HETEROBELTIOSIS AND INBREEDING DEPRESSION IN TOMATO (*Solanum lycopersicum* L.) FOR YIELD, YIELD ATTRIBUTES AND QUALITY

ABSTRACT

The present investigation was carried out during *rabi* 2010-11, *kharif*,2011 and *rabi*,2011-2012 at Vegetable Research Station, Rajendranagar, Hyderabad to study the genetic parameters, heterosis, combining ability, gene action governing the inheritance of the traits, correlation coefficient analysis, path coefficient analysis and inbreeding depression. Ten parents (EC-165749, EC-157568, EC-164838, LE-56, LE-62, LE-64, LE-65, LE-66, LE-67 and LE-68) were crossed in diallele mating design (without reciprocals). The resultant 45 F1's were evaluated along with their parents and two standard checks (Siri and US-618). Four best F1's and F2's were selected and evaluated along with their parents for inbreeding depression for sixteen characters *viz.*, plant height (cm), number of primary branches per plant, days to 50 % flowering, number of flowers per cluster, number of fruits per cluster, fruit length (cm), fruit width (cm), average fruit weight (g), fruit yield per plant (kg), number of locules per fruit, pericarp thickness (mm), TSS (°Brix), titrable acidity (%), ascorbic acid content (mg/100 g), total sugars (%) and lycopene content (mg 100/ g).

Key words: *Tomato, heterosis, heterobeltiosis, inbreeding depression and yield*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) (2n=2x=24) is a significant solanaceous vegetable crop, originating from the Peru-Ecuador region (Singh et al., 2017). It is widely cultivated in tropical and subtropical regions and ranks second in importance after the potato (Gulati et al., 2022). Often referred to as the "poor man's orange" due to its appealing appearance and nutritional value (Ngadze et al., 2017), tomatoes are versatile in culinary uses, including sandwiches, salads, and various processed products such as paste, puree, soup, sauce, juice, ketchup, whole canned fruit, and drinks (Geetha and Rani, 2020). Additionally, tomato juice is a key ingredient in the cocktail "Bloody Mary" (Ramana et al., 2017).

Nutritionally, tomatoes are a moderate source of essential vitamins and minerals, notably vitamin A, vitamin C, and various minerals (Erika et al., 2020). In India, tomatoes are commonly consumed raw or used in preparing chutneys and pickles (Chakraborty and Roy, 2018). Furthermore, lycopene, a major component of tomatoes, is highly valued for its anti-cancer properties. Acting as an antioxidant, lycopene helps neutralize free radicals, which are linked to carcinogenesis (Puah et al., 2021). It offers significant health benefits by potentially reducing oxidative damage to DNA and lipoproteins and inhibiting the oxidation of LDL (Low-Density Lipoprotein) cholesterol.

Tomato is universally recognized as a "Protective Food" due to its richness in minerals, vitamins, antioxidants, and organic acids (Sengar et al., 2023). Besides enhancing the diet with essential nutrients, color, and flavor, tomatoes are also a valuable source of antioxidants and chemo-protective compounds, classifying them as a "functional food" (Avdikos et al., 2021). The antioxidant potential of tomatoes is attributed to a combination of biomolecules such as lycopene, ascorbic acid, phenolics, flavonoids, and vitamin E (Kumar et al., 2021).

The tomato crop holds significant potential for heterosis breeding. Exploiting hybrid vigor is one of the crucial strategies in breeding programs, aimed at improving both the quality and productivity of the crop (Acharya et al., 2018). Although tomato is predominantly a self-pollinated crop, the high levels of heterosis observed can be traced back to its ancestral origins as a highly outcrossing genus, which later evolved into a self-pollinating species (Hussain et al., 2021). This study aimed to evaluate the extent of heterosis for fruit yield and its associated components, as well as to examine the effects of inbreeding depression within the segregating population. By analyzing these aspects, the research seeks to provide insights into the potential benefits of hybrid vigor and the genetic stability of tomato varieties, ultimately contributing to the improvement of crop productivity and quality.

MATERIALS AND METHOD

The investigation was conducted with the objective of identifying heterotic single-cross hybrids exhibiting high specific combining ability (SCA) effects, superior *per se* performance, and excellent quality. This was achieved by crossing promising horticulturally superior genotypes using a diallel mating design. The study outlines the techniques employed to generate data and details the statistical procedures used for data analysis.

The field experiment was conducted at the Vegetable Research Station, Dr. Y.S.R. Horticultural University, Rajendranagar, Hyderabad. The experimental material included ten lines (L1 to L10) as detailed in Table 1. The nursery for these parental lines was established in October 2010, with four-week-old seedlings transplanted in early November 2010 in the crossing block. The parents were grown in an unpaired planting pattern, with each genotype cultivated in a single row of 5 meters, spaced 1.0 x 0.5 meters apart.

For hybridization, floral buds of the female parents were emasculated a day before they opened, between 3 to 6 PM, using pointed forceps. The emasculated flowers were then bagged to prevent accidental pollination. The next morning, pollen from freshly opened flowers of the selected male parent was applied to the stigmatic surface of the emasculated flowers. After pollination, the flowers were tagged and bagged for identification. Once the fruits ripened, hybrid seeds were extracted using the fermentation method from the fully mature crossed fruits.

