**Assessment of Heterosis and Combining Ability for Quality Traits in Tomato (*Solanum lycopersicum* L.) Using Line × Tester analysis**

**Abstract:** The present study Explored about heterosis and combining ability analysis for quality traits in tomato (*Solanum lycopersicum* L.) Using Line × Tester analysis. Heterosis and combining capacity are two vital contemplations within the utilization of heterosis, which can be utilized to produce amazing hybrid asset candidates and is exceptionally vital in customary hybrid breeding. The combining capacity and heterosis of eight major agronomic characteristics were analyzed in 8 tomato guardians and 15 crosses between them. As well as EC- 163605, a recognized and official great assortment that's as of now offering well on the showcase was utilized as a control to conduct a control heterosis examination, with the objective of selecting perfect parents with tall combining capacity and modern hybrids with product esteem, plant tallness, natural product distance across, add up to abdicate per plant. The comes about appears that both additive and non-additive hereditary impacts are included within the expression of the characteristics and the additive hereditary impact is prevailing in characteristic legacy. In spite of the fact that common combining capacity (GCA) and specific combining capacity (SCA) were not correlated, and the quality of heterosis depends on SCA, the entirety of the parental GCA values (GCA sum) did predict heterosis for a few characteristics with higher predictive accuracy than did SCA. The variance attributable to GCA and SCA, which provide a relative measure of additive and non-additive gene effects, respectively, is estimated using the combining ability analysis. Because most yield components are known to be polygenic, plant breeders would need to perform phenotypic assessments on as many parents as feasible to determine their genetic makeup.

**Keywords: C**ombining ability, Heterosis, Line × Tester, Tomato, vegetable crops

**1. Introduction**

Heterosis and combining ability are two important considerations in the utilization of heterosis, which can be used to generate excellent hybrid resource candidates and is very important in conventional hybrid breeding (Reddy et al., 2023). Analyzing heterosis and combining ability are two important considerations in the utilization of heterosis; it is the first step in breeding inbred lines to develop commercial hybrids. Progeny selection is one of the most important stages in plant breeding, but producing excellent progeny depends on the chosen parents. Combining ability is useful for successfully predicting the genetic capabilities of parental lines and crosses (Liu et al., 2021; Izzo et al., 2022). Tomato is generally treated as “defensive nourishment” in India, tomato is developed in almost 0.87 million hectares uninterested parts and is well adjusted to shifted climatic conditions of the nation. Its generation is about 16.81million ton and its efficiency is 19.5mt./ha. (Anonymous, 2011). In created nations it is commonly devoured new; over 80% of the tomato utilization comes from handled items such as juice, glue, puree, It has tall nutritional esteem; one medium new tomato (135g) gives 47% Recommended Dietary Allowance (RDA) of vitamin C, 22% RDA vitamin A and25 calories. The mash and juice are edible, a promoter of gastric emission and blood purifier. It has antiseptic properties against intestinal infections. The line x Tester mating design is essentially a important for development of top cross analysis in that multiple testers are used as opposed to just one in top cross. Together and individually, they all contribute a shared genetic background that the inbreds' genotype is measured against A line is tested due to the utilization of several testers in vegetable crops (Singh et al., 2024). Tomato may be a great appetizer and its soup is said to be a great cure for quiets enduring constipation. It is one of the finest vegetables which keeps our stomach and digestive tract in arrange. Different breeding techniques have been supported considering the breeding conduct of trim species. Out of these hybrids, breeding is noticeable and utilized within the enhancement of vegetable crops. Heterosis in tomato was, to begin with watched by Hedrick and Booth (1968) for higher abdicate and more number of natural products per plant. Choudhary *et al.* (1965) emphasized the broad utilization of heterosis to step up tomato generation. The heterosis sign in tomato is in the frame of the more noteworthy energy, faster development and improvement, earliness in development, and expanded efficiency (Yordanov, 1983). So, an expedient change can be brought about by misusing heterosis for different surrender-contributing characteristics as well as earliness. Combining capacity features a prime significance in plant breeding since it gives information for the determination of guardians conjointly gives information with respect to nature of the quality activity. The information on hereditary structure and mode of legacy of distinctive characters makes a difference breeder to utilize appropriate breeding methodology for their advancement (Kiani *et al.* 2007). The concept of combining ability was introduced by Sprague and Tatum (1947).

