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# Estimation of Standard Heterosis Over Environments for Fruit Yield and Its Attributes in Tomato (*Solanum lycopersicum* L.)

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author GMP executed field/lab experiments, collected the data and prepared the original manuscript. Authors GMP and AIP conceptualized and designed the experiments, dis data analysis and interpretation. Authors CGI, HRP, AP, MRP, DPP, VBP, AS and SCM edited the manuscript. All authors read and approved the final manuscript.*

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## ABSTRACT

Heterosis breeding has shown to be a promising technique for enhancing crop yields. It allows for the early identification of superior or potential crosses, which is essential for managing the material efficiently and productively in subsequent generations. An experiment was conducted to evaluate 40 genotypes in three different environments. The experimental material consisted of forty genotypes; representing 28 hybrids developed in line x tester mating of 7 lines and 4 testers and check ‘Arka Rakshak’. Significant and high estimates of standard heterosis were observed for fruit yield per plant in all locations by seven hybrids. These crosses can be utilized for commercial cultivation and may also be developed further, as they are likely to produce superior transgressive segregants.


*Keywords: Standard heterosis; over the enviorments; line x tester; tomato.*

## 1. INTRODUCTION

Vegetables are an essential component of a healthy diet, providing a wealth of nutritional benefits. They are rich in essential vitamins, minerals, and dietary fibre, which are crucial for maintaining overall health and preventing chronic diseases. Vegetables are also low in calories and high in fibre, making them effective for weight management by promoting a feeling of fullness and reducing overall calorie intake. Regular consumption of vegetables is associated with a lower risk of heart disease, stroke, certain cancers, and digestive issues due to their antioxidant properties. Tomato (*Solanum lycopersicum* L.) (2n=2x=24), originating from Peru and Ecuador Rick, [1], is a highly significant solanaceous vegetable crop, particularly cultivated in tropical and subtropical regions. In numerous countries, it is referred to as the "poor man's orange" due to its appealing appearance and nutritional value [2]. Tomato is cooked as vegetable alone or eaten raw when ripe. Due to its fair amount of vitamin C and other elements like calcium, phosphorus, and iron, this fruit has a good nutritional value. Considering its low cost, it qualifies for inclusion in the daily diet of young and growing children [3]. Lycopene, which is abundant in the fruit, may have positive health effects. Carotenoid lycopene may be involved in cancer prevention, reducing the risk of cardiovascular disease and limiting the mortality of other chronic diseases. The major tomato producing countries are China, India and Turkey. India ranks second in the world production with the total area of 845 (000’ Ha) producing 218000 (000’ MT) with the productivity of 25.5 t/ha [4]. The states viz., Andhra Pradesh, Odhisa, Karnataka, Madhya Pradesh, West Bengal, and Bihar are the major tomato producing states in the country. In Gujarat, its area and production during 2022-23 was 67.87 (000’ Ha) and 1922.20 (000’ m tonnes) respectively, representing ten major tomato growing districts of state viz., Banaskantha, Ahmedabad, Mahesana, Anand, Kheda, Chhotaudepur, Sabarkantha, Valsad, Kutch and Vadodara. The landscape of tomato production in the country has dramatically evolved over the past few decades with the rising popularity of hybrids. It is crucial to develop hybrids with high yield potential and superior quality. Tomato has significant potential for improvement through heterosis breeding, which can be leveraged to create desirable recombinants. Heterosis breeding, or the exploitation of hybrid vigor, is a vital plant breeding method to produce high-yielding hybrids. Heterotic crosses indicate productive transgressive segregates, and the degree of heterosis provides insights into genetic control. Estimating heterosis can help determine whether hybrids are economically valuable and worth utilizing. Among various genetic approaches to overcome yield barriers in tomato, heterosis breeding is the most powerful. Understanding the nature and extent of heterosis in different cross combinations is essential for identifying crosses with high levels of exploitable heterosis. Thus, present investigation was carried out to estimate heterosis for yield and its components using line x tester mating design in tomato.