The resulting entries, including the four best F1 and F2 hybrids along with their respective parents, were planted during the kharif season of 2011 in a randomized block design with three replications. Each entry was cultivated in four rows, with 10 plants per row, maintaining an inter-row spacing of 60 cm and an intra-row spacing of 45 cm. For data collection, thirty plants per entry were randomly selected and tagged. Uniform cultural practices and plant protection measures, as prescribed by Dr. YSRHU, were consistently applied across all treatments.

The following parameters were recorded: plant height (cm), number of primary branches per plant, days to 50% flowering, number of flowers per cluster, number of fruits per cluster, fruit length (cm), fruit width (cm), average fruit weight (g), fruit yield per plant (kg), number of locules per fruit, pericarp thickness (mm), total soluble solids (°Brix), titratable acidity (%), ascorbic acid content (mg/100 g), total sugars (%), and lycopene content (mg/100 g).

RESULTS AND DISCUSSION

The heterosis and inbreeding depression for 16 quantitative and qualitative characters studied are presented in Tables 1 to 6. These tables summarize the findings for each character, including the relative heterosis, heterobeltiosis, and inbreeding depression values observed in the different hybrid crosses. The results are indicative of both additive and non-additive gene actions affecting the traits studied.

Each table provides detailed information on the magnitude and direction of heterosis (both relative heterosis and heterobeltiosis) and inbreeding depression for each of the characters evaluated, offering insights into their genetic mechanisms and potential for improvement through hybridization.

1. Plant height (cm)

For plant height, high relative heterosis was observed in three out of the four hybrids, indicating significant positive heterosis over the mid-parent. The range of relative heterosis was from -2.14 % to 34.73 %. Positive and significant heterobeltiosis was observed in EC-157568 x LE-66 (29.29%) and LE-64 x LE-66 (23.18%), whereas EC-157568 x LE-68 exhibited significant negative heterobeltiosis (-18.02%). In terms of inbreeding depression, the highest positive and significant inbreeding depression was observed in the cross EC-157568 x LE-68 (29.80%). For the other crosses, inbreeding depression was non-significant. The range of inbreeding depression across the hybrids was from 12.42% to 29.80%.

In the present study, the cross EC-157568 x LE-68 exhibited significant negative heterobeltiosis along with high positive inbreeding depression. This suggests that while the parents are genetically diverse, they do not exhibit heterotic effects due to high inbreeding depression. These results indicate that plant height is governed by both additive and non-additive gene actions. These findings agree with the reports of Rai et al. (1998), Bhatt et al. (1999), Baishya et al. (2001), Fageria et al. (2001), Shalaby et al. (2013), and others, who have similarly reported positive heterobeltiosis for plant height. Regarding inbreeding depression, the results align with those of Rai et al. (1998), Rai et al. (2007), Singh et al. (2009), Patel et al. (2010), Nosser (2012), Pramod Kumar Negi et al. (2012), and Shalaby et al. (2013), with Rai (1998) observing both positive and negative inbreeding depression values for this trait.

2. Number of primary branches per plant

All crosses exhibited significant and positive relative heterosis, ranging from 38.26 to 58.04 %, indicating improved performance over the mid-parental value. Heterobeltiosis for this character was also positive and significant, with the highest observed in the cross LE-64 x LE-66 (46.89%), followed by EC-164838 x LE-66 (38.97%), LE-56 x LE-68 (28.23%), and EC-157568 x LE-68 (26.64%).

Significant inbreeding depression was observed for the number of primary branches in all four crosses. Among these hybrids, the highest inbreeding depression was observed in EC-164838 x LE-66 (21.62%), followed by LE-64 x LE-66 (18.93%), EC-157568 x LE-68

(14.89%), and LE-56 x LE-68 (14.47%). The number of primary branches per plant is an important yield component in tomato. The presence of high positive heterobeltiosis and high inbreeding depression suggests the dominance of non-additive gene effects in this trait.The findings of this study align with those of Rai et al. (1998), Bhatt et al. (1999), Singh et al. (2009), Patel et al. (2010), Pramod Kumar Negi et al. (2012), Nosser (2012), and Shalaby et al. (2013), who also reported similar results for the number of primary branches in tomato.

3. Days taken to 50% flowering

All the evaluated hybrids showed significant negative relative heterosis and heterobeltiosis for days taken to 50% flowering, with heterosis in the negative direction being desirable for earliness. High negative and significant heterobeltiosis was observed for LE-56 x LE-68 (-9.09%), followed by EC-157568 x LE-68 (-12.12%), EC-164838 x LE-66 (-12.15%), and LE-64 x LE-66 (-14.56%). The negative and significant heterobeltiosis indicated a beneficial effect for this trait, which is governed by non-additive gene action.

All the hybrids showed negative inbreeding depression for days to 50% flowering, indicating an enhancement in flowering days in the F2 generation compared to the F1, which is undesirable. The inbreeding depression ranged from -9.09% to -6.90%. These results are in line with the findings of Rai et al. (1998), Baishya et al. (2001), Fageria et al. (2001), and Pramod Kumar Negi et al. (2012) regarding inbreeding depression for this trait.