**Material and Methods**

The examination entitled “line x tester mating arrange for abandon and yield characteristics in tomato (*Solanum lycopersicum* L.)” was carried out at the Test Develop, Mata Gujri College, Fatehgarh Sahib, Punjab, in the midst of winter Season, 2020-2021 and 2021-2022. The subtle components of exploratory area, texture utilized and strategies utilized in the midst of course of appear the examination. Eight different tomato cultivars /lines *viz.,* EC-163605, EC-631364, EC-164563, EC-145057, EC-620395, EC-249504, EC-631379, EC-620427 were crossed in a line x tester, so get 15 cross combination. The seedlings of guardians were raised in February, 2021 and encourage transplant in inquire about cultivate to endeavour crosses and create F1's.

**Estimation of Heterosis**

The data were subjected to statistical analysis according to Steel and Torrie, (1980) Heterosis was examined over the superior parent (heterobeltiosis), over the mid parent and over the standard variety, *i.e*., Standard checks (economic heterosis), following the method described by Kempthorne (1957):-

Mid parent = $\frac{\overbar{F}\_{1}-\overbar{MP}}{\overbar{MP}}×100$

Heteroeltiosis$=\frac{\overbar{F}\_{1}-\overbar{BP}}{\overbar{BP}}×100$

Economic check =$\frac{\overbar{F}\_{1}-\overbar{EC}}{\overbar{EC}}×100$

Where,

$\overbar{F}\_{1}$ = Mean value of the F1generation

MP = Mean performance of mid parent;

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

$\overbar{EC}$ = Mean value of the economic cultivar (check).

**Estimation of combining capacity impacts**

The combining ability analysis was carried out by the procedure given by Griffing (1956). Method-2 and Model-1 was adopted for the present study. Method-2 includes P inbreds (parents) and P (P-1)/2 F1s, in all P (P+1)/2 different genotypes which form a set of treatments. Model-1 is also known as fixed effect model in which inferences drawn are applicable only to the lines (treatments) involved in the experiment and not beyond these errors. The statistical model for combining ability analysis under Model-1 is:-

$$Y\_{ijk }=μ+g\_{i}+g\_{j}+S\_{ij}+\frac{1}{b}\sum\_{i}^{}\sum\_{k}^{}e.ijk$$

For i, j = 1, 2,….., P (number of parents);

 K = 1, 2,….., b (number of replications),

Where,

 μ = Populationmean

 g*i* = General combining ability effect of ith parent

 g*j* = General combining ability of jth parent

 S*ij* = Specific combining activity effect of ijth combination

 Such that S*ij* = S*ji*

 E*ijk* = the environmental effect pertaining to ijkth observation.

The restrictions imposed on the model are:

 $\sum\_{i}^{}gi=o and \sum\_{j}^{}Sij+Sii=o for each$

**Estimation of the General Combining Ability and Specific Combining Ability Effects**

The following formulae were adopted to determine the G.C.A. and S.C.A.:

General combining ability (GCA effects of ith parent was calculated as:

$$\hat{g}\_{i}=\frac{1}{p+2}(Y\_{io}+Y\_{oi}-\frac{2}{p}Y\_{oo}$$

Specific combining ability (SCA effects of ijthcross was calculated as

$$\hat{S}\_{ij}=\frac{1}{p+2}(Y\_{io}+Y\_{oi}+Y\_{jo}+Y\_{oj})+\frac{2}{\left(p+1\right)(p+2)}Y\_{oo}$$

All of analyses in this research were computed using INDOSTAT statistical package.

