**Variability Analysis for Growth and Yield Contributing Traits in Tomato (*Lycopersicon esculentum* Mill.) Grown in Karnal Conditions of Haryana**

**Abstract**

Tomato (*Solanum lycopersicum* L.) is a major crop in the ***S***olanaceae family with a chromosome number of 2n = 2x = 24, is widely consumed in multiple forms—fresh, in salads, as a culinary ingredient, or processed into products like tomato paste, diced or peeled tomatoes, juices, and soups. It is a rich source of essential nutrients such as vitamins, minerals, and antioxidants, contributing significantly to a balanced and healthy diet. Given its nutritional importance and commercial value, identifying high-performing genotypes with desirable growth and yield traits is crucial. The present study estimated the variability analysis for Growth and Yield Contributing Traits in Tomato (*Lycopersicon esculentum* Mill.) Grown in Karnal Conditions of Haryana. A field experiment was conducted during the rabi season of 2016–17 at the Regional Research Station, Karnal, and the Laboratory of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar. Among the evaluated genotypes, Punjab Upma recorded the highest plant height (60.78 cm), NT-8 had the maximum number of branches per plant (7.00), Punjab Chhuhara showed the largest polar diameter (6.76 cm), and Castle Rock had the highest equatorial diameter (5.11 cm). The thickest pericarp (7.44 mm) was observed in DVRT-8, while DVRT-5 produced the highest number of marketable fruits per plant (38.53). The maximum marketable fruit weight per plant (1356.70 g) was found in PNR-7. Additionally, the minimum number of unmarketable fruits per plant (7.90) was recorded in S-12, and the earliest flowering (36.67 days to 50% flowering) was observed in Pusa Ruby. These findings highlight the potential of certain genotypes for improving tomato productivity and sustainability. Most traits showed high heritability and genetic advance, particularly those related to yield and plant architecture, suggesting the presence of additive gene action and good potential for genetic improvement through selection. These results underline the importance of exploiting superior genotypes for enhancing tomato productivity in breeding programs. The study offers useful insights for both researchers and growers in selecting suitable genotypes for enhanced tomato cultivation.