4. Number of flowers per cluster

Highly significant and positive relative heterosis was observed in all the hybrids for the number of flowers per cluster, with the highest recorded in LE-56 x LE-68 (34.08%) and the lowest in EC-164838 x LE-66 (20.45%). Significant and positive heterobeltiosis was observed in EC-157568 x LE-68 (25.00%), followed by LE-56 x LE-68 (23.45%), LE-64 x LE-66 (15.92%), and EC-164838 x LE-66 (15.22%).

Inbreeding depression was highly positive and significant in all the hybrids for the number of flowers per cluster, ranging from 15.22% to 25.00%. The highest inbreeding depression was observed in EC-164838 x LE-66 (42.14%), followed by EC-157568 x LE-68 (38.82%), LE-56 x LE-68 (29.61%), and LE-64 x LE-66 (23.08%). These results suggest that all crosses exhibited high inbreeding depression along with high levels of heterobeltiosis, indicating the presence of non-additive gene action for this trait.

5. Number of fruits per cluster

Significant and positive relative heterosis was observed in three crosses, ranging from 10.06% (LE-64 x LE-66) to 20.27% (EC-164838 x LE-66) for the number of fruits per cluster. Positive and significant heterobeltiosis was observed in EC-164838 x LE-66 (17.11%), while LE-56 x LE-68 (4.08%) exhibited non-significant heterobeltiosis, and the other crosses showed non-significant heterobeltiosis in the negative direction.

Regarding inbreeding depression, the highest positive and significant inbreeding depression was observed in EC-164838 x LE-66 (39.33%), followed by LE-56 x LE-68 (25.49%) and LE-64 x LE-66 (16.13%). Positive inbreeding depression for the number of fruits per cluster is undesirable. However, the cross EC-164838 x LE-66 exhibited significant positive heterobeltiosis, suggesting the possibility to improve this trait. In the present investigation, all the crosses showed high inbreeding depression coupled with different levels of heterobeltiosis, indicating non-additive gene action.These results align with the findings of Rai et al. (1998), Pandey et al. (2001), Singh et al. (2009), Patel et al. (2010), and Pramod Kumar Negi et al. (2012). Rai et al. (1998) also recorded significant and positive inbreeding depression for fruits per plant.

6. Fruit length (cm)

For fruit length, significant and negative relative heterosis was observed in the cross EC-164838 x LE-66 (-11.61%), while other crosses showed non-significant relative heterosis. Regarding heterobeltiosis, significant and negative values were observed in LE-56 x LE-68 (-12.22%), followed by LE-64 x LE-66 (-14.38%) and EC-164838 x LE-66 (-22.88%). For this trait, all the crosses, except EC-157568 x LE-68, exhibited negative and significant heterobeltiosis, indicating an undesirable heterotic effect.The range of inbreeding depression was from 3.09% to 14.75%. Out of the four hybrids, only one hybrid, EC-164838 x LE-66 (14.75%), showed significant positive inbreeding depression for this trait.

In this study, all the crosses displayed negative heterobeltiosis with positive inbreeding depression, suggesting that while the parents are diverse, they are not heterotic due to the high inbreeding depression.The findings related to inbreeding depression align with those of Pandey et al. (2001), who found positive inbreeding depression for fruit length, and Rai et al. (1998) and Patel et al. (2010), who observed inbreeding depression values in both directions.

7. Fruit width (cm)

For fruit width, significant and negative relative heterosis was observed in the cross EC-164838 x LE-66 (-9.00%), while other crosses showed significant and positive relative heterosis, ranging from 8.88% (LE-64 x LE-66) to 23.41% (EC-157568 x LE-68). Heterobeltiosis ranged from -9.82% to 20.54%, with high positive and significant heterobeltiosis observed in EC-157568 x LE-68 (20.54%), and negative and significant heterobeltiosis in EC-164838 x LE-66 (-9.82%).

Regarding inbreeding depression, positive and significant inbreeding depression was observed in three hybrids: EC-164838 x LE-66 (14.79%), LE-64 x LE-66 (13.95%), and LE-56 x LE-68 (5.89%), which is undesirable for fruit width.

These results align with the findings of Baishya et al. (2001), Fageria et al. (2001), and Patil et al. (2010), who observed similar heterobeltiosis values for this trait. Regarding inbreeding depression, Pandey et al. (2001) reported positive inbreeding depression values for fruit width, while Rai et al. (1998) and Patel et al. (2010) observed both positive and negative inbreeding depression values for this trait.

8. Average fruit weight (g)

For average fruit weight, significant and negative relative heterosis was observed in the cross EC-157568 x LE-68 (-23.20%), while other crosses showed non-significant relative heterosis. Negative and significant heterobeltiosis was also observed in EC-157568 x LE-68 (-25.81%), with other crosses showing non-significant results for this trait. Regarding inbreeding depression, positive and significant inbreeding depression was observed for the crosses LE-64 x LE-66 (21.53%), followed by EC-164838 x LE-66 (11.91%) and LE-56 x LE-68 (11.40%). The range of inbreeding depression from F1 to F2 generation for average fruit weight was between 11.40% and 21.53%.

The observed significant negative heterobeltiosis for average fruit weight aligns with reports from Reddy and Reddy (1994), Nosser (2012), and Shalaby et al. (2013). For inbreeding depression, the results are consistent with the findings of Rai et al. (1998), Pandey and Dixit (2001), who reported positive inbreeding depression for this trait. Additionally, Rai et al. (2007), Patel et al. (2010), and Dagade et al. (2015) found both positive and negative inbreeding depression values for average fruit weight.