1. **Result And Discussion**

Gauges of cruel squares for all the characters considered were exceedingly noteworthy demonstrating wide hereditary contrasts among the genotypes. Heterosis was estimated in table 5. Average fruit weight showed positive heterosis over mid-parent range varies from EC-620427 x EC-163605  to EC-145057 x EC- 164563 EC-620427 x EC-163605 to EC-249504 x EC-164563 showed significant negative heterosis over better parent for average fruit weight heterosis for the trait fruit weight was reported by many authors as Scott et al*.* (1986). Fruit shape index revealed table 6 positive heterosis range varies from EC-145057x EC- 163605 to EC- 249504 x EC- 631379 showing significant positive heterosis over better parent for fruit shape index. Fruit diameter revealed table 5 positive heterosis over mid-parent range varies from EC-620427 x EC-163605 to EC-145057 x EC- 164563. Positive heterosis over better parent EC-620427 x EC-163605 (232.31) to EC-249504 x EC-164563.Ascorbic acids revealed table 5 run shifts from the EC- 620427 x EC- 163605 to EC- 249504 x EC-164563. Lycopene substance appears the positive heterosis run changes from the EC- 249504 x EC-163605 to EC-620395 x EC-631379. Positive heterosis over mid parent range varies from EC-631379 x EC-163605 to EC-620395 x EC-631379. Heterosis appeared the higher pericarp thickness revealed in table 4 over better parent positive range varies from EC-631364 x EC-163605 to EC-249504 x EC-164563. Heterosis appeared in the total soluble solids revealed table 7 positive heterosis over mid parent range varies from EC- 631364 x EC-164563to EC-620395 x EC-631379. Positive heterosis over better parent range varies from EC-631364 x EC-164563 to EC-631364 x EC-163605. Titrable acidity recorded in table 4 positive heterosis over mid parent range varies from EC- 631364 x EC-163605 to EC-620395 x EC-631379. Heterosis appeared in the EC-620395 x EC-164563 to EC-620427 x EC-163605 and showed significant positive heterosis over better parents for Titrable acidity. Lycopene content recorded in table 5 positive heterosis over mid parent range varies from EC- 249504 x EC-163605 (163.42) to EC-620395 x EC-631379 (19.07). Lycopene content ranges vary from EC-249504 x EC- 164563 and showed significant negative heterosis over mid parent for lycopene content. EC-620427 x EC-163605 to EC-620395 x EC-631379 showed significant positive heterosis over better parents for lycopene content. Total yield per plant revealed table 7 shows significant positive heterosis over the mid-parent range varies from EC-620427 x EC-163605 to EC-249504 x EC- 164563. EC- 620427 x EC-163605 to EC- 249504 x 631379 shows significant positive heterosis over better parent for total yield per plant. Singh and Singh (1993) and Ahmed *et al.* (1988) also reported heterosis over better parents in yield per plant or total yield in tomato. Heterosis for the trait of fruit weight was reported by many authors as Scott *et al.* (1986). Singh and Singh (1993) and Ahmed *et al.* (1988) also reported heterosis over better parents in yield per plant or total yield in tomato. Shankarappa *et al.* (2008), Kumar *et al*. (2006), Singh *et al.* (2007), and Singh, *et al*. (2008) also reported heterosis over fruit shape index.

**Examination of Common Combining Capacity Impact of distinctive characteristics in parents**

The estimate of *GCA* effects revealed that out of 8 parents, Table number 3 average fruit weight EC- 631379 and EC- 620427 recorded significant and positive *GCA* effects. While the (EC- 163605) to (EC- 145057) exhibited significant negative *GCA* effects for this trait. Fruit diameter range varies from EC- 163605 and EC- 620395 recording significant and positive *GCA* effects. On other hand, (EC- 164563) to (EC- 631364) exhibited significant negative *GCA* effects for this trait. Fruit shape index EC- 163605 and EC- 620427 recorded significant and positive *GCA* effects. On other hand, (EC- 631379) to (EC- 620395) exhibited significant negative *GCA* effects for this trait. Pericarp thickness EC- 631364 and EC- 620427 recorded significant and positive *GCA* effects. On another hand, EC- 249504 negative GCA effect for this trait. Total soluble solids EC- 145057 recorded significant and positive *GCA* effects. On other hand, (EC- 631364) to (EC- 145057) exhibited significant negative *GCA* effects for this trait. The ascorbic acidity range varies from EC- 163605 and EC- 145057 recording significant and positive *GCA* effects. On other hand, (EC- 620395) to (EC- 631364) exhibited significant negative *GCA* effects for this trait. Titrable acidity range varies EC- 163605 and EC- 620427 recorded significant and positive *GCA* effects. On other hand, (EC- 164563) to -0.085 (EC- 631364) exhibited significant negative *GCA* effects for this trait. Lycopene content range varies from EC- 631364 and EC- 620427 recorded significant and positive *GCA* effects. On other hand, (EC- 620395) to (EC- 249504) exhibited significant negative GCA effects for this trait. Total yield per plant varied from EC- 631379 and EC- 620395 recording significant and positive GCA effects. On other hand, (EC- 164563) to (EC- 249504) exhibited significant negative GCA effects for this trait. These findings are in close agreement with Hannan et al. (2007), Kumar *et al*. (2013), and Shankar *et al.* (2013) on tomato crops.

