8.05*	-4.41	25.40*	20.61*	40.81*	36.94*	69.74*	80.23*	227.67*	101.16*	130.81*	135.44*
6	$L_3 \times T_2$	-14.53*	-13.04*	-8.90*	-5.29	7.94	3.82	22.17*	34.63*	41.73*	50.49*	101.63*	90.73*	80.96*	84.59*
7	$L_4 \times T_1$	-18.42*	-19.13*	2.74	-0.88	-17.22*	-4.58	18.54*	33.14*	40.21*	72.86*	-2.92	41.31*	57.41*	107.41*
8	$L_4 \times T_2$	8.94*	16.52*	7.31	3.52	-17.22*	-4.58	23.67*	38.9*	-20.17*	-1.57	-28.12*	4.63	-10.94	17.35
9	$L_5 \times T_1$	-20.18*	-20.87*	-2.20	-2.20	0.00	15.27*	46.94*	42.9*	34.57*	97.98*	46.83*	61.00*	39.92*	165.03*
10	$L_5 \times T_2$	-8.94*	-2.61	-4.41	-4.41	1.32	16.79*	-1.00	9.1*	0.82	48.33*	26.06*	38.22*	7.63	103.88*
11	$L_6 \times T_1$	0.93	-6.09*	-4.66	-0.88	25.44*	9.16	26.85*	23.37*	4.48	24.96*	3.93	22.39*	53.94*	58.81*
12	$L_6 \times T_2$	6.54*	-0.87	-5.86	-0.88	21.19*	9.16	24.45*	37.14*	-20.43*	-4.84	-28.52*	-15.83	-14.31	-11.6
13	$L_7 \times T_1$	-31.58*	-32.17*	-6.81	-3.52	20.80*	15.27*	38.91*	35.1*	22.31*	60.39*	72.18*	64.86*	46.18*	124.15
14	$L_7 \times T_2$	-7.83*	-7.83*	-6.81	-3.52	13.60*	8.4	22.63*	35.14*	-19.66*	5.36	47.18*	40.93*	-28.86*	9.08
15	$L_8 \times T_1$	-5.26*	-6.09*	-5.08	-1.32	26.32*	9.92	11.05*	8.00*	76.71*	76.53*	105.18*	52.90*	149.10*	135.03*
16	$L_8 \times T_2$	2.50	6.96*	-11.34*	-3.52	7.63	-3.05	4.59*	15.25*	-7.27	-5.09	5.31	-0.39	5.59	-1.02
	SE (d)	0.96	0.96	3.06	3.06	2.65	2.65	2.08	2.08	2.06	2.06	0.10	0.10	1.01	1.01

$L_1 \times T_1$ = DPT 1×12^{-1}, $L_1 \times T_2$ = DPT 1× Palam Pride, $L_2 \times T_1$ = DPT 3×12^{-1}, $L_2 \times T_2$ = DPT 3 × Palam Pride,
$L_3 \times T_1$ = DPT 4×12^{-1}, $L_3 \times T_2$ = DPT 4 × Palam Pride, $L_4 \times T_1$ = DPT 5×12^{-1}, $L_4 \times T_2$ = DPT 5 × Palam Pride,
$L_5 \times T_1$ = DPT 6×12^{-1}, $L_5 \times T_2$ = DPT 6 × Palam Pride, $L_6 \times T_1$ = DPT 7×12^{-1}, $L_6 \times T_2$ = DPT 7 × Palam Pride,
$L_7 \times T_1$ = DPT 8×12^{-1}, $L_7 \times T_2$ = DPT 8 × Palam Pride, $L_8 \times T_1$ = 2015/TOINVAR-4×12^{-1},
$L_8 \times T_2$ = 2015/TOINVAR-4 × Palam Pride

