**Original Research Article**

**STUDIES ON HETEROSIS, INBREEDING DEPRESSION AND ITS COMPONENT TRAITS FOR YIELD AND ITS ATTRBUTING TRAITS IN TOMATO**

**(*Solanum lycopersicum* L.)**

**ABSTRACT**

Tomato (Solanum lycopersicum L.) is a widely cultivated vegetable valued for its nutritional and economic significance, with strong potential for genetic improvement. Significant positive heterobeltiosis was observed in family DVRT 2 × IIHR 335 for seeds per fruit, total soluble sugars, and locules per fruit, in family ATL 17-06 × GAT 5 for fruit yield per plant, fruit weight, fruits per plant, total soluble sugars, and lycopene content and in family GAT 8 × ATL 18-04 and NTL 12-02 × GP 11 for total soluble sugars. Positive relative heterosis was recorded across all families for traits including locules per fruit, seeds per fruit, total soluble sugars, lycopene content, β-carotene, and branches per plant. Notably, the family DVRT 2 × IIHR 335 showed significant negative heterosis (–7.77%) and inbreeding depression (–7.21%) for days to flowering, indicating its potential for early flowering improvement. Family II demonstrated significant positive heterobeltiosis for yield-related traits governed by additive, dominance, and epistatic gene interactions.

**Key Words**

Tomato, Heterosis, Heterobeltiosis, Inbreeding Depression, Yield

**Introduction**

Vegetables are increasingly recognized as an essential part of nutritional security. Due to their high nutritional and economic importance, fruits and vegetables now contribute more to the global economy than food grains. Among them, tomato (*Solanum lycopersicum* L., 2n = 2x = 24) is one of the most commonly cultivated vegetables in both tropical and subtropical regions of the world. The cleistogamy flower of the crop leads to high percentage of self-pollination. The natural cross-pollination of tomato has been reported up to the extent of 5 % and insects play major role for cross pollination (Salunkhe *et al*., 1987). The major objective in the most tomato breeding programme is to improve the genetic potential for fruit yield. The utmost goal of plant breeding programme is to develop the best hybrids or improved cultivars superior to those already under the commercial cultivation. The awareness of farmers and consumers regarding nutritional security demands superior cultivars with higher and superior quality tomatoes.

When two genetically different individuals cross to create an F1 population, the phenomenon known as "heterosis" occurs when the F1 populations mean value changes from its mid parental value. Positive heterosis is defined as a hybrid expression that is better than the mid parental value and negative heterosis is defined as a decreased trend. Inbreeding refers to the mating between closely related individuals sharing a common gene pool, essentially involving individuals related by ancestry. Inbreeding depression may manifest in F2 and subsequent generations, with the severity varying across different traits, generations, and the number of parents involved in the initial cross. Typically, depression is more pronounced in the early generations and tends to diminish over time. The rapid decline from F1 to F2 is often attributed to the breakdown of specific gene combinations responsible for heterosis in F1 due to segregation in the F2 generation.

Jinks and Jones (1958) proposed a method for estimating the components of heterosis under digenic and trigenic interactions. These components were estimated using weighted least squares of generation mean. Table 1 summarized the components of heterobeltiosis and inbreeding depression for various traits.

**Methodology**

The present investigation scrutinizes the inheritance pattern of morphological characters and analyze to estimate the magnitude of heterosis and inbreeding depression for economic traits during the *kharif*-*rabi* season of 2024-25 at the Main Vegetable Research Station, Anand Agricultural University, Anand. Eight diverse parents of tomato *viz*., DVRT 2, IIHR 335, ATL 17-06, GAT 5, GAT 8, ATL 18-04, NTL 12-02 and GP 11 were used for the development of various generations. The seeds were obtained from Main Vegetable Research Station (MVRS), Anand Agricultural University, Anand. Four families *viz*., Family-I (DVRT 2 × IIHR 335), Family -II (ATL 17-06 × GAT 5), Family -III (GAT 8 × ATL 18-04) and Family -IV (NTL 12-02 × GP 11) each with 12 generations *viz*., P1, P2, F1, F2, B1, B2, B11, B12, B21, B22, B1S and B2S were generated during the *kharif-rabi* season of 2024-25.

**Estimation of heterosis, inbreeding depression and components of heterosis**

**Heterosis**

Heterosis uttered in % was calculated as the eccentricity of F1 over mid-parent (Turner,1953) by subsequent formulae

 $ Relative heterosis \left(\%\right) = \frac{\overbar{F\_{1}}-\overbar{MP}}{\overbar{MP}}×100$

Where, $F\_{1}$ = Mean performance of F1

 $\overbar{MP}$ = Mean value of mid parent value

**Heterobeltiosis**

Heterosis articulated in percentage was premeditated as the aberration of F1 over better parent (Fonseca and Patterson, 1968) by following formulae

$$Heterobeltiosis \left(\%\right) = \frac{\overbar{F\_{1}}-\overbar{BP}}{\overbar{BP}}×100$$

Where, $F\_{1}$ = Mean performance of F1

$\overbar{BP}$ = Mean value of better parent of respective cross combination

**Inbreeding depression**

Inbreeding depression was calculated by using the following formula,

 Inbreeding depression (%) = 

**Components of heterosis**

Components of heterosis in the presence of digenic interactions were premeditated as recommended by Jinks and Jones (1958) as under.