The SCA effect is recorded in table 4. Shows that the average fruit weight range varies from (EC- 620427 x EC- 163605) to (EC- 620395 x EC- 164563) show significant positive SCA (EC- 620395 x EC-631379) to (EC- 620427 x EC- 164563) shows significant negative SCA for this trait. Fruit diameter range varies from (EC- 620427 x EC- 164563) to (EC-145057 x EC- 163605) and shows significant positive SCA as well range varies from (EC- 620395 x EC- 164563) to (EC- 620427 x EC- 163605) shows significant negative SCA for this trait. The fruit shape index range varies from (EC-145057 x EC- 163605) to (EC- 620395 x EC-631379) shows significant positive SCA as well (EC-249504 x EC-164563) to (EC-145057 x EC- 164563) shows significant negative SCA for this trait. Pericarp thickness range varies from (EC-249504 x EC-164563) to (EC- 631364 x EC-163605) shows significant positive SCA as well varies from (EC- 620427 x EC- 164563) to (EC-249504 x EC-163605) shows significant negative SCA for this trait. Total soluble solids cross range varies from (EC- 620427 x EC- 163605) to (EC- 49504 x EC-164563) and shows significant positive SCA as well (EC- 631364 x EC-631379) to (EC-249504 x EC-163605) shows significant negative SCA for this trait. Ascorbic acidity range varies from (EC-249504 x EC-631379) to (EC- 620427 x EC- 163605) shows significant positive sca varies from (EC-249504 x EC-163605) to (EC-249504 x EC-164563) shows significant negative sca for this trait. Titrable acidity range varies from (EC-249504 x EC-163605) to (EC- 631364 x EC-631379) shows significant positive SCA, as well as negative crosses, range varies from (EC- 631364 x EC-164563) to (EC-249504 x EC-631379). Lycopene content crosses range varies from (EC- 631364 x EC-164563) to (EC- 620427 x EC- 163605) and shows significant positive SCA as well range varies from (EC-249504 x EC-164563) to (EC- 620427 x EC- 164563) shows significant negative SCA for this trait. Total yield per plant range varies from (EC- 631364 x EC-163605) to (EC- 620427 x EC- 631379) shows significant positive SCA as well range varies from EC-249504 x EC-163605 to (EC- 631364 x EC-631379) show significant negative SCA for this trait. Some studies also report greater participation of additive effects on the expression of the average fruit weight, such as Amaral Júnior *et al.* (1999), Garg *et al.* (2008).

**Conclusions**

The high yielding F1 hybrid (EC- 620427 x EC- 163605) had an 83.43 percent heterosis for yield above the mid parent and could be recommended for commercial use. The variance attributable to GCA and SCA, which provide a relative measure of additive and non-additive gene effects, respectively, is estimated using the combining ability analysis. Because most yield components are known to be polygenic, plant breeders would need to perform phenotypic assessments on as many parents as feasible to determine their genetic makeup. The general (GCA) and specialized (SCA) combining ability impacts are some practical factors to suit this goal. It was concluded that the SCA combiner of the F1 hybrid (EC-6313 64 x EC-163605) produced a greater yield in tomatoes.

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**Table 1. Analysis of variance forparents and hybrid and check various characters in tomato.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | DF | Plant Height(cm) | Days to firstflowering | Days to 50%Flowering | No. of Pri.Branches | No. of Sec.Branches | No.of Fruit /Plant | Average fruitwt (g) | Fruit Diameter(mm) |
| Replicates | 2 | 31.403 | 15.406 \*\* | 7.667 \* | 0.565 | 0.304 | 10.764 | 3.652 | 15.014 \* |
| Treatments | 22 | 1311.907 \*\*\* | 31.028 \*\*\* | 28.589 \*\*\* | 23.692 \*\*\* | 9.269 \*\*\* | 482.456 \*\*\* | 775.477 \*\*\* | 441.814 \*\*\* |
| Error | 44 | 22.177 | 2.057 | 1.727 | 1.565 | 1.213 | 5.514 | 6.319 | 3.257 |
| Total | 68 | 439.714 | 11.823 | 10.593 | 8.694 | 3.793 | 159.973 | 255.086 | 145.489 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | DF | Fruit ShapeIndex | No. Fruit /Cluster | Pericarpthickness (mm) | TSS (Brix) | Ascorbic acidity(100g) | TitratableAcidity (%) | LycopeneContent | Total yield perplant (g) |
| Replicates | 2 | 0.001 | 0.115 | 0.081 | 0.171 | 2.885 | 0.002 | 0.130 | 19508.800 |
| Treatments | 22 | 0.328 \*\*\* | 2.184 \*\*\* | 4.571 \*\*\* | 4.008 \*\*\* | 113.052 \*\*\* | 0.146 \*\*\* | 4.787 \*\*\* | 2198712.000 \*\*\* |
| Error | 44 | 0.005 | 0.115 | 0.169 | 0.179 | 9.024 | 0.008 | 0.102 | 26122.780 |
| Total | 68 | 0.110 | 0.785 | 1.591 | 1.418 | 42.499 | 0.052 | 1.618 | 728824.900 |