**Keywords:**  *Lycopersicon esculentum,* *antioxidants, phenolic compounds, functional food*

**Introduction**

“Assessment of genetic variability enables breeders to select superior germplasm, develop cultivars with desired trait combinations, and improve crop performance under various environmental conditions. Furthermore, studies of genetic variability can help breeders identify and exploit the existing variation within the gene pool, accelerating the selection of tomato genotypes with improved yield, disease resistance, and adaptability to climate change. Developing new and improved tomato genotypes is more vital than ever to maintaining tomato production and ensuring global food security, especially as the global population grows rapidly and the climate changes abruptly. The lack of genetic diversity and the unavailability of high-yielding cultivars are the main reasons for low yield” (Zannat et al., 2023). “Tomato (*Lycopersicon esculentum Mill.*) is a significant crop belonging to the Solanaceae family, with a chromosome number of 2n = 2x = 24. It originated in its wild form in the Andean region of South America, specifically in Peru, Ecuador, and Bolivia, and is now cultivated worldwide” (Patel and Udit, 2021). “Tomato contains a number of nutritive elements, almost double compared to apple. Tomatoes are a good source of vitamins A, C and E and minerals that are very good for the body and protect the body against diseases. The tomato is composed mainly of water(approximately 90%), soluble and insoluble solids (5-7%), citric and other organic acids, and vitamins and minerals” (Akhter & Najnine, 2022). Tomatoes are eaten fresh on their own, used in salads, included as ingredients in numerous recipes, or processed into various products such as tomato paste, whole peeled tomatoes, diced varieties, and different types of juices and soups. It consists of essential nutrients, including vitamins, minerals, and antioxidants, all of which play a vital role in maintaining a well-balanced human diet (Dadi et. al., 2024). It offers significant health benefits and plays a role in disease prevention. It is used in managing conditions such as diabetes, hypertension, and cancer. Additionally, it is commonly incorporated into stews and vegetable salads. With its low calorie content and high levels of fiber, minerals, phenolic compounds, and vitamins A, C, and E, along with powerful antioxidants like lycopene and β-carotene, it is considered an excellent "functional food" that meets essential nutritional requirements (Omoyeni et. al., 2024). Tomatoes are one of the most widely consumed vegetables globally and hold significant importance as a processing crop due to their remarkable qualities. Although once mistakenly believed to be poisonous, tomatoes are now cultivated across nearly every continent and are a staple ingredient in a wide variety of dishes, thanks to their unique characteristics. Tomato plants possess a small genome, are self-fertile, and exhibit a low rate of genetic mutations. Their ease of breeding is further supported by their self-pollinating nature and high level of homozygosity (Gautham et. al., 2024). So far, the efforts of many vegetable breeders have resulted in spectacular improvements in yield and quality characters. As a result of these efforts, hundreds of new cultivars have been developed in last 50 years to meet the diverse needs. Considering the potential of this crop, there is a need to develop varieties suitable for cultivation under specific agroecological conditions and also for specific end use. A thorough knowledge of the amount of genetic variability existing for various characters is essential for initiating the crop improvement programme. With limited variability, much improvement cannot be achieved; hence, the breeder will have to enrich the germplasm or create greater variability through hybridization, mutation and polyploidy breeding. The phenotypic expression of plant characters is mainly controlled by the interaction genetic makeup of a plant and the environment in which it is grown. Further, the genetic variance of any quantitative trait is composed of additive (heritable) and non-additive variance including dominance and epitasis (non-allelic interaction), hence, it becomes necessary to partition the observed phenotypic variability into its heritable and non-heritable components with suitable parameters such as phenotypic and genotypic coefficient of variation, heritability and genetic advance. The genetic advance can also be used to predict the efficiency of selection. Yield is a complex character, and selection for yield and yield components deserves considerable attention. A crop-breeding programme aimed at increasing the productivity requires consideration not only of yield but also of its components that have a direct or indirect bearing on yield. For any effective selection programme, it would be desirable to consider the relative magnitude of various characters associated with yield. Correlation and **path coefficient analysis** give an insight into the genetic variability present in the population. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which the selection can be based for improvement in yield. Path analysis splits the correlation coefficients into direct and indirect effects of a set of dependent variables on the independent variable, thereby aids in the selection of elite genotype. Based on these studies, the quantum importance of individual characters is marked to facilitate the selection programme for better gains. The commercial F1 hybrids are common in tomato and the selection of new parents for higher heterosis is a continuous process. Generally, the genetically diverse plants are expected to give high hybrid vigour. Hence, it necessitates the study of genetic divergence among the 2 existing varieties and germplasm for the identification of parents for the hybridisation programme. The information on genetic divergence of various traits, particularly of those that contribute to yield and quality, would be of most useful in planning the breeding programme. An improvement in yield and quality in a self-pollinated crop like tomato is normally achieved by selecting the genotypes with desirable character combinations existing in nature or by hybridisation. Information on the nature and extent of variability present in genetic stocks, heritability, genetic advance and interrelationship among various characters is prerequisite for framing any selection programme. The breeding of vegetable crops is primarily concerned with the improvement of both quantitative and qualitative plant characters; thus, complete knowledge of genetics is very essential in a vegetable breeding programme for obtaining desired results. The success of vegetable breeding depends on the extent and the magnitude of variability existing in the germplasm. Variability is the basic requirement for successful genetic improvement in a crop. Germplasm evaluation studies would help in the identification of genetic material for quality and yield traits in crop plants, effectively to generate noble variants having adaptation and yielding potential far better than parental types Sekhar et. al., (2008).

**Materials and Methods**

**Trial Location**

The field trial was conducted at Regional Research Station, Karnal and Laboratory of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar during rabi season of 2016-17. The experimental field is situated at latitude of 29º 43' North and a longitude of 76º 58' East, with an elevation of 253 meters above mean sea level. It is located 5 kilometers north of the district headquarters in Karnal and 132 kilometers from the state capital, Chandigarh, positioned on the eastern side of the Jammu-Delhi Grand Trunk (GT) Road.

**Properties of the soil prior to the experiment conducted**

The soil of the experimental field was analysed for mechanical and chemical properties, and cropping history details are given below in Table 1.

Experimental details: The particulars of the present experiment entitled “Evaluation of tomato (*Lycopersicon esculentum* Mill.) genotypes for growth, yield and quality traits” are given below:

Number of genotypes investigated : 22 along with one standard check

Experimental design : Randomized block design (RBD)

Plot size : 3 rows of 4.5 meter length

Spacing (row x plant) : 60 cm x 45 cm

Replications : Three

Crop season : Rabi 2016-17

**Observations:**

**Plant height (cm):** The height of five randomly selected individual plants was measured at final harvest stage from the ground to tip of the plant and replication-wise wise the average plant height of each genotype was worked out.