F1 – BP = [(h) – (i)] – [(d) – ½ (j)] or [(h) – (i) – (d) + ½ (j)]

 Components of heterosis in the presence of trigenic interactions Hill (1966)

 F1 – BP = [(h) + ¼ (l) +  (z)] – [(d) + (i) – ½ (j) + ¼ (l) + (w) – (×) + ¼ (y) - (z)]

**Results**

**Fruit yield per plant**

Fruit yield per plant is one of the most critical and economically valuable traits in tomato. As a dependent trait, it is influenced by various other plant characteristics. Therefore, understanding the relationships between yield and its contributing traits is essential for gaining insight into heterosis for fruit yield per plant. The data presented in Table 1 and Figure 1 show both positive and negative values for relative heterosis. Significant and positive (desirable) relative heterosis was observed only in family ATL 17-06 × GAT 5 (12.20%), whereas family DVRT 2 × IIHR 335 (3.80%) showed positive (desirable) relative heterosis. Significant and negative (undesirable) heterosis was observed in family GAT 8 × ATL 18-04 (-12.79), while families NTL 12-02 × GP 11 (-5.33%) also showed negative value. Similar result of higher heterosis was also observed by Kumar *et al.* (2017), Prajapati *et al*. (2023) and Kumar *et al*. (2024) for fruit yield per plant consistent with the performance of the family ATL 17-06 × GAT 5. The heterobeltiosis for fruit yield per plant across the four families ranged from -25.65 (GAT 8 × ATL 18-04) to 10.60% (ATL 17-06 × GAT 5) indicating the presence of both positive and negative heterotic effects. Among all families, ATL 17-06 × GAT 5 (10.60 %) showed the highest positive and significant heterobeltiosis suggesting enhanced fruit yield over the better parent and potential suitability for hybrid development. The family DVRT 2 × IIHR 335 recorded the highest positive and highly significant inbreeding depression (20.96%), followed by ATL 17-06 × GAT 5 (19.84%) which was positive but not significant. These results suggest reduced performance in selfed progeny, highlighting the presence of hybrid vigour in the F₁ generation. Similar outcome of inbreeding depression was earlier observed by Dagade and Dhaduk (2016), Kumar and Singh (2016), Amin *et al.* (2017) and Prajapati *et* *al*. (2023).

**Days to flowering**

For this trait, parent exhibiting early flowering was considered the better parent. Heterosis ranged from -1.36 (DVRT 2 × IIHR 335) to 8.35% (ATL 17-06 × GAT 5). The negative and desirable relative heterosis was found in DVRT 2 × IIHR 335 (-1.36%), as shown in Table 1. The magnitude of heterobeltiosis ranged from -7.77 (DVRT 2 × IIHR 335) to 2.66% (ATL 17-06 × GAT 5). DVRT 2 × IIHR 335 (-7.77%) recorded the highest significant and negative heterobeltiosis followed by NTL 12-02 × GP 11 (-4.39%) and GAT 8 × ATL 18-04 (-1.97%), indicating these hybrids as promising candidates for early flowering. Similar negative (desirable) heterobeltiosis were earlier reported by Kumar and Singh (2016), Shirisha *et al*. (2021) and Kumar *et al*. (2024). The lowest inbreeding depression was detected in ATL 17-06 × GAT 5 (-4.21%) followed by DVRT 2 × IIHR 335 (-6.55%). The significant and undesirable (negative) inbreeding depression for days to flowering was also manifested by Amin *et al.* (2017), Kumar *et al*. (2017), Kumar *et al*. (2020) and Prajapati *et al.* (2023).

**Plant height**

Magnitude of relative heterosis was detected positive (undesirable) as well as negative (undesirable). Among four families, the best family for relative heterosis was observed for family NTL 12-02 × GP 11 (-3.01%) followed by DVRT 2 × IIHR 335 (-2.50%) and GAT 8 × ATL 18-04 (-0.09%). Similar results for both negative and positive relative heterosis were also reported by Osei *et al*. (2020), Prajapati *et al.* (2023), Kumar *et al*. (2024) and Sairam *et al*. (2024). Among all four families, family NTL 12-02 × GP 11 (-13.27%) showed significant as well as negative (desirable) heterobeltiosis. Negative better parent heterosis were also reported earlier by Nevani and Sridevi (2022) and Sairam *et al*. (2024). The high positive (desirable) inbreeding depression was observed in family ATL 17-06 × GAT 5 (13.91%) followed by DVRT 2 × IIHR 335 (6.37%), NTL 12-02 × GP 11 (5.34%) and GAT 8 × ATL 18-04 (5.06%).