**Table 2. Analysis of variance forparents and hybrid and check various characters in tomato.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | DF | Plant Height(cm) | Days to firstflowering | Days to 50%Flowering | No. of Pri.Branches | No. of Sec.Branches | No.of Fruit /Plant | Average fruitwt (g) | Fruit Diameter(mm) |
| Replicates | 2 | 9.867 | 5.600 \* | 4.956 | 0.422 | 0.867 | 9.398 | 6.822 | 7.756 |
| Cross | 14 | 752.200 \*\*\* | 43.952 \*\*\* | 38.898 \*\*\* | 21.041 \*\*\* | 0.248 \*\*\* | 189.728 \*\*\* | 337.728 \*\*\* | 425.103 \*\*\* |
| Line effect | 4 | 1031.311 | 59.278 | 58.589 | 44.478 | 10.478 | 287.974 | 308.945 \*\*\* | 1281.144 \*\* |
| Tester effect | 2 | 468.367 | 16.200 | 11.822 | 7.622 | 6.067 | 4.485 | 112.156 | 24.422 |
| Line x Tester effect | 8 | 683.478 \*\*\* | 43.223 \*\*\* | 35.822 \*\*\* | 12.678 \*\*\* | 7.678 \*\*\* | 186.915 \*\*\* | 409.322 \*\*\* | 98.478 \*\*\* |
| Error | 28 | 5.224 | 1.338 | 0.164 | 1.637 | 1.486 | 3.929 | 5.084 | 3.875 |
| Total | 44 | 243.109 | 15.091 | 13.165 | 7.756 | 2.609 | 63.295 | 111.074 | 138.301 |

**Table 3. General Combing Ability effects of parents for different characters.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Average fruit****wt (g)** | **Fruit Diameter** | **Fruit Shape****Index** | **Pericarp****Thickness** | **TSS (Brix)** | **Ascorbic acidity(100g)** | **Titratable****Acidity (%)** | **Lycopene****content** | **Total yield per****plant (g)** |
|
| EC- 249504 | -3.622 \*\*\* | -11.289 \*\*\* | 0.036 | -1.522 \*\*\* | -0.333 \* | 2.002 | -0.070 \* | -0.806 \*\*\* | -707.222 \*\*\* |
| EC- 631364 | 3.267 \*\*\* | -13.733 \*\*\* | -0.039 | 0.913 \*\*\* | -0.050 | -4.610 \*\*\* | -0.085 \*\* | 0.400 \*\*\* | -633.778 \*\*\* |
| EC- 620427 | 5.267 \*\*\* | 3.711 \*\*\* | 0.264 \*\*\* | 0.918 \*\*\* | 1.024 \*\*\* | 2.534 \* | 0.161 \*\*\* | 0.527 \*\*\* | 367.222 \*\*\* |
| EC- 145057 | -8.511 \*\*\* | 8.156 \*\*\* | 0.038 | -0.160 | -0.753 \*\*\* | 3.169 \*\* | -0.061 \* | 0.162 | 38.778 |
| EC- 620395 | 3.600 \*\*\* | 13.156 \*\*\* | -0.299 \*\*\* | -0.150 | 0.112 | -3.095 \*\* | 0.055 | -0.283 \* | 935.000 \*\*\* |
| EC- 163605 | -2.111 \*\* | 1.356 \*\* | 0.039 \* | -0.186 | 0.148 | 1.885 \* | 0.115 \*\*\* | 0.415 \*\*\* | -13.533 |
| EC- 631379 | 3.089 \*\*\* | -0.178 | -0.150 \*\*\* | 0.081 | -0.089 | -1.169 | -0.031 | -0.053 | 170.200 \*\*\* |
| EC- 164563 | -0.978 | -1.178 \* | 0.111 \*\*\* | 0.106 | -0.059 | -0.716 | -0.084 \*\*\* | -0.362 \*\*\* | -156.667 \*\*\* |
| CD 95% GCA(Line) | 1.716 | 1.232 | 0.049 | 0.281 | 0.289 | 2.051 | 0.060 | 0.218 | 110.359 |
| CD 95% GCA(Tester) | 1.330 | 0.955 | 0.038 | 0.217 | 0.224 | 1.589 | 0.047 | 0.169 | 85.484 |