## 2. MATERIALS AND METHODS

Present investigation was carried out during Rabi 2021-22 at three different locations was carried out at three different locations *viz*., Vegetable Research Station, Regional Horticulture Research Station (R.H.R.S), NAU, Navsari (L1) (20.94°N, 72.95°E), Hill Millet Research Station, NAU, Waghai (L2), (20.77°N, 73.49°E) and Cotton Research Substation, NAU, Achhaliya (L3) (21.78°N, 73.27°E) situated in the region of south Gujarat. The experimental material consisted of 40 genotypes; representing 28 hybrids developed in line x tester mating of 7 lines, 4 testers (Seven lines *viz*., NTL-19, NTL-24, NTL-25, NTL-27, NTL-42, NTL-45, NTL-50 and four testers *viz*., Arka Anamika, DVRT-2, GT-6, GT-7 and AT-3) and check 'Arka Rakshak'. All the genotypes were evaluated in Randomized Block Design (RBD) replicated thrice in three environments. Observations were recorded on 14 characters *viz*., days to 50 % flowering, plant height (cm), branches per plant, fruits per plant, fruit yield per plant (kg), fruit weight (g), fruit length (cm), fruit girth (cm), pericarp thickness (mm), locules per fruit, total soluble solids (%), titrable acidity (mg/100g), ascorbic acid (mg/100g) and lycopene content (mg/100g). The data was analyzed using the Line x Tester method, and the magnitude of heterosis was calculated according to standard procedures. The significance of heterosis was assessed using the formula recommended by Wynne et al. [5].

## 3. RESULTS AND DISCUSSION

The current study uses heterosis analysis to determine the optimal parent combination for a high degree of standard heterosis, exploits this combination to produce better and more profitable transgressive segregants, and characterises the parents in order to assess their potential for use in a breeding program in the future. Table 1 displays the ranges of the mean, standard heterosis range, and number of significant crosses. Different heterotic effects vary in strength and degree from one cross to the next and from one character to the next. A significant degree of standard heterosis was noted in the fruit production and its characteristics. The magnitude of heterosis varied in different locations for various traits. In case of days to 50 % flowering, negative heterosis is preferred since early flowering would result in a greater number of fruits and a better fruit production. Earliness also leads to early supply of the produce in the market and enables it to fetch a higher price [6]. The range of standard heterosis for days to 50 % flowering from -15.15 % (NTL-24 × AT-3) to 15.15 % (NTL-45 x GT-6) at Navsari (L1), -12.88 % (NTL-45 × GT-7) to 12.88 % (NTL-45 × GT-6) at Waghai (L2) and -13.20 % (NTL-24 × AT-3) to 16.54 % (NTL-25 × GT-6) at Achhaliya (L3). The hybrid *viz*., NTL-24 × AT-3 (-15.15 %) at Navsari (L1), NTL-45 × GT-7 (- 12.88 %) and NTL-24 × AT-3 (-10.61 %) at Waghai (L2) while, hybrids *viz*., NTL-24 × AT-3 (-13.20 %) and NTL-24 × DVRT-2 (-11.28 %) at Achhaliya (L3) had significant and negative standard heterosis for day to 50 % flowering. Similar report was found by Kathimba et al. [7] and Madhavi et al. [8]. The ideal plant type is one which is long and acts as source trait to support yield and its component traits [6]. The range of standard heterosis for plant height (cm) was -17.78 % (NTL-27 × AT-3) to 30.53 % (NTL-24 × GT-6) at Navsari (L1), -18.90 % (NTL-42 × DVRT-2) to 27.74 % (NTL-19 × GT-6) at Waghai (L2) and -16.24 % (NTL-27 × AT-3) to 18.77 % (NTL-24 × GT-6) at Achhaliya (L3). The best performing hybrids for standard heterosis were *viz*., NTL-24 × GT-6 (30.53 %), NTL-19 × GT-6 (20.13 %) and NTL-25 × GT-6 (20.03 %) at Navsari (L1), NTL-19 × GT-6 (27.74 %), NTL-24 × GT-6 (24.95 %) and NTL-25 × GT-6 (20.89 %) at Waghai (L2) while, hybrids *viz*., NTL-24 × GT-6 (18.77 %), NTL-19 × GT-7 (18.47 %) and NTL-42 × GT-6 (9.07 %) at Achhaliya (L3). These findings are in conformity with Liu et al. [9] and Madhavi et al. [8]. the number of primary branches per plant is one of the major contributing traits for fruit yield per plant (kg), hence, positive heterosis is desirable for this trait The range of standard heterosis for branches per plant was - 35.51 % (NTL-42 ×GT-7) to 36.96 % (NTL-42 × DVRT-2) at Navsari (L1), -34.72 % (NTL-24 × DVRT-2) to 24.31 % (NTL-42 × DVRT-2, NTL-45 × GT-6) at Waghai (L2) and -39.57 % (NTL-42 ×AT-7) to 23.02 % (NTL-42 × DVRT-2) at Achhaliya (L3). For branches per plant, top three hybrids *viz*., NTL-42 × DVRT-2 (36.96 %) followed by, NTL-45 × GT-6 (28.99 %) and NTL-25 × DVRT-2 (27.54 %) at Navsari (L1), NTL-42 × DVRT-2 (24.31 %), NTL-45 × GT-6 (24.31 %) and NTL-25 × DVRT2 (16.67%) at Waghai (L2) whereas, NTL-42 × DVRT-2 (23.03 %), NTL-25 × DVRT2 (20.14%) and NTL-45 × GT-6 (7.19 %), at Achhaliya (L3) exhibited significant and positive standard heterosis. Similar result was reported by Khalil and Mahmoud [10] and Madhavi et al. [8]. Number of fruits per plant is economically important character to get higher yield. Standard heterosis for fruit yield per plant is positively associated with heterosis for number of fruits per plant [6]. Hence, emphasis should be given to developing such hybrids which possess more number of fruits per plant. The quantum of standard heterosis ranged for fruits per plant from -21.61 % (NTL-19 × AT-3) to 25.93 % (NTL-42 × DVRT-2) at Navsari (L1), -24.34 % (NTL25 × GT-7) to 23.20 % (NTL-42 × DVRT-2) at Waghai (L2) and -25.29 % (NTL-19 × AT-3) to 26.30 % (NTL-42 × DVRT-2) at Achhaliya (L3). The positive and significant hybrids for this trait were viz., NTL-42