**Branches per plant**

The relative heterosis ranged from -15.64 to 15.11% has shown in Table 1. Positive relative heterosis was also reported by Kumar *et al*. (2017) and Triveni *et al.* (2017). Heterobeltiosis ranged from -18 % (DVRT 2 × IIHR 335.88) to 8.84 % (NTL 12-02 × GP 11). Significant and positive results were estimated for ATL 17-06 × GAT 5 (4.46 %). Heterosis in the positive direction is desirable as it suggests an increase in the branches per plant. For all four families, significant inbreeding depression ranged from 12.97 to 22.71 %. The highest and significant inbreeding depression was observed in the family ATL 17-06 × GAT 5 (4.46 %). These results are in favour of Sahu *et al*. (2016), Amin *et al.* (2017), Kumar *et al*. (2017), Prajapati *et al*. (2023) and Kumar *et al*. (2024).

**Fruits per plant**

Variation in relative heterosis for fruits per plant was evident in four tomato families, with values ranging from -15.58 (NTL 12-02 × GP 11) to 14.92 % (ATL 17-06 × GAT 5). The family ATL 17-06 × GAT 5 demonstrated highly significant relative heterosis (14.92 %), indicating a marked improvement over the mid-parent value as shown in Table 1 and Figure 1. The magnitude of heterosis was in accordance with the findings of Dagade and Dhaduk (2016), Kumar and Singh (2016), Amin *et al.* (2017), Kumar *et al.* (2017) and Prajapati *et al*. (2023). Heterobeltiosis ranged from -17.38 (NTL 12-02 × GP 11) to 11.42% (ATL 17-06 × GAT 5) among the four families. The family ATL 17-06 × GAT 5 recorded positive and significant heterobeltiosis (11.42 %), suggesting better performance over the superior parent and highlighting its hybrid potential. A wide range of inbreeding depression values was observed among the four tomato families, spanning from -31.18 (NTL 12-02 × GP 11) to 38.53% (DVRT 2 × IIHR 335) reflects both hybrid breakdown and inbred advantage. Conversely, NTL 12-02 × GP 11 exhibited a significant negative inbreeding depression (-31.18%), suggesting that the hybrid performed better than its parents. The results is accordance with the findings of Kumar and Singh (2016) and Prajapati *et al*. (2023).

**Fruit weight**

The family ATL 17-06 × GAT 5 recorded the positive and highly significant heterosis (30.25%), indicating substantial improvement over the mid-parent value. A positive but non-significant relative heterosis was also observed in DVRT 2 × IIHR 335 (4.37%) and NTL 12-02 × GP 11 (6.72%) as shown in Table 1 and Figure 1. Family ATL 17-06 × GAT 5 showed the highly significant positive heterobeltiosis (18.07%), demonstrating its strong hybrid advantage. In contrast, GAT 8 × ATL 18-04 exhibited negative (undesirable) and significant heterobeltiosis (-24.46%) followed by DVRT 2 × IIHR 335 (-10.31%). The relative heterosis and heterobeltiosis for family ATL 17-06 × GAT 5 was found similar with the finding of Kumar *et al*. (2017), Prajapati *et al.* (2023) and Kumar *et al*. (2024). The family DVRT 2 × IIHR 335 recorded highly significant inbreeding depression (15.57%), followed closely by NTL 12-02 × GP 11 (15.31%) and ATL 17-06 × GAT 5 (14.27%). The similar findings for inbreeding depression were registered by Dagade and Dhaduk (2016), Amin *et al.* (2017) and Prajapati *et al*. (2023) for fruit weight.

**Locules per fruit**

The family DVRT 2 × IIHR 335 (54.19%) showed the highest positive and significant value followed by ATL 17-06 × GAT 5 (25.00%), GAT 8 × ATL 18-04 (12.20%) and NTL 12-02 × GP 11 (1.41%) as shown in Table 1. The significant positive relative heterosis was reported earlier reported by Sahu *et al.* (2016) and Prajapati *et al*. (2023). Positive value of heterobeltiosis was observed in family GAT 8 × ATL 18-04 (17.65%) followed by NTL 12-02 × GP 11 (0.12%) and ATL 17-06 × GAT 5 (-4.17%). Positive better parent heterosis were also earlier reported by Sahu *et al.* (2016), Avdikos *et al*. (2021) and Shirisha *et al*. (2021). The range of inbreeding depression observed from -10.33 (ATL 17-06 × GAT 5) to 21.67% (GAT 8 × ATL 18-04). The highest inbreeding depression was observed for family GAT 8 × ATL 18-04 (21.67%) followed by DVRT 2 × IIHR 335 (8.64%), NTL 12-02 × GP 11 (-6.94 %) and ATL 17-06 × GAT 5 (-10.33 %). Negative as well as positive inbreeding depression were also earlier reported by Sahu *et al.* (2016) and Prajapati *et al*. (2023).

**Seeds per fruit**

Significant and positive relative heterosis was found only for family DVRT 2 × IIHR 335 (15.99%) as shown in Table 1. Positive (desirable) and significant heterobeltiosis was shown by family DVRT 2 × IIHR 335 (10.26%). In contrast, negative and significant heterobeltiosis was reported by family ATL 17-06 × GAT 5 (-22.87%). All the four families manifested significant and positive (undesirable) inbreeding depression. The lowest inbreeding depression was observed in ATL 17-06 × GAT 5 (35.10%) followed by GAT 8 × ATL 18-04 (31.61%), DVRT 2 × IIHR 335 (26.04%) and NTL 12-02 × GP 11 (12.48%). Similar results of positive (undesirable) heterobeltiosis and inbreeding depression were earlier reported by Kumar *et al*. (2017).