9. Fruit yield per plant (kg)

For fruit yield per plant, significant and positive relative heterosis was observed, ranging from 8.27% (EC-164838) to 56.29% (LE-64 x LE-66). Positive and significant heterobeltiosis was observed for LE-56 x LE-68 (47.98%), followed by LE-64 x LE-66 (46.58%) and EC-157568 x LE-68 (17.33%). Regarding inbreeding depression, positive significant inbreeding depression was observed for the cross EC-164838 x LE-66 (19.97%), while for the other crosses, the inbreeding depression was non-significant. Non-significant and positive inbreeding depression indicates a low level of decrease in fruit yield in the F2 generation.

The highly significant and positive heterobeltiosis with low or non-significant inbreeding depression suggests that the parents may be diverse, but the inbreeding depression is non-significant or low. In such crosses, the pedigree method of selection could be adopted for the development of high-yielding lines.

These findings agree with those of Rai et al. (1998), Bhatt et al. (1999), Singh et al. (2009), Pramod Kumar Negi et al. (2012), and Shalaby T.A (2013), who reported significant and positive heterobeltiosis for this trait. Regarding inbreeding depression, Rai et al. (1998), Pandey et al. (2001), and Shalaby T.A (2013) reported positive inbreeding depression for fruit yield per plant.

10. Number of locules per fruit

For the number of locules per fruit, significant and negative relative heterosis was observed for all the hybrids, ranging from -29.82% (LE-64 x LE-66) to -3.09% (EC-164838 x LE-66). Significant and negative heterobeltiosis was observed in LE-56 x LE-68 (-27.18%), followed by EC-157568 x LE-68 (-30.10%) and LE-64 x LE-66 (-38.93%). Regarding inbreeding depression, negative but non-significant inbreeding depression was observed for three crosses: LE-64 x LE-66 (-1.25%), EC-164838 x LE-66 (-2.13%), and EC-157568 x LE-68 (-2.78%). For the other crosses, the inbreeding depression was positive but non-significant. The negative inbreeding depression from F1 to F2 indicated an enhanced number of locules per fruit in the F2 generation. For this character, the crosses EC-157568 x LE-68 and LE-64 x LE-66 exhibited highly significant heterobeltiosis in the negative direction, which is desirable. These findings are in line with reports by Rai et al. (1998), Patel et al. (2010), Nosser (2012), and Dagade et al. (2015). Patel et al. (2010) reported both positive and negative inbreeding depression for the number of locules per fruit.

11. Pericarp thickness (mm)

For pericarp thickness, significant and negative relative heterosis was observed in all the hybrids, with values ranging from -24.31% (LE-64 x LE-66) to -9.94% (EC-157568 x LE-68). Negative and significant heterobeltiosis was observed in EC-157568 x LE-68 (-

20.08%), followed by EC-164838 x LE-66 (-21.79%), LE-64 x LE-66 (-25.55%), and LE-56 x LE-68 (-28.86%). Regarding inbreeding depression, positive and significant inbreeding depression was observed for EC-157568 x LE-68 (40.00%) and EC-164838 x LE-66 (29.01%), while the other crosses exhibited positive but non-significant inbreeding depression, with the range from 1.04% to 40.00%. All crosses showed highly significant heterobeltiosis in the negative direction, indicating an undesirable heterotic effect for this trait. These results suggest that pericarp thickness is governed by non-additive gene action. The findings are consistent with reports by Rai et al. (1998), Patel et al. (2010), Pandey et al. (2001), and Shalaby et al. (2013), who also reported positive inbreeding depression for this trait.

12. Total Soluble solids (^{0}Brix)

For total soluble solids (TSS), significant and positive relative heterosis and heterobeltiosis were recorded for all hybrids. Relative heterosis ranged from 25.53% (LE-56 x LE-68) to 44.67% (EC-157568 x LE-68), with the highest heterobeltiosis observed for EC-164838 x LE-66 (36.59%), followed by EC-157568 x LE-68 (29.39%) and LE-64 x LE-66 (23.58%). Regarding inbreeding depression, highly significant positive inbreeding depression was observed in LE-64 x LE-66 (17.76%), followed by LE-56 x LE-68 (17.57%) and EC-157568 x LE-68 (12.43%). The crosses EC-157568 x LE-68, EC-164838 x LE-66, and LE-64 x LE-66 exhibited significant heterobeltiosis in the positive direction, indicating a desirable heterotic effect for TSS. The high magnitude of positive inbreeding depression observed in three hybrids (ranging from 11.90% to 17.76%) suggests that the trait is governed by non-additive genes. These results align with earlier studies by Chen et al. (1990), Ghosh et al. (1997), Rai et al. (1998), Bhatt et al. (2001), Patel et al. (2010), Nosser (2012), and Shalaby et al. (2013), while Pandey et al. (2001) also observed positive inbreeding depression for TSS.

13. Titrable acidity (%)

For titrable acidity, significant and negative relative heterosis and heterobeltiosis were recorded across all hybrids. The lowest relative heterosis was observed in EC-157568 x LE-68 (-55.07%), while the highest was in LE-56 x LE-68 (-37.88%). Regarding heterobeltiosis, highly significant and negative values were noted, with EC-164838 x LE-66 (-48.87%) showing the least, followed by LE-56 x LE-68 (-53.81%), LE-64 x LE-66 (-58.65%), and EC-157568 x LE-68 (-65.56%). This negative heterobeltiosis is desirable for titrable acidity.