× DVRT2 (25.93 %), NTL-45 × GT-6 (20.33 %) and NTL-25 × DVRT-2 (12.03 %) at at Navsari (L1); NTL-42 × DVRT-2 (23.20 %), NTL-50 × GT-6 (10.40 %) and NTL-45 × GT-6 (9.71 %) at Waghai (L2) and NTL-42 × DVRT-2 (26.30 %), NTL-25 × DVRT-2 (25.29 %) and NTL-45 × DVRT-2 (18.55 %) at Achhaliya (L3). Similar result was reported by Triveni et al. [11] and Kumar et al. [12]. Improvement in fruit yield in tomato is one of most important breeding objective of plant breeder. So, the superiority of hybrids over best cultivated hybrid is essential for increasing its commercial value and yield in any crop is the final product of different yield components. Therefore, positive standard heterosis is highly desirable for this character [6]. The quantum of standard heterosis ranged for fruit yield per plant (kg) from - 33.81 % (NTL-42 × GT-7) to 43.65 % (NTL-25 × DVRT-2) at Navsari (L1); -33.78 % (NTL-42 × GT-7) to 36.54 % (NTL-25 × DVRT-2) at Waghai (L2) and -36.08 % (NTL42 × GT-7) to 37.16 % (NTL-42 × DVRT-2) at Achhaliya (L3). Among hybrids top three hybrids were *viz*., NTL-25 × DVRT-2 (43.65 %), NTL-42 × DVRT-2 (42.76 %) and NTL-25 × AT-3 (37.35 %) at Navsari (L1), hybrids *viz*., NTL-25 × DVRT-2 (36.54 %), NTL-42 × DVRT-2 (29.68 %) and NTL-25 × AT-3 (28.76 %) at Waghai (L2) and hybrids *viz*., NTL-42 × DVRT-2 (37.16 %), NTL-25 × DVRT-2 (35.64 %) and NTL25 × AT-3 (34.89 %) at Achhaliya (L3). Similar finding in accordance to the above result has also been reported by Liu et al. [9], Kathimba et al. [7] and Madhavi et al. [8]. Fruit weight (g) is one of the important component traits having positive correlation with the fruit yield. So, positive and significant heterosis is desirable for this trait [6]. The magnitude of standard heterosis for this trait ranged between -20.87 % (NTL-19 × GT-7) to 25.86 % (NTL-25 × DVRT-2) at Navsari (L1); -19.48 % (NTL19 × GT-7) to 27.08 % (NTL-25 × DVRT-2) at Waghai (L2) and -26.22 % (NTL-19 × GT-7) to 23.64 % (NTL-25 × DVRT-2) at Achhaliya (L3). Top three hybrids for fruit weight were *viz*., NTL-25 × DVRT-2 (25.82 %), NTL-25 × AT-3 (16.11 %) and NTL-24 × GT-6 (10.02 %) at Navsari (L1); NTL-25 × DVRT-2 (27.08 %), NTL-24 × GT-6 (11.97 %) and NTL-25 × AT-3 (11.95 %) at Waghai (L2); NTL-25 × DVRT-2 (23.64 %), NTL-25 × AT-3 (14.14 %) and NTL-27 × GT-6 (7.82 %) at Achhaliya (L3). Positive and significant standard heterosis were also found by Liu et al. (2021) and Madhavi et al. [8] Fruit length is an important parameter of fruit deciding consumer preference [11] . A perusal of the data on average fruit length (cm) revealed that the per cent standard heterosis was in the range of -23.97% (NTL-50 × GT-6) to 14.88 % (NTL-25 × DVRT-2) at Navsari (L1), -23.66 % (NTL-50 × GT-6) to 13.27 % (NTL-24 × GT-6) at Waghai (L2) and -23.32 % (NTL-50 × GT-6) to 10.84 % (NTL-24 × GT-6) at Achhaliya (L3). The outstanding positive and significant three hybrids were NTL-25 × DVRT2 (14.88 %) followed by NTL-24 × GT-6 (11.28 %) and NTL-42 × DVRT-2 (9.96 %) at Navsari (L1); NTL-24 × GT-6 (13.27 %) followed by NTL-25 × DVRT-2 (10.72 %) and NTL-42 × DVRT-2 (9.18 %) at Waghai (L2) and NTL-24 × GT-6 (10.84 %) followed by NTL-19 × GT-6 (9.86 %) and NTL-25 × DVRT-2 (8.75 %) at Achhaliya (L3). Positive and significant standard heterosis for fruit length (cm) was also observed by Triveni *et al.* (19), Kumar and Pal [6] and Kumar *et* al. [12] Fruit girth is also one of the parameters that contributes towards fruit yield of tomato and also commercially important traits to gain high market value through high productivity (Triveni et al. 19). The standard heterosis over check for fuit girth (cm) varied from -34.25% (NTL-45 × AT-3) to 6.78 % (NTL-42 × DVRT-2); -33.55 % (NTL-45 × AT-3) to 17.87 % (NTL-42 × DVRT-2) and -35.63 % (NTL-50 × GT-7) to 21.34 % (NTL-42 × DVRT2) at Navsari (L1), Waghai (L2) and Achhaliya (L3), respectively. Top three performing hybrids were viz., NTL-50 × DVRT-2 (6.78 %), NTL-24 × GT-6 (6.04 %) and NTL-25 × DVRT-2 (5.19 %) at Navsari (L1); NTL-42 × DVRT2 (17.87 %), NTL-25 × AT-3 (11.58 %) and NTL-24 × GT-6 (7.24 %) at Waghai (L2) while, NTL-42 × DVRT-2 (21.34 %), NTL-25 × AT-3 (15.71 %) and NTL-19 × GT-6 (9.78 %) at Achhaliya (L3). These results were in close conformity with the earlier finding of Triveni et al. [8] Kumar and Pal [13] and Kumar et al. [14] Thicker pericarp is considered desirable for distant transportation. Pericarp thickness commercially important traits to gain high market value through high productivity (Khan and Jindal, 5). The standard heterosis over check for pericarp thickness (mm) varied from - 25.66% (NTL-45 × GT-6) to 10.60 % (NTL-19 × AT-3); -24.19 % (NTL-50 × GT-6) to 14.72 % (NTL-19 × AT-3) and -27.09 % (NTL-45 × GT-6) to 5.41 % (NTL-19 × AT-3) at Navsari (L1), Waghai (L2) and Achhaliya (L3), respectively. Top performing hybrids were viz., NTL-19 × AT-3 (10.60 %) at Navsari (L1); NTL-19 × AT-3 (14.72 %); at Waghai (L2) and NTL-19 × AT-3 (5.41 %) at Achhaliya (L3). These results were in close conformity with the earlier finding of Kumar et al. [8] and Kumar et al. [15]. Locules per fruit is also an important character and it is an indicator of the fruit firmness. Lesser the number of the locules per fruit, more is the fruit firmness and vice versa [6]. For locules per fruit, magnitude of standard heterosis was ranged from -44.44 % (NTL-25 × GT-6) to 22.22 % (NTL-27 × AT-3) at Navsari (L1); -40.85 % (NTL-45 × GT-7) to 32.39 % (NTL-25 × AT-3) at Waghai (L2); -31.75 % (NTL-45 × GT-6, NTL-45 × GT-7) to 23.81 % (NTL-27 × AT-3) at Achhaliya (L3). Top three performing hybrids were *viz*., NTL-25 × GT-6 (-44.44 %), NTL-45 × GT-7 (-36.51 %) and NTL-50