 **Table 4. Specific combining abilityeffects of hybrids for different characters.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Hybrids** | **Average fruit** | **Fruit Diameter** | **Fruit Shape****Index** | **Pericarp** | **TSS (Brix)** | **Titratable****Acidity (%)** | **Titrable** | **Lycopene** | **Total yield per** |
| EC-249504 x EC-163605 | -7.778 \*\*\* | 0.089 | 0.017 | -1.467 \*\*\* | -1.566 \*\*\* | -5.642 \*\* | 0.177 \*\* | 2.051 \*\*\* | -200.911 \* |
| EC-249504 x EC-631379 | -0.311 | 4.956 \*\*\* | 0.072 | -0.474 | 0.208 | 9.648 \*\*\* | -0.110 \* | -0.227 | 182.022 |
| EC-249504 x EC-164563 | 8.089 \*\*\* | -5.044 \*\*\* | -0.089 \* | 1.941 \*\*\* | 1.358 \*\*\* | -4.005 \* | -0.067 | -1.825 \*\*\* | 18.889 |
| EC- 631364 x EC-163605 | 1.333 | 4.533 \*\*\* | -0.395 \*\*\* | 0.782 \*\* | -0.202 | -0.147 | 0.085 | -1.934 \*\*\* | 331.311 \*\* |
| EC- 631364 x EC-631379 | -8.533 \*\*\* | -2.600 \* | -0.097 \* | -0.322 | -0.616 \* | -2.937 | 0.111 \* | -0.282 | -460.756 \*\*\* |
| EC- 631364 x EC-164563 | 7.200 \*\*\* | -1.933 | 0.492 \*\*\* | -0.460 | 0.818 \*\* | 3.084 | -0.196 \*\*\* | 2.216 \*\*\* | 129.444 |
| EC- 620427 x EC- 163605 | 14.333 \*\*\* | -7.911 \*\*\* | -0.174 \*\*\* | 0.066 | 0.654 \* | 6.083 \*\* | -0.011 | 0.505 \* | 176.644 |
| EC- 620427 x EC- 631379 | 7.467 \*\*\* | -1.711 | 0.038 | 0.439 | 0.268 | -3.540 | -0.021 | 0.113 | 263.911 \*\* |
| EC- 620427 x EC- 164563 | -21.800 \*\*\* | 9.622 \*\*\* | 0.136 \*\* | -0.506 \* | -0.922 \*\*\* | -2.543 | 0.032 | -0.618 \*\* | -440.556 \*\*\* |
| EC-145057 x EC- 163605 | -6.889 \*\*\* | 2.978 \*\* | 0.578 \*\*\* | 0.871 \*\* | 1.134 \*\*\* | -0.779 | -0.132 \* | -0.013 | -243.911 \* |
| EC-145057 x EC- 631379 | 4.578 \*\* | -2.489 \* | -0.120 \*\* | -0.003 | -0.299 | -2.709 | -0.015 | 0.052 | 82.689 |
| EC-145057 x EC- 164563 | 2.311 | -0.489 | -0.458 \*\*\* | -0.868 \*\* | -0.836 \*\* | 3.488 | 0.147 \*\* | -0.039 | 161.222 |
| EC- 620395 x EC-631379 | -3.200 \* | 1.844 | 0.107 \* | 0.360 | 0.439 | -0.461 | 0.035 | 0.343 | -67.867 |
| EC- 620395 x EC- 164563 | 4.200 \*\* | -2.156 \* | -0.081 | -0.108 | -0.418 | -0.024 | 0.084 | 0.265 | 131.000 |
| CD 95% SCA | 2.973 | 2.134 | 0.086 | 0.486 | 0.501 | 3.553 | 0.104 | 0.377 | 191.147 |

**Table 5. Estimates of mid parent (MP), better parent (BP) and standard parent heterosis for different quality in tomato**