All crosses exhibited positive but non-significant inbreeding depression for this trait, ranging from 0% to 5.88%. Negative inbreeding is preferred to obtain desirable segregants for titrable acidity. These findings are consistent with earlier reports by Dagade et al. (2015), Pandey et al. (2001), and Shalaby et al. (2013), who reported both positive and negative inbreeding depression for this trait.

14 . Ascorbic acid content (mg/100 g)

For ascorbic acid content, significant and negative relative heterosis and heterobeltiosis were recorded in three hybrids. The highest significant and negative heterobeltiosis was observed in EC-164838 x LE-66 (-23.53%), followed by LE-64 x LE-66 (-27.18%), while the other crosses showed non-significant results for ascorbic acid content. Regarding inbreeding depression, all crosses exhibited positive but non-significant values, ranging from 2.00% to 7.37%. These findings align with the results of Nosser et al. (2012) and Dagade et al. (2015), who reported both positive and negative inbreeding depression for ascorbic acid content.

15.Total sugars (%)

Significant and positive relative heterosis for total sugars was observed in all hybrids except LE-64 x LE-66, which exhibited a negative value of -14.86%. Positive and significant heterobeltiosis was noted in three crosses: LE-56 x LE-68 (40.35%), EC-157568 x LE-68 (19.10%), and EC-164838 x LE-66 (13.34%). Conversely, the cross LE-64 x LE-66 showed significant and negative heterobeltiosis at -15.70%. The study found positive inbreeding depression for total sugars across all crosses, although these values were statistically non-significant, ranging from 0% to 5.88%. This suggests that total sugars are likely governed by non-additive gene action.

16. Lycopene content (mg/100 g)

Significant and positive relative heterosis and heterobeltiosis for lycopene content were observed in the cross EC-164838 x LE-66, with values of 24.14% and 16.25%, respectively. Other crosses exhibited negative heterosis for this trait. Notably, significant and negative heterobeltiosis was recorded for the crosses LE-56 x LE-68 (-33.38%) and LE-64 x LE-66 (-33.58%). The positive heterobeltiosis observed in EC-164838 x LE-66 for lycopene content is considered desirable. Inbreeding depression estimates for lycopene content were found to be non-significant, ranging from 0.84% to 9.23%. These findings align with the observations of Dagade et al. (2015), who reported both positive and negative inbreeding depression for lycopene content.

Table 1. **Analysis of Variance in F2 generation for yield, yield attributes and quality Characters in tomato**

		Mean sum of squares								
Source of variation	**Df**	**Plant height (cm)**	**No. of Primary branches/plant**	**Days to 50% flowering**	**Number of flowers per cluster**	**Number of fruits per cluster**	**Fruit length (cm)**	**Fruit width (cm)**	**Average fruit weight (g)**	**Fruit yield per plant (kg)**
Replicates	2	647.290 *	0.1403	2.5333	0.0263	0.0963	0.1353	0.0087	43.8189	0.1319*
Treatments	9	959.247 **	9.1911 **	18.8481**	1.5187**	0.3437**	0.6376**	0.7362**	94.7086	0.5852**
Hybrids	3	807.451 **	2.0608**	3.8612*	0.3567**	0.1933**	0.0967	0.1499	130.4387	0.4949**
Parents	5	671.300 **	1.3946**	2.0887	0.5409**	0.4316**	1.0500**	1.0616**	31.4935	0.0441
Hybrids vs Parents	1	2854.377 **	69.5643**	147.6063**	9.8936**	0.3556**	0.1980	0.8681**	303.5974*	3.5617**
Error	18	143.209	0.0896	1.1260	0.0419	0.0289	0.0815	0.0896	47.3756	0.0254
Total	29	431.226	2.9177	6.7230	0.4991	0.1313	0.2578	0.2847	61.8199	0.2065

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

		Mean sum of squares						
Source of variation	**Df**	**Number of locules per Fruit**	**Pericarp thickness (mm)**	**Total soluble solids (ºBrix)**	**Titrable acidity (%)**	**Ascorbic acid content (mg/100 g)**	**Total sugars (%)**	**Lycopene content (mg/100 g)**
Replicates	2	0.0723	0.2875*	0.0523	0.0005	1.5543	0.0042	0.4735
Treatments	9	0.9556**	2.0948**	2.4982**	0.0959**	16.9817**	0.9084**	6.1225**
Hybrids	3	0.3164**	1.0345**	0.6164**	0.0065	7.6302	1.3890**	8.2472**
Parents	5	0.7262**	1.1212**	0.6995**	0.0683**	17.1324**	0.4438**	5.7443**
Hybrids vs Parents	1	4.0201**	10.1436**	17.1372**	0.5024**	44.2822**	1.7900**	1.6398*
Error	18	0.0583	0.0335	0.0531	0.0034	3.5119	0.0057	0.3262
Total	29	0.3377	0.6907	0.8119	0.0319	7.5572	0.2857	2.1352

Table 2:Mean performance of parents of F1 generation (P1) and parents of F2 generation (P2) for yield attributes and quality for sixteen characters in tomato.