**Table 1. Range of mean, range of standard heterosis and number of significant crosses in tomato over the different loctions**

| Character | Location | Range of | | Number of significant crosses | |
|---|---|---|---|---|---|
| | | Mean performance | Standard heterosis (%) | Positive | Negative |
| Days to 50 % flowering | L1 | 37.33 to 50.67 | -15.15 to 15.15 | 3 | 1 |
| | L2 | 38.33 to 49.67 | -12.88 to 12. 88 | 6 | 10 |
| | L3 | 38.33 to 51.67 | -13.20 to 16.54 | 9 | 9 |
| Plant height (cm) | L1 | 87.90 to 139.54 | -17.78 to 30.53 | 15 | 3 |
| | L2 | 87.32 to 137.55 | -18.90 to 27.74 | 14 | 8 |
| | L3 | 92.90 to 131.74 | -16.24 to 18.77 | 9 | 10 |
| Branches per plant | L1 | 5.93 to 12.60 | - 35.51 to 36.96 | 3 | 21 |
| | L2 | 6.27 to 11.93 | -34.72 to 24.31 | 3 | 21 |
| | L3 | 5.60 to 11.40 | -39.57 to 23.02 | 3 | 22 |
| Fruits per plant | L1 | 44.73 to 71.87 | -21.61 to 25.93 | 8 | 12 |
| | L2 | 44.13 to 71.87 | -24.34 to 23.20 | 5 | 12 |
| | L3 | 39.20 to 66.27 | -25.29 to 26.30 | 7 | 10 |
| Fruit yield per plant (kg) | L1 | 2.00 to 4.33 | -33.81 to 43.65 | 8 | 13 |
| | L2 | 2.16 to 4.45 | -33.78 to 36.54 | 7 | 11 |
| | L3 | 1.97 to 4.22 | -36.08 to 37.16 | 7 | 13 |
| Fruit weight (g) | L1 | 46.48 to 73.92 | -20.87 to 25.86 | 8 | 10 |
| | L2 | 47.14 to 74.39 | -19.48 to 27.08 | 9 | 13 |
| | L3 | 42.66 to 71.48 | -26.22 to 23.64 | 5 | 14 |
| Fruit length (cm) | L1 | 3.94 to 5.58 | -23.97 to 14.88 | 5 | 19 |
| | L2 | 3.99 to 5.78 | -23.66 to 13.27 | 5 | 18 |
| | L3 | 3.89 to 5.87 | -23.32 to 10.84 | 3 | 17 |
| Fruit girth (cm) | L1 | 3.59 to 5.69 | -34.25 to 6.78 | 6 | 21 |
| | L2 | 3.73 to 5.89 | -33.55 to 17.87 | 5 | 20 |
| | L3 | 3.61 to 5.98 | -35.63 to 21.34 | 3 | 23 |
| Pericarp thickness (mm) | L1 | 5.00 to 7.44 | -25.66 to 10.60 | 1 | 22 |
| | L2 | 5.10 to 7.71 | -24.19 to 14.72 | 3 | 20 |
| | L3 | 4.94 to 7.15 | -27.09 to 5.41 | 1 | 23 |
| Locules per fruit | L1 | 2.33 to 5.13 | -44.44 to 22.22 | 6 | 17 |
| | L2 | 2.80 to 5.33 | -40.85 to 32.39 | 3 | 21 |
| | L3 | 2.87 to 5.47 | -31.75 to 23.81 | 3 | 16 |
| Total Soluble Solids (%) | L1 | 3.79 to 5.08 | -21.84 to 3.57 | 2 | 1 |
| | L2 | 3.68 to 7.71 | -22.91 to 2.71 | 1 | 0 |
| | L3 | 3.98 to 7.58 | -30.16 to 4.71 | 1 | 0 |
| Titrable acidity (mg/100 g) | L1 | 0.35 to 0.71 | -33.33 to 33.33 | 3 | 21 |
| | L2 | 0.30 to 0.72 | 36.81 to 50.69 | 7 | 13 |
| | L3 | 0.34 to 0.68 | -35.44 to 17.09 | 3 | 17 |
| Ascorbic acid content (mg/100 g) | L1 | 21.56 to 27.94 | -24.96 to 16.92 | 4 | 22 |
| | L2 | 22.11 to 28.74 | -20.66 to 3.10 | 1 | 19 |
| | L3 | 21.33 to 28.92 | -23.15 to 4.20 | 0 | 25 |
| Lycopene content (mg/100 g) | L1 | 0.13 to 0.21 | -36.67 to 3.33 | 0 | 24 |
| | L2 | 0.13 to 0.21 | -30.00 to 3.33 | 0 | 25 |
| | L3 | 0.12 to 0.20 | -32.14 to 3.57 | 0 | 25 |