|  |  |  |  |
| --- | --- | --- | --- |
| Hybrids | **Fruit diameter** | **Average fruit weight** | **Ascorbic acidity** |
| Mean | Mid | Better | Mean | Mid | Better | Mean | Mid | Better |
| EC-249504 x EC-163605 | 30.67 | -3.66 | -31.85 \*\* | 41 | 92.19 \*\* | 39.77 \*\* | 29.3 | 48.97 \*\* | 18.8 |
| EC-249504 x EC-631379 | 34 | -11.30 \*\* | -24.44 \*\* | 53.67 | 50.47 \*\* | 27.78 \*\* | 41.54 | 77.18 \*\* | 68.41 \*\* |
| EC-249504 x EC-164563 | 23 | -42.02 \*\* | -48.89 \*\* | 58 | 53.30 \*\* | 25.18 \*\* | 28.34 | 18.87 \* | 14.89 |
| EC- 631364 x EC-163605 | 32.67 | 83.18 \*\* | 75.00 \*\* | 57 | 222.64 \*\* | 159.09 \*\* | 28.19 | 38.60 \*\* | 8.41 |
| EC- 631364 x EC-631379 | 24 | -1.37 | -24.21 \*\* | 52.33 | 63.54 \*\* | 24.60 \*\* | 22.34 | -7.33 | -14.06 |
| EC- 631364 x EC-163563 | 23.67 | -7.79 | -31.07 \*\* | 64 | 87.32 \*\* | 38.13 \*\* | 28.82 | 17.58 | 10.83 |
| EC- 620427 x EC- 163605 | 37.67 | 69.92 \*\* | 46.75 \*\* | 72 | 311.43 \*\* | 232.31 \*\* | 41.56 | 107.77 \*\* | 64.05 \*\* |
| EC- 620427 x EC- 631379 | 42.33 | 47.67 \*\* | 33.68 \*\* | 70.33 | 120.94 \*\* | 67.46 \*\* | 28.88 | 21.47 \* | 14.01 |
| EC- 620427 x EC- 164563 | 52.67 | 75.56 \*\* | 53.40 \*\* | 37 | 8.82 | -20.14 \*\* | 30.33 | 25.47 \*\* | 19.74 |
| EC-145057 x EC- 163605 | 53 | 110.60 \*\* | 67.37 \*\* | 37 | 89.74 \*\* | 44.16 \*\* | 35.33 | 53.60 \*\* | 12.77 |
| EC-145057 x EC- 631379 | 46 | 45.26 \*\* | 45.26 \*\* | 53.67 | 58.62 \*\* | 27.78 \*\* | 30.35 | 13.34 | -3.14 |
| EC-145057 x EC- 164563 | 47 | 42.42 \*\* | 36.89 \*\* | 47.33 | 31.48 \*\* | 2.16 | 37 | 36.15 \*\* | 18.09 \* |
| EC- 620395 x EC- 163605 | 55.33 | 137.14 \*\* | 97.62 \*\* | 55 | 118.54 \*\* | 48.65 \*\* | 30.33 | 54.21 \*\* | 22.97 \* |
| EC- 620395 x EC-631379 | 55.33 | 85.47 \*\* | 74.74 \*\* | 58 | 46.84 \*\* | 38.10 \*\* | 26.33 | 12.32 | 6.76 |
| EC- 620395 x EC- 164563 | 50.33 | 61.50 \*\* | 46.60 \*\* | 61.33 | 47.20 \*\* | 32.37 \*\* | 27.22 | 14.18 | 10.36 |

**Table 6 Estimates of mid parent (MP), better parent (BP) and standard parent heterosis for different quality in tomato**

|  |  |  |  |
| --- | --- | --- | --- |
| Hybrids | Lycopene content | fruit shape index | Pericarp thickness |
| Mean | Mid | Better | Mean | Mid | Better | Mean | Mid | Better |
| EC-249504 x EC-163605 | 5.86 | 163.42 \*\* | 117.99 \*\* | 1.32 | 65.34 \*\* | 55.91 \*\* | 2.49 | -46.28 \*\* | -53.31 \*\* |
| EC-249504 x EC-631379 | 3.11 | 1.08 | -10.29 | 1.19 | 39.06 \*\* | 24.04 \*\* | 3.75 | -23.26 \*\* | -29.69 \*\* |
| EC-249504 x EC-164563 | 1.2 | -65.91 \*\* | -72.48 \*\* | 1.29 | 47.05 \*\* | 28.67 \*\* | 6.19 | 22.45 \*\* | 16.06 \* |
| EC- 631364 x EC-163605 | 3.08 | -8.39 | -37.93 \*\* | 0.83 | 1.42 | -1.57 | 7.17 | 102.07 \*\* | 82.22 \*\* |
| EC- 631364 x EC-631379 | 4.26 | 1.15 | -14.06 \* | 0.94 | 7.6 | -1.39 | 6.34 | 66.68 \*\* | 42.72 \*\* |
| EC- 631364 x EC-163563 | 6.45 | 38.26 \*\* | 30.13 \*\* | 1.79 | 99.63 \*\* | 79.33 \*\* | 6.22 | 56.76 \*\* | 30.29 \*\* |
| EC- 620427 x EC- 163605 | 5.64 | 163.09 \*\* | 123.06 \*\* | 1.36 | 54.46 \*\* | 49.08 \*\* | 6.46 | 50.25 \*\* | 38.50 \*\* |
| EC- 620427 x EC- 631379 | 4.78 | 59.53 \*\* | 37.98 \*\* | 1.38 | 47.86 \*\* | 44.25 \*\* | 7.1 | 56.00 \*\* | 52.21 \*\* |
| EC- 620427 x EC- 164563 | 3.74 | 8.45 | -14.41 \* | 1.74 | 82.20 \*\* | 74.00 \*\* | 6.18 | 30.96 \*\* | 29.45 \*\* |
| EC-145057 x EC- 163605 | 4.76 | 117.02 \*\* | 81.22 \*\* | 1.88 | 122.44 \*\* | 122.44 \*\* | 6.19 | 59.33 \*\* | 57.24 \*\* |
| EC-145057 x EC- 631379 | 4.36 | 43.00 \*\* | 25.67 \*\* | 1 | 10.54 | 4.18 | 5.58 | 34.97 \*\* | 25.75 \*\* |
| EC-145057 x EC- 164563 | 3.96 | 13.05 | -9.53 | 0.92 | -0.36 | -8 | 4.74 | 10.18 | -0.7 |
| EC- 620395 x EC- 163605 | 3.72 | 38.98 \*\* | 3.53 | 0.94 | 6.19 | 1.43 | 5.08 | 9.53 | -4.81 |
| EC- 620395 x EC-631379 | 4.2 | 19.07 \*\* | 16.98 \* | 0.89 | -6.01 | -7.32 | 5.96 | 21.90 \*\* | 11.69 |
| EC- 620395 x EC- 164563 | 3.82 | -4.18 | -12.73 \* | 0.96 | -0.52 | -4 | 5.51 | 9.07 | 3.37 |