**1000 Seed Weight**

Here, the magnitude of relative heterosis was recorded both positive and negative directions. It ranged from -19.19 (ATL 17-06 × GAT 5) to 0.13% (NTL 12-02 × GP 11). Positive relative heterosis found for the family NTL 12-02 × GP 11 (0.13%). All families exhibited significant and negative heterobeltiosis. The highest significant and negative heterobeltiosis recorded for the family DVRT 2 × IIHR 335 (-28.60%) followed by ATL 17-06 × GAT 5 (-24.36%), GAT 8 × ATL 18-04 (-13.22%) and NTL 12-02 × GP 11 (-4.74%). The inbreeding depression was ranged from -13.27 (DVRT 2 × IIHR 335) to 7.22% (NTL 12-02 × GP 11). Negative and non-significant value was observed for the family DVRT 2 × IIHR 335 (-13.27%) followed by ATL 17-06 × GAT 5 (-2.49%). Similar results for relative heterosis, heterobeltiosis and inbreeding depression were reported by Prajapati *et al*. (2023).

**Components of heterosis**

The significant positive heterobeltiosis was observed in ATL 17-06 × GAT 5 indicating presence of hybrid vigour in fruit yield per plant. The contributing gene effects were dominance (h), additive × dominance (j), additive × additive × additive (w), additive × additive × dominance (x) and additive × dominance × dominance (y) (as per Table 2). Highly significant and negative heterobeltiosis for days to flowering were found in DVRT 2 × IIHR 335. For this family, the contributing gene effect were additive (d), dominance (h), additive × additive (i), additive × dominance (j), additive × additive × additive (w), additive × dominance × dominance (y) and dominance × dominance × dominance (z). For plant height, none of the families exhibited positive significant heterobeltiosis, indicating a predominance of additive gene action and lack of favourable dominance effects. Family IV (NTL 12-02 × GP 11) exhibited significant positive heterobeltiosis for branches per plant. The contributing gene effects were additive (d), dominance (h), additive × additive (i), additive × additive × additive (w) and dominance × dominance × dominance (z). For fruits per plant, the family ATL 17-06 × GAT 5 showed highly significant and positive heterobeltiosis, which could be attributed to the prominent role of epistatic interactions involving additive × dominance (j), additive × additive × additive (w), additive × additive × dominance (x) and additive × dominance × dominance (y) gene effects. For fruit weight, the family ATL 17-06 × GAT 5 exhibited highly significant and positive heterobeltiosis. This favourable response was largely influenced by a combination of additive and non-additive gene action. Specifically, epistatic interactions involving additive (d), dominance (h), additive × additive (i), additive × additive × additive (w), additive × additive × dominance (x) and additive × dominance × dominance (y) gene effects played a crucial role in enhancing the trait. These interactions likely contributed to improved transgressive segregation and better expression of favourable alleles in the hybrid combination. Family I (DVRT 2 × IIHR 335) demonstrated positive and highly significant heterobeltiosis for seeds per fruit. This enhanced performance was primarily attributed to a complex interplay of gene action, including additive (d), additive × additive (i), and additive × dominance (j) effects. Additionally, higher-order epistatic interactions such as additive × additive × additive (w), additive × additive × dominance (x), additive × dominance × dominance (y) and dominance × dominance × dominance (z) played a vital role in improving the trait expression in hybrid (as per Table 2).

**Conclusions**

Positive and significant heterosis over the mid-parent, along with negative inbreeding depression (8.35% and -4.21%, respectively), was observed in the family ATL 17-06 × GAT 5, suggesting its potential for early flowering improvement. Across the four families, significant and positive heterobeltiosis was recorded family I for seeds per fruit and locules per fruit, family II for fruit weight, fruits per plant and fruit yield per plant. Similarly, all four families displayed significant positive relative heterosis family I for locules per fruit and seeds per fruit, family II for fruit yield per plant, days to flowering, fruits per plant and fruit weight, family III for locules per fruit and family IV for branches per plant. These results highlighted the genetic potential of these families for improving key yield and quality traits in tomato. The family ATL 17-06 × GAT 5 exhibited significant positive heterobeltiosis for fruit yield per plant, attributed to dominance, additive × dominance effect and higher-order epistatic interactions. DVRT 2 × IIHR 335 showed highly significant negative heterobeltiosis for days to flowering, governed by additive, dominance and complex epistatic effects.

**References**

Amin A., Wani K. P., Nayeema J., & Faheema, M. (2017). Heterosis studies in tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry*, 6 (6), 2487-2490.