× GT-6 (-31.75 %) at Navsari (L1); NTL-45 × GT-7 (- 40.85 %), NTL-24 × GT-6 (-38.03 %) and NTL-24 × GT-7 (-36.62 %) at Waghai (L2) while, NTL-45 × GT-6 and NTL-45 × GT-7 (-31.75 %), NTL-25 × GT-6 (-30.16 %) and NTL-50 × GT-7 (-28.57 %) at Achhaliya (L3). These results were in close conformity with the earlier finding of Khan and Jindal [6] and Kumar et al. [12].

The fruit's taste is influenced by the Total Soluble Solids (%) value, which might reveal how sweet the fruit is. A fruit with a higher TSS (%) has a better taste, and consumers will favour it more.So, the positive standard heterosis is desirable (Khan and Jindal, 5). The range of standard heterosis for total soluble solids was from -21.84 % (NTL-45 × DVRT-2) to 3.57 % (NTL-24 × GT-6); -22.91 % (NTL-45 × DVRT-2) to 2.71 % (NTL-19 × AT-3) and -30.16 % (NTL-45 × DVRT-2) to 4.71 % (NTL-45 × AT-3) at Navsari (L1), Waghai (L2) and Achhaliya (L3), respectively. Top hybrids having significant and positive standard hetrosis in terms of total soluble solids were viz.,

**Table 2. Promising hybrids for standard heterosis for fruit yield per plant and its component traits over environments in tomato**

| Sr. No. | Hybrid | Location | Fruit yield per plant (kg) | Standard heterosis (%) | Significant standard heterosis (%) for yield components |
|---|---|---|---|---|---|
| 1. | NTL-25 × DVRT-2 | L1 | 4.33 | 43.65 ** | Branches per plant, fruit weight (g), fruit length (cm), fruit girth (cm) |
| | | L2 | 4.45 | 36.54 ** | Branches per plant, fruit weight (g), fruit length (cm), fruit girth (cm), pericarp thickness (mm) |
| | | L3 | 4.17 | 37.16** | Branches per plant, fruits per plant, fruit weight (g), fruit length (cm) |
| 2. | NTL-42 × DVRT-2 | L1 | 4.30 | 42.76 ** | Branches per plant, fruits per plant, fruit weight (g), fruit length (cm), fruit girth (cm), locules per fruit |
| | | L2 | 4.22 | 29.68 ** | Branches per plant, fruits per plant, fruit weight (g), fruit length (cm), locules per fruit |
| | | L3 | 4.22 | 37.16 ** | Branches per plant, fruit weight (g), fruit girth (cm), locules per fruit |
| 3. | NTL-25 × AT-3 | L1 | 4.14 | 37.53** | Fruits per plant, fruit weight (g), fruit length (cm), fruit girth (cm) |
| | | L2 | 4.19 | 28.76** | Fruits per plant, fruit weight (g), fruit length (cm), fruit girth (cm) |
| | | L3 | 4.15 | 34.89** | Fruits per plant, fruit weight (g), fruit length (cm), fruit girth (cm) |
| 4. | NTL-45 × GT-6 | L1 | 3.96 | 31.27** | Plant height (cm), branches per plant, fruits per plant |
| | | L2 | 3.82 | 17.30** | Plant height (cm), fruit weight (g), fruit girth (cm) |
| | | L3 | 3.89 | 26.54** | Plant height (cm), branches per plant, fruits per plant |
| 5. | NTL-19 × GT-6 | L1 | 3.92 | 29.94** | Plant height (cm), fruits per plant, fruit weight (g), fruit girth (cm) |
| | | L2 | 3.93 | 20.78** | Plant height (cm), branches per plant, fruits per plant |
| | | L3 | 3.81 | 23.94** | Plant height (cm), fruits per plant |
| 6. | NTL-50 × GT-6 | L1 | 3.62 | 20.00** | Plant height (cm), fruits per plant |
| | | L2 | 3.64 | 11.87** | Plant height (cm), fruits per plant |
| | | L3 | 3.51 | 13.98** | Plant height (cm), fruits per plant |
| 7. | NTL-50 × DVRT-2 | L1 | 3.53 | 16.91** | Plant height (cm), fruits per plant |
| | | L2 | 3.65 | 11.98** | Plant height (cm), fruits per plant |
| | | L3 | 3.45 | 12.24** | Plant height (cm), fruits per plant |