**Number of branches per plant:** The total number of fruiting branches of five plants was counted at the time of final picking and then averaged for the number of branches per plant.

**Days to 50% flowering:** The number of days taken from transplanting to the anthesis of first flowers on 50% plants of each genotype per replication was recorded and the average was expressed as days to 50% flowering.

**Days to first picking:** The number of days taken from transplanting to picking of first ripened fruits of each genotype per replication was recorded and the average was expressed as days to first picking.

**Days to last picking:** The number of days taken from transplanting to the picking of last ripened of each genotype per replication was recorded and the average was expressed as days to last picking.

**Polar Diameter (cm):** Fruits polar diameter was measured from stalk end to blossom end with the help of digital Vernier calliper.

**Equatorial diameter (cm):** Fruits equatorial diameter was measured from fruit breadth at highest bulged portion of the fruit with the help of digital Vernier calliper.

**Pericarp thickness (mm):** Fruit pericarp thickness was measured after cutting the fruits transversely with the help of digital Vernier callipper.

**Number of marketable fruits per plant:** Fruits of good quality were identified and counted from five marked plants and their average was calculated.

**Weight of marketable fruits per plant:** Fruits of good quality were identified and collected from five marked plants and their weight was calculated and their average was taken.

**Number of unmarketable fruits per plant:** Fruits of inferior quality and diseased one were **identified** and counted from five marked plants and their average was calculated.

**Weight of unmarketable fruits per plant:** 18 Fruits of inferior quality and diseased one were identified and collected from five marked plants and their weight was calculated and their average was taken.

**Total number of fruits per plant:** The fruits harvested from five selected plants of each genotype from all the pickings were summed up separately and then averaged per plant.

**Yield of fruits per plant (g):** The yield of fruits per plant of individual genotypes was counted by adding up the weight of marketable fruits per plant into the weight of unmarketable fruits per plant obtained from all pickings and averaged.

**Yield of fruits per hectare (q):** The weight of fruits collected from each plot all plants in all replications, was recorded and then converted into quintal per hectare.

**Number of locules per fruit:** The randomly five fruits of each genotype were selected and dissected transversely. The number of locules per fruit was counted and averaged.

**Fruit firmness (kg/cm2):** Fruit firmness was determined after the rate of penetration of a needle driven into the fruits with the help of a digital penetrometer. Two readings were taken at two different positions on the flesh of each fruits.

**Specific gravity (g/cm3):** A weighed number of fruits were placed in a graduated cylinder, and their volume was determined by water displacement. Specific gravity of fruits was obtained by dividing the weight of fruits (g) to the volume of fruit (ml).

**Statistical Analysis**

The collected data were systematically compiled and analysed statistically to determine the extent of variability using variances and coefficients of variation (Burton and Devane, 1953). Correlation coefficient analysis will be carried out following the method of Al-Jibouri, et. al. (1958), while **path coefficient analysis** will be performed according to **Dewey and Lu, (1959).** Hierarchical cluster analysis was conducted using the approach proposed by Romesburg (1990).

**Analysis of variance**

 The analysis of variance was carried out for individual characters to test the significance of differences among the genotypes following the method given by Fischer and Yates (1963) and described by Panse and Sukhatme (1967). The following model was used:

Yij = μ+ ai + bj+ eij

Where,

Yij = Observation for the ith treatment in jth block

μ = General mean

ai= Effect of ith treatment

bj= Effect of jth block

eij= Random error (uncontrolled variation) associated with ith treatment in jth block

**chart 1. Analysis of variance**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of variation** | **d. f.** | **Mean Squares** | **Expected mean squares** | **F value** |
| Replications | (r-1) | Mr | σe2 + gσr2 |  |
| Genotypes | (g-l) | Mg | σe2 + rσg2 | Mg / Me |
| Error | (r-l)(g-l) | Me | σe2 |  |

Where,

r = Number of replications

g = Number of genotypes

Assumptions of the model:

The following assumptions were made during analysis of variance-

1. All the observations should be independent.

2. The different effects in the model should be additive.

3. Error involved in the population should be normally and independently

 distributed with mean zero and variance *σe2*.

The significance of Mr and Mg was tested against Me by ‘F’ test at 5 and 1 per cent level of significance.

**Parameters of variability**

**Mean**

The mean value of each character was calculated by summing up of all the observations and dividing the total by the corresponding number of observations:

$$\overbar{x}=\frac{∑Xij}{N}$$

Where,

∑ xij : Summation of ith treatment in jth replication

N : Total number of observations

**Range**

The minimum and maximum value of observation means for each character was taken as range.