	Parents	Plant height (cm)		No. of Primary branches/plant		Days to 50% flowering		Number of flowers/ cluster		Number of fruits/ cluster		Fruit length (cm)		Fruit width (cm)		Average fruit weight (g)	
		P1	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**
T1	EC157568	102.40	114.00	9.07	8.13	32.33	33.00	4.87	4.53	2.60	3.03	4.13	4.60	5.35	4.30	67.69	73.12
T2	EC164838	88.73	84.00	8.40	7.10	31.67	34.67	4.80	4.60	2.47	2.53	4.71	3.80	5.17	5.40	67.14	70.19
T3	LE56	108.20	109.00	9.47	8.27	32.33	33.00	5.00	4.83	2.73	3.27	4.20	4.80	5.60	5.20	69.89	67.55
T4	LE64	112.20	106.00	10.47	8.03	36.33	32.67	5.00	5.23	2.80	3.23	4.48	4.10	5.73	4.60	72.95	68.42
T5	LE66	86.00	91.00	8.40	6.90	37.33	34.33	4.33	4.20	2.47	2.40	3.85	5.10	5.15	5.50	65.42	63.28
T6	LE68	82.70	77.00	8.33	6.76	40.67	33.00	3.93	4.07	2.40	2.60	4.18	3.60	5.13	4.10	63.63	68.14
	Mean	**96.70**	**96.83**	**9.02**	**7.53**	**35.11**	**33.44**	**4.66**	**4.58**	**2.58**	**2.84**	**4.26**	**4.33**	**5.35**	**4.85**	**67.79**	**68.45**

	Parents	Fruit yield per plant (kg)		Number of locules per fruit		Pericarp thickness (mm)		Total soluble solids (ºBrix)		Titrable acidity (%)		Ascorbic acid content (mg/100 g)		Total sugars (%)		Lycopene content (mg/100 g)	
		P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
T1	EC157568	2.04	2.10	3.27	3.33	7.07	6.84	3.33	3.60	0.60	0.60	19.96	19.24	2.92	2.81	4.70	4.20
T2	EC164838	1.99	2.05	4.33	3.23	5.44	5.40	3.30	4.03	0.72	0.44	28.67	22.37	3.53	3.27	4.10	5.98
T3	LE56	2.07	1.84	3.07	2.93	5.41	6.21	3.33	3.30	0.63	0.66	23.36	19.64	3.06	2.24	4.30	3.84
T4	LE64	2.20	1.88	3.47	4.37	5.04	5.40	4.00	3.40	0.34	0.69	20.54	22.28	2.58	2.53	6.96	3.98
T5	LE66	1.96	2.15	3.20	3.23	5.06	5.58	4.30	4.10	0.31	0.41	26.51	25.66	2.51	2.48	7.20	6.85
T6	LE68	1.93	1.98	2.73	3.43	5.73	5.30	5.20	4.56	0.28	0.32	21.28	20.33	2.31	2.30	7.50	6.58
	Mean	2.03	2.00	3.34	3.42	5.63	5.79	3.91	3.83	0.48	0.52	23.39	21.59	2.82	2.61	5.79	5.24

Table 3. Mean performance of F1s and F2 s for yield attributes, yield and quality characters in tomato.

Crosses	Plant height (cm)			No. of Primary branches/plant			Days to 50% flowering			Number of flowers per cluster			Number of fruits per cluster			Fruit length (cm)			Fruit width (cm)			Average fruit weight (g)		
	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.	F1	F2	C.D.
EC157568XLE68	93.45	65.60	21.96	10.30	8.77	0.59	29.00	31.00	2.27	5.67	3.47	0.35	2.80	2.57	0.29	4.16	3.82	0.77	5.18	4.66	0.61	54.25	43.40	12.24
EC164838XLE66	117.65	92.94	34.34	9.87	7.73	0.41	27.33	29.67	4.14	5.30	3.07	0.40	2.97	1.80	0.54	3.93	3.35	0.43	4.96	4.22	0.28	66.52	58.61	7.05
LE56XLE68	125.31	109.74	34.16	10.60	9.07	0.29	30.00	32.67	2.93	5.97	4.20	0.52	3.40	2.53	0.40	4.21	4.09	0.94	5.15	4.84	0.22	58.77	52.07	6.35
LE64XLE66	130.57	111.40	28.20	11.80	9.57	0.49	29.33	32.00	2.93	6.07	4.67	0.52	3.10	2.60	0.36	4.37	4.11	0.30	5.50	4.73	0.53	68.28	53.58	6.35
Mean	116.75	94.92		10.64	8.79		28.92	31.34		5.75	3.85		3.07	2.38		4.17	3.84		5.20	4.61		61.96	51.92	