NTL-24 × GT-6 (3.57 %) and NTL-19 × AT-3 (2.28 %) at Navsari (L1) and NTL-19 × AT-3 (6.61) at Waghai (L2). The derived results were in conformity with Kumari and Sharma [16] and Kumar et al. [14]. Range of standard heterosis of titrable acidity (mg/100g) were reported in between -33.33 % (NTL-24 × GT-7) to 33.33 % (NTL-27 × GT-7) at Navsari (L1); - 36.81 % (NTL-24 × GT-7) to 50.69 % (NTL-27 × GT-7) at Waghai (L3) and -35.44 % (NTL-24 × GT-7) to 17.09 % (NTL-45 × GT-7) at Achhaliya (L3). Among these, top three promising hybrids were viz., NTL-27 × GT-7 (33.33 %), NTL-50 × GT-6 (12.58 %) and NTL-45 × GT-7 (11.32 %) at Navsari (L1), hybrid viz., NTL-27 × GT-7 (50.69 %), NTL-25 × GT-6 (15.97 %) and NTL-27 × DVRT-2 (12.50 %) at Waghai (L2) and hybrid viz., NTL-45 × GT-6 (19.16 %), NTL-45 × GT-7 (17.09 %) and NTL-50 × GT-7 (7.59 %) at Achhaliya (L3) exhibited positive and significant standard heterosis for this traits.The positive and significant standard heterosis were also reported by Mali and Patel [17] Savale and Patel [18]. and Kumar et al. [15]. The higher ascorbic acid content would increase the nutritive value of the fruits, which would help better retention of colour and flavour (Kumar et al. 7). Range of standard heterosis were reported in between -24.96 % (NTL-50 × GT7) to 16.92 % (NTL-42 × DVRT-2) at Navsari (L1); -20.66 % (NTL-50 × GT-7) to 3.10% (NTL-24 × GT-7) atWaghai (L3) and -23.15 % (NTL-50 × GT-7) to 4.20 % (NTL25 × AT-3) at Achhaliya (L3). Among these, the promising hybrids were viz., NTL-42 × DVRT-2 (16.92 %), NTL-27 × AT-3 (14.65 %) and NTL-42 × AT-3 (12.62 %) at Navsari (L1) and hybrid viz., NTL-24 × GT-7 (3.10 %) at Waghai (L2). The positive and significant standard heterosis were also reported by Mali and Patel (13), Metwally et al. (14) and Kumar et al. [12]. High lycopene content imparts deep red colour to the tomato, which is preferred for table as well as processing purpose. Moreover, lycopene had greatest antioxidant property among all carotenoids and is valued for its anti-cancer property, since it acts as a scavenger of free radicals (Khan and Jindal, 5). There were no positive significance heterosis were found in lycopene content. From the above result about standard heterosis for various characters in different hybrid combination, none of the hybrid exhibited consistence standard heterosis for all the characters. This finding was also supported by Mali and Patel [17] Khan and Jindal [6] Kumar et al. [12] Panchal et al. [19] and Kathimba et al. [7].

Fruit yield is complex character which is influenced by many traits like number of fruits per plant, fruit weight (g), fruit length (cm), plant height (cm), branches per plant etc. [7]. A comparative performance of the most heterotic crosses for fruit yield per plant (kg) and its component characters in each individual environment is presented in Table 2. It cannot be taken as a single entry. In this experiment, 7 hybrids viz., NTL-42 × DVRT-2, NTL-45 × GT-6, NTL-25 × AT-3, NTL-25 × DVRT-2, NTL-19 × GT-6, NTL-50 × DVRT-2 and NTL-50 × GT-6 at Navsari (L1), Waghai (L2) and Achhaliya (L3) exhibited positive and significant standard heterosis for fruit yield per plant (kg).