Avdikos, I. D., Nteve, G. M., Apostolopoulou, A., Tagiakas, R., Mylonas, I., Xynias, I. N., & Mavromatis, A. G. (2021). Analysis of heterosis for yield and fruit quality in restructured hybrids, generated from crossings among tomato recombinant lines. *Agronomy*, 11 (5), 822.

Dagade, S. B., & Dhaduk, L. K. (2016). Diallel cross analysis of nutritional characters of tomato. *International Journal of Farm Science,* 6 (2), 65-72.

Fonesca, S., & Patterson, F. L. (1968). Hybrid vigour in a seven parent’s diallel cross in common winter wheat (*T. aestivum* L.). *Crop Science*, 8 (1), 85-88.

Hill, J. (1966). Recurrent backcrossing in the study of quantitative inheritance. *Heredity*, 21, 85-120.

Jinks, J. L., & Jones, R. M. (1958). Estimation of components of heterosis. *Genetics*, 43 (2), 223-34.

Kumar, B., Pal, A. K., Singh A. K., Arya, D., Pattnaik, P., & Yadav N. (2024). Studies of heterosis and inbreeding depression for growth parameters in tomato hybrids (*Solanum lycopersicum* L.). *International Journal of Advanced Biochemistry Research*, 8 (1), 16-20.

Kumar, C., & Singh, S. P. (2016). Heterosis and inbreeding depression to identify superior F1 hybrids in tomato (*Solanum lycopersicum* L.) for the yield and its contributing traits. *Journal of Applied and Natural Science,* 8 (1), 290- 296.

Kumar, P., Singh, N., & Singh, P. K. (2017). A study on heterosis in tomato (*Solanum lycopersicum* L.) for yield and its component traits. *International Journal of Current Microbiology and Applied Sciences*, 6 (7), 1318-1325.

Kumar, R., & Srivastava, K. (2020). Gene effects and heritability for yield traits in tomato (*Solanum lycopersicum* L.). *Bangladesh Journal of Botany*, 50(3), 453-465.

Nevani, S., & Sridevi, O. (2022). Study of heterosis, residual heterosis and inbreeding depression in two crosses of tomato. *International Journal of Agriculture and Environmental Biotechnology*, 12, 140-307.

Osei, M. K., Danquah, A., Danquah, E., Blay, E., & Adu-Dapaah, H. (2020). Gene action of shelf-life and other fruit quality traits in a cross between a regular cultivar and Alc mutant of tomato. *Agricultural and Food Science Journal of Ghana*, 13, 1224-1236.

Prajapati, P. J., Patel, J. N., Patel, N., & Parmar, D. J. (2023). Heterosis and inbreeding depression in tomato (*Lycopersicon esculentum* L.) lines. *The Pharma Innovation Journal*, 12 (6), 3103-3107.

Sahu, M., Sahu, K. K., Tirkey, A., Padayay, D. U., & Mehta, N. (2016). Heterosis and inbreeding depression for agro-morphological characters in tomato (*Lycopersicon* *esculentum* Mill.). *International Journal of Farm Sciences*, 6 (2), 51-64.

Sairam, V., Raut, N., Kumar B. A., Chittapur, R., Mallayya, V., & Hiremath, R. S. J. (2024). Development of tomato (*Solanum lycopersicum* L.) hybrids for protected cultivation. *Vegetable Science*, 51 (2), 249-256.

Salunkhe, D. K., Desai, B. B., & Bhat, N. R. (1987). Vegetables and Flower Seed Production(1st ed., pp. 118-119.). Agricola Publishing Academy, New Delhi, India.

Shirisha, T., Pidigam, S., Adapa, K. K., Natarajan, S., & Amarapalli, G. (2021). Evaluation of parents and hybrids for yield and yield contributing traits in tomato (*Solanum lycopersicum* L.) for per se performance. *Journal of Pharmacognosy Phytochemistry*, 10, 1770-1776.

Triveni, D., Saidaiah, P. K., Ravinder, R. K., & Pandravada, S. R. (2017). Studies on combining ability and gene action for growth and quality characters in tomato (*Solanum lycopersicum* (L.). *International Journal of Pure and Applied Bioscience*,5(4), 1835-1840.

Turner Jr, J. H. (1953). A study of heterosis in upland cotton II. Combining ability and inbreeding effects 1. *Agronomy Journal*, 45 (10), 487-490.

**Table 1. Estimation of relative heterosis, heterobeltiosis (HB%) and inbreeding depression (ID%) for yield and its attributing traits**