**Standard error (SE)**

$$S.E.\left(d\right)= \sqrt{\frac{2MSe}{r}}$$

Where,

SE (d) = Standard error of difference of two means

MSe = Error mean sum of squares

r = Number of replications

**Critical Difference (CD)**

Critical difference was calculated for all the traits to compare the treatment means using difference of two means and tabulated value of t (p=0.05) at error degree of freedom using the following formula :

CD =SE(d) X ‘t’ value at error degree of freedom

Where,

SE (d) = Standard error (difference of two means)

**Coefficient of variation (CV)**

The coefficient of variation as percentage of mean was estimated as mentioned bellow:

CV (%) = $\frac{S.D}{Mean}×100$

Where,

 CV (%) = Coefficient of variation in per cent,

S.D. = Standard deviation

**Variances**

Genotypic and phenotypic variances were computed as follows:

 $Genotypic variance \left(σ^{2}g\right)= \frac{Treatment MSS-Error MSS}{r}$

$$Phenotypic variance \left(σ^{2}p\right)= σ^{2}g+σ^{2}e$$

Where,

 r = Number of replications

 Mg= Mean squares due to genotypes

 Me = Mean squares due to error

 σ2g = Genotypic variance

 σ2e = Environmental variance

 σ2p = Phenotypic variance

**Estimation of coefficient of variation**

 Genotypic and phenotypic coefficients of variation for different characters were calculated by the formula as suggested by Burton and Devane (1953).

 $Genotypic coefficient of variability \left(GCV \%\right)= \frac{σ^{2}g X 100}{\overbar{X}}$

 $Phenotypic coefficient of variability \left(PCV \%\right)= \frac{σ^{2}p X 100}{\overbar{X}}$

Where,

GCV = Genotypic coefficient of variation

PCV= Phenotypic coefficient of variation

σ2g = Genotypic variance

σ2p = Phenotypic variance

 GCV and PCV was classified as low (0-10%), moderate (10-20%) and high (>20%) as suggested by Sivasubramanium and Madhavamenon, (1973).

**Heritability (Broad sense)**

Heritability (broad sense) in per cent was estimated as per the formula given by Burton and Devane (1953), Johnson, et. al. (1955) and Hanson, et. al. (1956).

 h2bs= $\frac{σ\_{g}}{σ\_{p}}$ x 100

Heritability was classified in following categories as suggested by Robinson, 1966

Low : 0-50%

Moderate : 50-70%

High : >70%

**Genetic advance**

The expected genetic advance was calculated by the formula as suggested by Johnson, et. al. (1955).

 Genetic advance (G.A.) = kσph2

Where,

GA= Genetic advance

σp = Phenotypic standard deviation

h2 = heritability in broad sense

k = selection intensity

 Genetic advance was classified as low (0-10%), moderate (10-30%) and high (>30%) (13).

**Estimation of correlation co-efficient**

Genotypic and phenotypic coefficients of correlation were determined by using the variance and covariance components as suggested by Al-Jibouri, et al., 1958.

rij(G) =$ \frac{σ^{2}gij}{ \sqrt{σ^{2}gii × σ^{2}gjj}}$ $\frac{σ^{2}g\_{ij}}{\sqrt{\frac{}{}σ^{2 }g\_{ii}×σ^{2}g\_{jj}}}$

Where,

σ2gij = Genotypic co-variance of character xi and xj

σ2gii = Genotypic variance of character xi

σ2gjj = Genotypic variance of character xj

rij (P) = $\frac{σ^{2}pij}{\sqrt{σ^{2}pii × σ^{2}pjj}}$ $\frac{σ^{2 }p\_{ij}}{\sqrt{σ^{2}p\_{ii}× σ^{2}p\_{jj}}}$

Where,

σ2pij= Phenotypic co-variance of character xi and xj

σ2pii= Phenotypic variance of character xi

σ2pjj= Phenotypic variance of character xj

**Path Coefficient analysis**

Path analysis was originally developed by Wright, 1921 and elaborated by Dewey and Lu, 1959. Path coefficient analysis splits the genotypic correlation coefficient into the measure of direct and indirect effects. It measures the direct and indirect contribution of independent variables on dependent variable.