	Fruit yield per plant (kg)			Number of locules per fruit			Pericarp thickness (mm)			Total soluble solids (ºBrix)			Titrable acidity (%)			Ascorbic acid content (mg/100 g)			Total sugars (%)			Lycopene content (mg/100 g)		
Crosses	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**	**F1**	**F2**	**C.D.**
EC157568XLE68	2.46	2.12	0.45	2.40	2.47	0.52	5.47	3.28	0.44	5.90	5.17	0.52	0.21	0.20	0.09	17.16	16.82	1.93	3.35	3.18	0.19	5.96	5.61	1.23
EC164838XLE66	2.27	1.82	0.36	3.13	3.20	0.81	4.37	3.10	0.37	5.60	4.93	0.69	0.23	0.21	0.07	19.62	19.21	2.59	3.71	3.48	0.38	7.96	7.90	1.38
LE56XLE68	2.93	2.73	0.47	2.50	2.40	0.45	4.42	4.33	0.32	4.93	4.07	0.52	0.30	0.28	0.10	20.95	20.11	5.48	3.22	3.09	0.27	4.38	4.20	0.80
LE64XLE66	3.15	2.99	0.26	2.67	2.70	0.74	4.16	4.11	0.46	5.07	4.17	0.55	0.29	0.26	0.13	18.69	17.31	4.77	2.13	2.08	0.16	4.55	4.13	1.31
Mean	2.70	2.42		2.68	2.69		4.61	3.71		5.38	4.59		0.26	0.24		19.11	18.36		3.10	2.96		5.71	5.46	

Table 4. Relative heterosis and heterobeltiosis in F2 generation for yield attributes and quality characters in tomato

S. No	Cross	Plant height (cm)		No. of Primary branches/plant		Days to 50% flowering		Number of flowers per cluster		Number of fruits per Cluster	
		MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
1	EC-157568 x LE-68	-2.14	-18.02 *	38.26 **	26.64 **	-12.12 **	-12.12 **	31.78 **	25.00**	-0.59	-7.69
2	EC-164838 x LE-66	34.46 **	29.29 *	40.95 **	38.97 **	-20.77 **	-21.15 **	20.45 **	15.22**	20.27 **	17.11 **
3	LE-56 x LE-68	34.73 **	14.96	41.02 **	28.23 **	-9.09 **	-9.09 **	34.08 **	23.45**	15.91 **	4.08
4	LE-64 x LE-66	32.55 **	23.18 *	58.04 **	46.89**	-12.44 **	-14.56 **	28.62 **	15.92**	10.06 *	-4.12
	S.Ed	8.46	9.77	0.21	0.24	0.75	0.87	0.14	0.17	0.12	0.14
	CD @ 5% Level	17.78	20.53	0.44	0.51	1.58	1.82	0.3	0.35	0.25	0.29
	CD @ 1% Level	24.36	28.13	0.61	0.7	2.16	2.49	0.42	0.48	0.35	0.4

S. No	Cross	Fruit length (cm)		Fruit width (cm)		Average fruit weight (g)		Fruit yield per plant (kg)		Number of locules per fruit	
		MP	**BP**	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**
1	EC-157568 x LE-68	1.42	-9.57	23.41 **	20.54**	-23.20**	-25.81**	20.69 **	17.33*	-29.06 **	-30.10 **
2	EC-164838 x LE-66	-11.61 *	-22.88 **	-9.00 *	-9.82 *	-0.32	-5.23	8.27	5.75	-3.09	-3.09
3	LE-56 x LE-68	0.32	-12.22 *	10.71 *	-1.02	-13.36	-13.74	53.40 **	47.98**	-21.47 **	-27.18 **
4	LE-64 x LE-66	-5.11	-14.38 **	8.88 *	0	3.69	-0.2	56.29 **	46.58**	-29.82 **	-38.93 **
	S. Ed	0.2	0.23	0.21	0.24	4.87	5.62	0.11	0.13	0.17	0.2
	CD @ 5% Level	0.42	0.49	0.44	0.51	10.23	11.81	0.24	0.27	0.36	0.41
	CD @ 1% Level	0.58	0.67	0.61	0.7	14.01	16.18	0.32	0.37	0.49	0.57
MP: Mid parentBP: Better parent											

MP: Mid parent **BP: Better parent**

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

Table 5. Relative heterosis and heterobeltiosis in F2 generation for yield attributes and quality characters in tomato

S.No	Cross	Pericarp thickness (mm)		Total soluble solids (ºBrix)		Titrable acidity (%)		Ascorbic acid content (mg/100 g)		Total sugars (%)		Lycopene content(mg/100 g)	
		MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
1	EC-157568 x LE-68	-9.94 **	-20.08 **	44.61 **	29.39 **	-55.07 **	-65.56 **	-13.25	-15.56	31.07 **	19.10 **	10.64	-9.37
2	EC-164838 x LE-66	-20.49 **	-21.79 **	37.70 **	36.59 **	-46.67 **	-48.87 **	-18.28 **	-23.53 **	29.04 **	13.34 **	24.14 **	16.25 **
3	LE-56 x LE-68	-23.22 **	-28.86**	25.53 **	8.19	-37.88 **	-53.81**	4.85	3.08	42.10 **	40.35 **	-15.84	-33.38**
4	LE-64 x LE-66	-24.31 **	-25.55**	35.11 **	23.58 **	-47.88 **	-58.65**	-22.05 **	-27.18 **	-14.86 **	-15.70 **	-15.97 *	-33.58**
	S.Ed	0.13	0.15	0.16	0.19	0.04	0.05	1.33	1.53	0.05	0.06	0.4	0.47
	CD @ 5% Level	0.27	0.31	0.34	0.4	0.09	0.1	2.78	3.21	0.11	0.13	0.85	0.98
	CD @ 1% Level	0.37	0.43	0.47	0.54	0.12	0.14	3.81	4.4	0.15	0.18	1.16	1.34

MP: Mid parent **BP: Better parent**

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

Table 6: Relative heterosis (%) Heterobeltios (%) and Inbreeding Depression (%) for yield attributes, yield and quality characters in tomato.