|  |
| --- |
| **Fruit yield per plant** |
| **Family** | **RH (%)** | **HB (%)** | **ID (%)** |
| **Estimates** | **SE ±** | **Estimates** | **SE ±** | **Estimates** | **SE ±** |
| **I** | 3.80 | ±0.07 | -2.75 | ±0.06 | 20.96\*\* | ±0.08 |
| **II** | 12.20\*\* | ±0.07 | 10.60\* | ±0.08 | 19.84\*\* | ±0.09 |
| **III** | -12.79\*\* | ±0.09 | -25.65\*\* | ±0.08 | -3.32 | ±0.06 |
| **IV** | -5.33 | ±0.10 | -10.77 | ±0.11 | -19.33\* | ±0.12 |
| **Days to flowering** |
| **I** | -1.36 | ±0.88 | -7.77\*\* | ±0.99 | -7.21\*\* | ±0.86 |
| **II** | 8.35\*\* | ±0.73 | 2.66 | ±0.92 | -4.21\*\* | ±0.70 |
| **III** | 3.60 | ±1.36 | -1.97 | ±1.54 | 3.24 | ±1.35 |
| **IV** | 1.43 | ±0.85 | -4.39 | ±1.09 | 2.19 | ±0.86 |
| **Plant height** |
| **I** | -2.50 | ±5.01 | -4.93 | ±5.57 | 6.37 | ±7.08 |
| **II** | 3.66 | ±10.18 | -3.70 | ±10.78 | 13.91 | ±10.89 |
| **III** | -0.09 | ±5.76 | -8.11 | ±7.25 | 5.06 | ±7.60 |
| **IV** | -3.01 | ±6.64 | -13.27\* | ±7.13 | 5.34 | ±7.59 |
| **Branches per plant** |
| **I** | -15.64\* | ±0.59 | -18.88\* | ±0.66 | 17.46\* | ±0.63 |
| **II** | 8.97 | ±0.56 | 4.46 | ±0.74 | 22.71\*\* | ±0.57 |
| **III** | -0.75 | ±0.70 | -15.29 | ±0.79 | 12.97 | ±0.79 |
| **IV** | 15.11\* | ±0.54 | 8.84\* | ±0.60 | 20.00\*\* | ±0.60 |
| **Fruits per plant** |
| **I** | 2.78 | ±1.51 | -4.90 | ±1.74 | 38.53\*\* | ±1.53 |
| **II** | 14.92\*\* | ±1.23 | 11.42\* | ±1.34 | 30.81\*\* | ±1.36 |
| **III** | -2.24 | ±1.97 | -5.54\*\* | ±2.12 | 22.00\*\* | ±2.16 |
| **IV** | -15.58 | ±1.70 | -17.38 | ±1.79 | -31.18\* | ±1.81 |
| **Fruit weight** |
| **I** | 4.37 | ±2.40 | -10.31\* | ±2.81 | 15.57\*\* | ±2.85 |
| **II** | 30.25\*\* | ±4.36 | 18.07\*\* | ±4.86 | 14.27\*\* | ±5.43 |
| **III** | -21.51\*\* | ±5.22 | -24.46\*\* | ±5.75 | -9.52 | ±5.39 |
| **IV** | 6.72 | ±3.96 | -4.09 | ±2.75 | 15.31\* | ±4.61 |
| **Locules per fruit** |
| **I** | 54.29\*\* | ±0.53 | 35\* | ±0.53 | 8.64 | ±0.56 |
| **II** | 12.20 | ±0.27 | -4.17 | ±0.28 | -10.33 | ±0.30 |
| **III** | 25.00\* | ±0.29 | 17.65 | ±0.31 | 21.67 | ±0.29 |
| **IV** | 1.41 | ±0.16 | 0.12 | ±0.19 | -6.94 | ±0.16 |
| **Seeds per fruit** |
| **I** | 15.99\*\* | ±1.64 | 10.26\*\* | ±2.19 | 26.04\*\* | ±1.98 |
| **II** | -14.07 | ±5.66 | -22.87\* | ±5.93 | 35.10\*\* | ±5.89 |
| **III** | 17.14 | ±4.67 | -2.61 | ±4.95 | 31.61\* | ±4.92 |
| **IV** | -0.76 | ±1.60 | -7.79 | ±2.00 | 12.48\* | ±2.13 |
| **1000 seed weight** |
| **I** | -18.31\*\* | ±0.05 | -28.60\*\* | ±0.06 | -13.27 | ±0.07 |
| **II** | -19.19\*\* | ±0.07 | -24.36\*\* | ±0.08 | -2.49 | ±0.08 |
| **III** | -6.77\* | ±0.11 | -13.22\*\* | ±0.12 | 3.75 | ±0.12 |
| **IV** | 0.13 | ±0.08 | -4.74\* | ±0.10 | 7.22\*\* | ±0.08 |

Family I: DVRT 2 × IIHR 335 Family II: ATL 17-06 × GAT 5

Family III: GAT 8 × ATL 18-04 Family IV: NTL 12-02 × GP 11

**Fig. 1: Heterosis and inbreeding depression in fruit yield per plant, fruits per plant and fruit weight in four families of tomato**