S. No.	Hybrids	Marketable yield /plant (kg)		Average fruit weight (g)		Locules per fruit		Pericarp thickness (mm)		Fruit length (cm)		Fruit width (cm)		TSS (^{0}Brix)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	$L_1×T_1$	188.15*	177.86*	101.94*	59.26*	0.27	-6.82*	-17.27*	13.75	-19.48*	-15.82*	5.09*	-1.87	-7.14*	-16.73*
2	$L_1×T_2$	187.60*	165.00*	21.27*	10.83	-16.00*	-21.93*	-25.00*	3.13	-8.44*	-4.28	2.29	-4.48*	3.00	-2.14
3	$L_2×T_1$	57.63*	99.29*	7.55	4.28	22.68*	22.68*	-18.00*	-23.13	5.90*	-15.95*	16.77*	0.13	-25.00*	-32.74*
4	$L_2×T_2$	-6.21	18.57	22.12*	18.42*	17.50*	18.96*	-32.79*	-23.13	-9.62*	-17.04*	8.74*	-5.95*	11.61*	6.05*
5	$L_3×T_1$	160.74*	151.43*	75.06*	10.96	26.77*	26.77*	-19.88*	-16.87*	-2.91	-22.95*	14.84*	-1.67	-3.56	-3.56
6	$L_3×T_2$	127.05*	97.86*	37.97*	26.09*	31.03*	41.26*	-2.73	11.25	3.77	-4.75*	32.10*	14.25*	-14.59*	-14.59*
7	$L_4×T_1$	43.08*	99.29*	-30.77*	-19.03	0.67	-7.06*	-3.45	22.50	6.92*	-15.00*	22.45*	0.33	-17.71*	-15.66*
8	$L_4×T_2$	-2.56	35.71*	-8.35	7.2	51.68*	40.02*	27.59*	61.87	22.78*	12.70*	38.52*	19.80*	-9.72*	-7.47*
9	$L_5×T_1$	55.31*	150.71*	8.82	-19.64*	15.24*	15.24*	-1.92	27.50	-5.56*	-7.67*	4.75*	0.33	-32.99*	-29.89*
10	$L_5×T_2$	-1.33	59.29*	1.14	-7.57	11.11*	11.52*	-8.65*	18.75	6.32*	3.94	6.63*	2.14	-27.55*	-24.20*
11	$L_6×T_1$	48.00*	85.00*	-1.16	-3.11	1.24	1.24	-8.99*	1.25	-2.15	-13.37*	4.46*	4.88*	-41.78*	-39.50*
12	$L_6×T_2$	-14.29	7.14	-9.51	-11.3	21.26*	30.73*	-3.28	10.63	15.46*	5.97*	20.05*	20.54*	-34.25*	-31.67*
13	$L_7×T_1$	43.33*	115.00*	39.85*	2.13	-14.50*	-14.5*	26.62*	21.88	2.06	19.75*	29.39*	6.02*	-18.44*	-18.15*
14	$L_7×T_2$	-20.48	19.29	44.97*	32.48*	22.59*	23.05*	19.67*	36.88	19.75*	9.91*	25.14*	8.23*	-33.33*	-33.10*
15	$L_8×T_1$	123.36*	118.57*	15.93*	-14.08	1.24	1.24	13.48*	26.25	-20.41*	-6.04*	-17.99*	-1.54	6.76*	6.76*
16	$L_8×T_2$	3.65	1.43	13.72*	3.93	30.11*	30.11*	-1.64	12.50	-4.60*	12.63*	-14.54*	2.61	3.56	3.56
	SE (d)	0.07	0.07	2.60	2.60	0.08	0.08	0.12	0.12	0.11	0.11	0.09	0.09	0.09	0.09

$L_1×T_1$ = DPT 1×12^{-1}, $L_1×T_2$ = DPT 1× Palam Pride, $L_2×T_1$ = DPT 3×12^{-1}, $L_2×T_2$ = DPT 3 × Palam Pride,
$L_3×T_1$ = DPT 4×12^{-1}, $L_3×T_2$ = DPT 4 × Palam Pride, $L_4×T_1$ = DPT 5×12^{-1}, $L_4×T_2$ = DPT 5 × Palam Pride,
$L_5×T_1$ = DPT 6×12^{-1}, $L_5×T_2$ = DPT 6 × Palam Pride, $L_6×T_1$ = DPT 7×12^{-1}, $L_6×T_2$ = DPT 7 × Palam Pride,
$L_7×T_1$ = DPT 8×12^{-1}, $L_7×T_2$ = DPT 8 × Palam Pride, $L_8×T_1$ = 2015/TOINVAR-4×12^{-1},
$L_8×T_2$ = 2015/TOINVAR-4 × Palam Pride

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