**Table 7 Estimates of mid parent (MP), better parent (BP) and standard parent heterosis for different quality in tomato**

|  |  |  |  |
| --- | --- | --- | --- |
| Hybrids | Total soluble solids | Titrable acidity | Total yield per plant |
| Mean | Mid | Better | Mean | Mid | Better | Mean | Mid | Better |
| EC-249504 x EC-163605 | 3.5 | -20.00 \*\* | -25.00 \*\* | 0.87 | 100.00 \*\* | 47.73 \*\* | 1257.67 | 58.86 \*\* | -5.75 |
| EC-249504 x EC-631379 | 5.04 | 8.86 | 7.93 | 0.43 | -27.98 \* | -29.73 \* | 1824.33 | 30.23 \*\* | 24.33 \* |
| EC-249504 x EC-164563 | 6.22 | 65.93 \*\* | 33.21 \*\* | 0.42 | 19.25 | -27.84 \* | 1334.33 | 21.47 \* | 0 |
| EC- 631364 x EC-163605 | 5.15 | 49.54 \*\* | 26.04 \*\* | 0.76 | 267.74 \*\* | 171.43 \*\* | 1863.33 | 318.88 \*\* | 190.84 \*\* |
| EC- 631364 x EC-631379 | 4.5 | 21.75 \* | -1.96 | 0.64 | 70.67 \*\* | 3.78 | 1255 | 19.07 | -14.47 |
| EC- 631364 x EC-163563 | 5.96 | 111.85 \*\* | 110.85 \*\* | 0.28 | 118.18 \* | 110 | 1518.33 | 102.00 \*\* | 76.00 \*\* |
| EC- 620427 x EC- 163605 | 7.08 | 79.92 \*\* | 73.31 \*\* | 0.91 | 80.79 \*\* | 25.23 \* | 2709.67 | 472.26 \*\* | 288.20 \*\* |
| EC- 620427 x EC- 631379 | 6.45 | 54.20 \*\* | 40.70 \*\* | 0.75 | 12.16 | 3.67 | 2980.67 | 175.31 \*\* | 103.13 \*\* |
| EC- 620427 x EC- 164563 | 5.29 | 60.16 \*\* | 39.91 \*\* | 0.75 | 77.25 \*\* | 3.67 | 1949.33 | 149.81 \*\* | 125.97 \*\* |
| EC-145057 x EC- 163605 | 5.78 | 52.71 \*\* | 41.55 \*\* | 0.57 | 19.72 | -15 | 1960.67 | 272.87 \*\* | 144.27 \*\* |
| EC-145057 x EC- 631379 | 4.11 | 1.82 | -10.39 | 0.54 | -16.36 | -19.5 | 2471 | 117.71 \*\* | 68.40 \*\* |
| EC-145057 x EC- 164563 | 3.6 | 14.15 | 3.35 | 0.65 | 63.71 \*\* | -3 | 2222.67 | 166.93 \*\* | 157.65 \*\* |
| EC- 620395 x EC- 163605 | 5.49 | 14.45 \* | -0.36 | 0.7 | 136.16 \*\* | 124.73 \*\* | 3037.67 | 194.78 \*\* | 67.64 \*\* |
| EC- 620395 x EC-631379 | 5.71 | 13.17 \* | 3.69 | 0.7 | 51.80 \*\* | 14.05 | 3216.67 | 96.18 \*\* | 77.52 \*\* |
| EC- 620395 x EC- 164563 | 4.89 | 17.23 \* | -11.31 | 0.7 | 223.08 \*\* | 125.81 \*\* | 3088.67 | 130.96 \*\* | 70.46 \*\* |