**Table 2. Components of heterosis over better parent for different characters in four families of tomato**

|  |  |  |  |
| --- | --- | --- | --- |
| **Components** | **Fruit yield per plant** | **Days to flowering** | **Plant height** |
| **Family I** | **Family II** | **Family III** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** |
| **(h)** | -0.27\*\* | -0.22\*\* | -0.32\*\* | 0.12 | 0.46\*\* | 0.96\*\* | -0.13 | -0.14\*\* | 0.20\*\* | -0.36\*\* | -0.40\*\* | -0.56\*\* |
| **-(i)** | 0.28\*\* | 0.27 | 0.17 | -0.25 | 0.50\*\* | 0.13 | -0.31\*\* | -0.27\*\* | -0.63\*\* | 0.65\*\* | 0.86\*\* | 0.10 |
| **½(x)** | 0.11 | 0.28\*\* | 0.27\*\* | 0.28\*\* | -0.1 | -0.19 | 0.40\*\* | 0.43\*\* | -0.06\*\* | 0.17 | 0.15\*\* | 0.16 |
| **¼(z)** | -0.04 | -0.02 | -0.18\*\* | -0.02\*\* | 0.11\*\* | 0.17 | -0.21\*\* | -0.02\*\* | 0.19\*\* | -0.05\*\* | -0.05\*\* | -0.10\*\* |
| **-(d)** | 0.35\*\* | 0.10 | -0.14 | 0.53\*\* | -0.35\*\* | 0.94\*\* | 0.12 | -0.28\* | -0.39\*\* | 0.18\*\* | 0.29\*\* | 0.11 |
| **½(j)** | 0.07\*\* | -0.31\*\* | -0.05\*\* | 0.15\*\* | -0.42\*\* | 0.43\*\* | 0.27\*\* | -0.37\*\* | -0.07 | -0.36\*\* | 0.42\*\* | 0.12 |
| **-(w)** | -0.26 | 0.77\*\* | -0.14 | 0.45\*\* | 0.82\*\* | 0.14 | -0.94\*\* | 0.54\*\* | 0.36\*\* | -0.29\*\* | -0.15 | 0.25\*\* |
| **-¼ (y)** | -0.03 | -0.09\*\* | -0.16\*\* | -0.03\*\* | -0.16\*\* | 0.14 | 0.16\*\* | -0.02 | 0.04 | 0.02 | -0.14\*\* | 0.04 |
| **F1 – BP** | -0.04 | 0.2 | -0.48 | -0.18 | -3.47 | 1.2 | -1 | -2.07 | -6.61 | -5.23 | -12.63\*\* | -18.99 |
| **S.E. ±****Heterobeltiosis (%)** | 0.06 | 0.08 | 0.08 | 0.11 | 0.99 | 0.92 | 1.54 | 1.09 | 5.57 | 10.78 | 7.25 | 7.13 |
| -2.75 | 10.60\* | -25.65\*\* | -10.77 | -7.77\*\* | 2.66 | -1.97 | -4.39 | -4.93 | -3.70 | -8.11 | -13.27\* |
| **F1 – F2** | 0.3 | 0.4 | -0.05 | -0.29 | -3.27 | -1.95 | 1.62 | 0.98 | 8.13 | 18.94 | 7.25 | 6.62 |
| **S.E. ±****Inbreeding depression (%)** | 0.08 | 0.09 | 0.06 | 0.12 | 0.86 | 0.70 | 1.35 | 0.86 | 7.08 | 10.89 | 7.60 | 7.59 |
| 20.96\*\*\* | 19.84\*\* | -3.32 | -19.33 | -7.21\*\* | -4.21\*\* | 3.24 | 2.19 | 6.37 | 13.91 | 5.06 | 5.34 |

\* and \*\* = 5 and 1% levels of significance, respectively

**Table 2. Contd...**

|  |  |  |  |
| --- | --- | --- | --- |
| **Components** | **Branches per plant** | **Fruits per plant** | **Fruit weight** |
| **Family I** | **Family II** | **Family III** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** |
| **(h)** | -0.50\*\* | 0.19\*\* | -0.32\*\* | 0.31\*\* | -0.11 | 0.12 | -0.58\*\* | 0.10 | -0.23\*\* | -0.14\*\* | -0.21\*\* | -0.22 |
| **-(i)** | -0.71\*\* | 0.47\*\* | -0.61\*\* | 0.23\*\* | -0.15 | 0.30 | -0.70\*\* | 0.21 | 0.33\*\* | 0.52\*\* | 0.22\*\*\* | 0.47\*\* |
| **½(x)** | 0.11 | -0.06 | 0.40\*\* | -0.14 | 0.275\*\* | -0.37\*\* | -0.34\*\* | -0.41\*\* | 0.23 | 0.07 | 0.06 | 0.08 |
| **¼(z)** | -0.09 | 0.05 | -0.04\*\* | 0.21\*\* | -0.15 | 0.03 | -0.03 | 0.15\*\* | -0.05 | -0.02\*\* | -0.05 | -0.02 |
| **-(d)** | 0.59\*\* | -0.14\*\* | 0.23\*\* | 0.14\*\* | 0.79\*\* | 0.18 | 0.58\*\* | 0.75 | 0.43\*\* | -0.41\*\* | -0.22\*\* | 0.58\*\* |
| **½(j)** | -0.37\*\* | 0.38\*\* | 0.48\*\* | 0.13 | 0.11\*\* | 0.07\*\* | 0.40\*\* | 0.15\*\* | 0.05 | -0.1 | -0.31\*\* | -0.05 |
| **-(w)** | -0.23\*\* | 0.17\*\* | -0.76\*\* | -0.95\*\* | -0.61\*\* | -0.89\*\* | -0.69\*\* | 0.80\*\* | -0.52\*\* | 0.13\*\* | 0.25\*\* | 0.18\*\* |
| **-¼ (y)** | -0.04 | 0.10\*\* | 0.03 | 0.02 | 0.05\*\* | 0.05\*\* | 0.16\*\* | -0.07\*\* | 0.03 | 0.04\*\* | 0.09\*\* | 0.07\*\* |
| **F1 – BP** | -1.8 | 0.46 | -1.6 | 0.87 | -1.33 | 3 | -1.54 | -3.8 | -6.83 | 17.35 | -20.29 | -3.37 |
| **S.E. ±****Heterobeltiosis (%)** | 0.66 | 0.74 | 0.79 | 0.60 | 1.74 | 1.34 | 2.12 | 1.79 | 2.81 | 4.86 | 5.75 | 2.75 |
| -18.88\* | 4.46 | -15.29 | 8.84\* | -4.90 | 11.42\* | -5.54\*\* | -17.38\*\* | -10.31 | 18.07\*\* | -24.46\*\* | -4.09 |
| **F1 – F2** | 1.35 | 2.48 | 1.15 | 2.14 | 9.97 | 9.02 | 5.75 | -5.63 | 9.26 | 16.18 | -5.96 | 12.08 |
| **S.E. ±****Inbreeding depression (%)** | 0.63 | 0.57 | 0.79 | 0.60 | 1.53 | 1.36 | 2.16 | 1.81 | 2.85 | 5.43 | 5.39 | 4.61 |
| 17.46\* | 22.71\*\* | 12.97 | 20.00\*\* | 38.53\*\* | 30.81\*\* | 22.00\*\* | -31.18\* | 15.57\*\* | 14.27\*\* | -9.52 | 15.31\* |