Estimates	EC-157568 X LE-68	EC-164838 X LE-66	LE-56 X LE-68	LE-64 X LE-66
Plant Height (cm)				
RH (%)	-2.14	34.46**	34.73**	32.55**
HB	-18.02*	29.29*	14.96	23.18*
ID	29.80*	21.00	12.42	14.68
No of Primary Branches				
RH	38.26**	40.95**	41.02**	58.04**
HB	26.64**	38.97**	28.23**	46.89**
ID	14.89**	21.62**	14.47**	18.93**
Days taken for 50% Flowering				
RH	-12.12**	-20.77**	-9.09**	-12.44**
HB	-12.12**	-21.15**	-9.09**	-14.56**
ID	-6.9	-8.54	-8.89	-9.09
No of Flowers per Cluster				
RH	31.78**	20.45**	34.08**	28.62**
HB	25.00**	15.22**	23.45**	15.92**
ID	38.82**	42.14**	29.61**	23.08**
No of fruits per cluster				

RH	-0.59	20.27**	15.91**	10.06*
HB	-7.69	17.11**	4.08	-4.12
ID	8.33	39.33**	25.49**	16.13*
Fruit length (cm)				
RH	1.42	-11.61*	0.32	-5.11
HB	-9.57	-22.88**	-12.22*	-14.38**
ID	7.94	14.75*	3.09	5.95
Fruit width (cm)				
RH	23.41**	-9.00*	10.71*	8.88*

Table 6 cont.,

Estimates	EC-157568 X LE-68	EC-164838 X LE-66	LE-56 X LE-68	LE-64 X LE-66
HB	20.54**	-9.82*	-1.02	0
ID	9.97	14.79**	5.89*	13.95*
Average fruit weight (gm)				
RH	-23.20**	-0.32	-13.36	3.69
HB	-25.81**	-5.23	-13.74	-0.20
ID	20	11.91*	11.40*	21.53**
Fruit yield per plant (kg)				
RH	20.69**	8.27	53.40**	56.29**
HB	17.33*	5.75	47.98**	46.58**
ID	13.82	19.97*	6.94	4.98
No of locules per fruit				
RH	-29.06**	-3.09	-21.47**	-29.82**
HB	-30.10**	-3.09	-27.18**	-38.93**
ID	-2.78	-2.13	4	-1.25
Pericarp thickness (mm)				
RH	-9.94**	-20.49**	-23.22**	-24.31**
HB	-20.08**	-21.79**	-28.86**	-25.55**
ID	40.00**	29.01**	2.04	1.04
Total soluble solids (^{0}brix)				
RH	44.61**	37.70**	25.53**	35.11**

HB	29.39**	36.59**	8.19	23.58**
ID	12.43*	11.90	17.57*	17.76*
Titrable Acidity (%)				
RH	-55.07**	-46.67**	-37.88**	-47.88**
HB	-65.56**	-48.87**	-53.81**	-58.65**
ID	0	5.88	6.59	8.14
Ascorbic Acid Content (mg/100G)				
RH	-13.25	-18.28**	4.85	-22.05**

Table 6 cont.

Estimates	EC-157568 X LE-68	EC-164838 X LE-66	LE-56 X LE-68	LE-64 X LE-66
HB	-15.56	-23.53**	3.08	-27.18**
ID	2	2.11	4.01	7.37
Total Sugars (%)				
RH	31.07**	29.04**	42.10**	-14.86**
HB	19.10**	13.34**	40.35**	-15.70**
ID	4.98	6.29	4.34	2.03
Lycopene Content (mg/100G)				
RH	10.64	24.14**	-15.84	-15.97*
HB	-9.37	16.25*	-33.38**	-33.58**
ID	5.98	0.84	4.18	9.23
*** Significant at 5% level** Significant at 1% level**				
RH: Relative heterosis	**HB: Heterobeltiosis**			**ID: Inbreeding depression**

CONCLUSION

In the inbreeding depression studies, a positive and significant inbreeding depression was observed for traits such as the number of primary branches per plant, number of flowers per cluster, fruit length, fruit width, average fruit weight, and total soluble solids (TSS) across all crosses. Conversely, positive but non-significant inbreeding depression was noted for plant height, pericarp thickness, titratable acidity, ascorbic acid content, total sugars, and lycopene content in the crosses EC-157568 x LE-68, EC-164838 x LE-66, LE-56 x LE-68, and LE-64 x LE-66. Negative and non-significant inbreeding depression was observed for days to 50% flowering and the number of locules per fruit in the same crosses. The extent of inbreeding depression varied across different traits in the F2 generation. Among the promising crosses, EC-164838 x LE-66 exhibited highly significant positive inbreeding depression for fruit yield per plant. Meanwhile, crosses EC-157568 x LE-68, LE-56 x LE-68, and LE-64 x LE-66 showed significant heterobeltiosis in F1 along with low or non-significant inbreeding depression in F2, suggesting that while the parents are genetically diverse, the inbreeding depression is minimal. For such crosses, the pedigree method of selection could be effective in developing high-yielding lines for these traits in tomato.

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