The hybrid NTL-19 × GT-6 had positive and significant standard heterosis for plant height (cm), fruit girth (cm) and fruit weight (g), while the hybrid NTL-25 × DVRT-2 had positive and significant standard heterosis for branches per plant, fruits per plant, fruit girth (cm), fruit length (cm) and fruit girth (g). Hybrid NTL-25 × AT-3 had positive and significant standard heterosis fruit weight (g), fruit length (cm) and fruit girth (cm); while hybrid NTL-42 × DVRT-2 had significant and positive standard heterosis for branches per plant, fruits per plant, fruit weight (g), and fruit length (cm), while hybrid NTL-45 × GT-6 had significant and positive standard heterosis for plant height (cm), branches per plant and fruits per plant, while hybrid NTL-50 × GT-6 forfruits per plant and plant height (cm). This was due to interacting effects of different components in manifestation of standard heterosis for fruit yield (kg). Therefore, to achieve the greatest heterotic effects for fruit yield, the desired level of heterosis for each component characteristic must be determined in order to identify superior cross combinations. Similar results were recorded by Triveni et al. [11]. Kumar and Pal [13] and Madhavi et al. [12]. Hybrids exhibiting high heterotic effects may provide better opportunities for cultivation and for identifying desirable pure lines in subsequent advanced generations. Among the parental genotypes, DVRT-2 and GT-6 yielded superior heterotic crosses for fruit yield and its component characters; Early flowering leads to earliness and also early supply of the produce in the market and enables it to fetch a remunerative price. On the other hand, for higher standard heterosis, early flowering is responsible and also early hybrids fit well in multiple cropping systems [6]. For this trait, negative standard heterosis is to be considered as desirable. From the top hybrids, NTL-24 × AT-3, had negative and significant

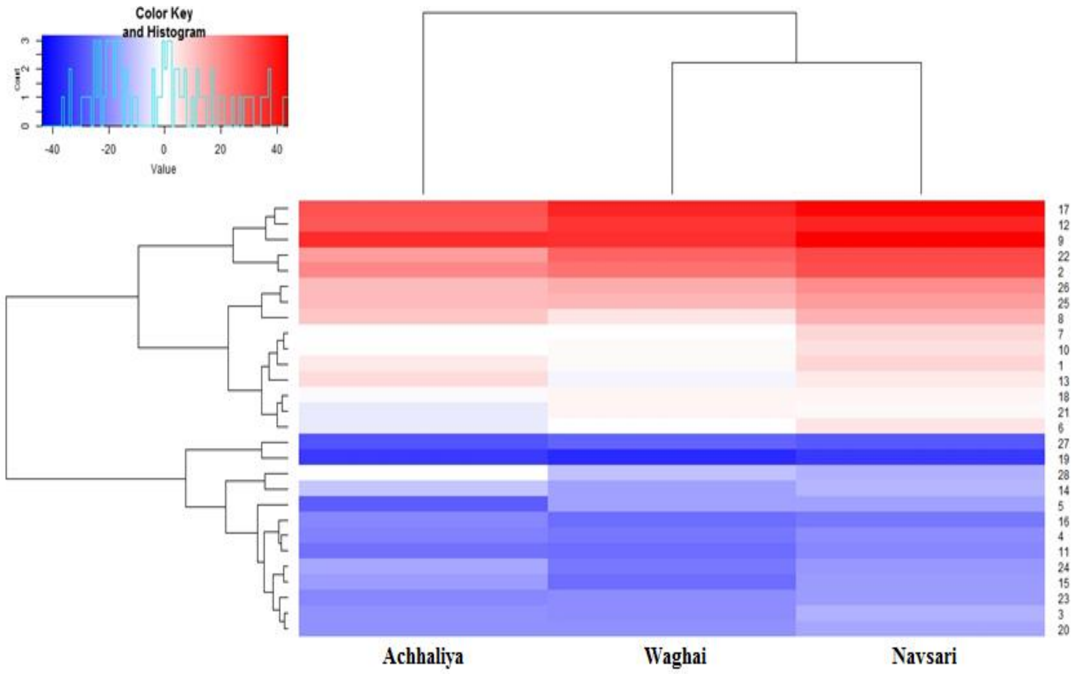


**Fig. 1. A heatmap illustrating the heterosis for fruit yield per plant (kg) across three different locations (Achhaliya, Waghai, Navsari) for 28 hybrids**

standard heterosis, which is desirable. These findings were in agreement with the findings reported by Kumar and Pal et al. [13,20].

## 4. CONCLUSION

Estimation of standard heterosis suggested that maximum heterosis for fruit yield per plant were observed in hybrid viz., NTL-25 × DVRT-2, NTL-42 × DVRT-2, NTL-25 × AT-3, NTL-45× GT-6, NTL-19 × GT-6, NTL-50× DVRT-2 and NTL-50 × GT-6 at all locations. None of the hybrid showed positive and significant standard heterosis for all the traits. The hybrids showing strong heterotic effects could provide improved opportunities for growing and selecting preferred pure lines in subsequent generations.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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