\* and \*\* = 5 and 1% levels of significance, respectively

**Table 2. Contd...**

|  |  |  |  |
| --- | --- | --- | --- |
| **Components** | **Locules per fruit** | **Seeds per fruit** | **1000 seed weight** |
| **Family II** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** | **Family I** | **Family II** | **Family III** | **Family IV** |
| **(h)** | 0.2 | 0.19 | -0.10 | -0.49 | -0.19 | -0.19 | -0.64\*\* | 0.24\*\* | -0.32\*\* | -0.10\*\* |
| **-(i)** | -0.35\*\* | 0.35 | 0.15\*\* | 0.89\*\* | -0.62\*\* | -0.32\*\* | 0.21\*\* | 0.19 | -0.25 | 0.18 |
| **½(x)** | -0.3\*\* | -0.05\*\* | 0.21\*\* | 0.11 | 0.20\*\* | 0.08 | -0.41\*\* | -0.06 | 0.07\*\* | 0.15 |
| **¼(z)** | 0.03 | 0.03 | -0.18\*\* | -0.07 | -0.03 | 0.09\*\* | -0.02 | -0.05\*\* | -0.12\*\* | 0.03\*\* |
| **-(d)** | 0.4 | -0.70\*\* | -0.64\*\* | -0.50\*\* | -0.13\*\* | -0.15\*\* | 0.83\*\* | -0.12 | -0.29\*\* | -0.93 |
| **½(j)** | 0.16\*\* | -0.09\*\* | -0.10\*\* | -0.06 | -0.15\*\* | -0.25\*\* | 0.07 | -0.18 | -0.47\*\* | 0.05 |
| **-(w)** | -0.86\*\* | 0.64\*\* | 0.81\*\* | 0.45\*\* | 0.20\*\* | 0.12\*\* | -0.33\*\* | 0.96\*\* | 0.26\*\* | 0.72\*\* |
| **-¼ (y)** | 0.05\*\* | 0.02 | -0.04\*\* | -0.21\*\* | -0.05\*\* | -0.16\*\* | 0.24\*\* | -0.09 | -0.05 | 0.05 |
| **F1 – BP** | 0.70 | 0.07 | 3.73 | -13.4 | -1.06 | -3.67 | -1.18 | -0.99 | -0.5 | -0.21 |
| **S.E. ±****Heterobeltiosis (%)** | 0.28 | 0.19 | 2.19 | 5.93 | 4.95 | 2.00 | 0.06 | 0.08 | 0.12 | 0.10 |
| -4.17 | 0.12 | 10.26\*\* | -22.87\* | -2.61 | -7.79 | -28.60\* | -24.36\*\* | -13.22\*\* | -4.74\* |
| **F1 – F2** | -0.31 | -0.17 | 10.45 | 15.87 | 12.6 | 5.42 | -0.39 | -0.07 | 0.13 | 0.3 |
| **S.E. ±****Inbreeding depression (%)** | -10.33 | 0.30 | 1.98 | 5.89 | 4.92 | 2.13 | 0.07 | 0.08 | 0.12 | 0.08 |
| -6.94 | 0.16 | 26.04\*\* | 35.10\*\* | 31.61\* | 12.48\* | -13.27 | -2.49 | 3.75 | 7.22\*\* |

\* and \*\* = 5 and 1% levels of significance, respectively