**Setting up of simultaneous equations**

 For estimation of various direct and indirect effects, a set of simultaneous equations were formed.

|  |  |  |
| --- | --- | --- |
| r1y | = | P1y + r12 P2y + r13P3y+ + P1kPky |
| r2y | = | r21 P1y + P2y + r23P3y+ + r2kPky |
| riy | = | ri1 P1y + Pi2 P2y + ri3 P3y+ + r ikPky |
| rky | = | rk1 P1y + Pk2 P2y +rk3Pky+ +. rkkPky |

**Solution of simultaneous equations**

The above equations were written in a matrix form as under.

r1y r11 r12 r13 ……r1j

r2y r21 r22 r23 ……r2j

r3y r31 r32 r33 ……r3j

riy ri1 ri2 ri3 …….rij

The technique given by Goulden, 1954 was followed for inversion (B-1) of B matrix. Path coefficients Pjy were obtained as follows:

Pjy = (B-1) x (A)

 The indirect effect for a particular character through other character was obtained by multiplication of direct path and particular correlation coefficient between those two characters, respectively.

Indirect effect = rij x Pjy

Where,

i = 1, 2…………..n

j = 1, 2…………..n and

Pjy = P1y, P2y......Pny

 The residual factor, *i.e.* the variation in yield unaccounted for (by such traits which could not be studied) was calculated as:

Residual factor (x) = 1-R2

Where,

R2 = P1y r1y + P2y r2y + ………..Pny rny

R2 = Squared multiple correlation coefficients and the amount of variation in yield

that can be accounted for by the yield component characters.

**Genetic divergence**

**Hierarchical cluster analysis**

 This analysis was performed using SPSS statistical software (version 20.0). Cluster analysis was employed to assess the similarity and divergence among genotype pairs within the dataset. The hierarchical clustering method, specifically the agglomerative approach, was applied in this study. In this method, each genotype initially starts as an individual cluster, and clusters are progressively merged based on their similarity until all genotypes are grouped into a single cluster. This approach facilitates the identification of relatively homogeneous groups of genotypes.

Among various clustering techniques—such as between-group linkage, within-group linkage, nearest neighbor, furthest neighbor, centroid clustering, median clustering, and Ward’s method—the between-group linkage method, also known as UPGMA (Unweighted Pair Group Method Using Arithmetic Averages), was selected for this study, following the recommendation of Romesburg, 1990.

UPGMA calculates the distance between two clusters as the average of all pairwise distances between members of one cluster and those of the other. These distances are computed using the Proximity procedure in SPSS. To measure similarity and dissimilarity, the City Block distance (also known as Manhattan distance) was used, which is defined as the sum of the absolute differences between corresponding values of all variables for two given cases.

 **City Block Distance (X,Y)** = **∑ │Xi – Yi│**

After computing the distance matrix, clustering was initiated by merging the two cases with the smallest absolute distance between them. The distance between any two clusters was then calculated as the average of all pairwise distances between members of one cluster and members of the other. For instance, if cases 1 and 2 form Cluster A, and cases 3, 4, and 5 form Cluster B, the distance between Clusters A and B is determined by averaging the distances between the following pairs: (1,3), (1,4), (1,5), (2,3), (2,4), and (2,5). This agglomerative process continued until all cases were merged into a single cluster. At each stage, either individual cases were added to existing clusters or clusters were combined. Once a cluster was formed, it remained intact and could only merge with other clusters—it could not be separated or reassigned.

Following the clustering process, a dendrogram was generated using rescaled distances. This scaling preserved the ratio between steps and minimised issues related to large distance values, thereby enhancing the visualisation of similarities and differences among the objects. The dendrogram displayed the sequence of cluster combinations and the corresponding distance coefficients at each step.

Determining the optimal number of clusters is inherently subjective. However, selecting a point on the dendrogram within a broad range of resemblance coefficients where the number of clusters remains stable. A wide range suggests well-separated clusters and reduces sensitivity to error (Romesburg, 1990). This guideline was followed to decide the final number of clusters retained in the analysis.

**Results and Discussion**

Under field conditions plant height (cm), number of branches per plant, number of fruits per plant, fruit diameter(cm), fresh fruit yield per plant (kg/ha), and marketable fresh fruit yield per hectare (ton) were measured.

 The results of this study showed that most growth and yield-related traits were significantly influenced by the different genotypes. As presented in Table 3, plant height exhibited a highly significant variation among genotypes. The tallest plants (145.22 cm) were observed in the genotype Pusa Ruby, which was statistically comparable to PNR-7. In contrast, the shortest plants were recorded in the genotype Punjab Upma (60.78 cm). The number of branches per plant was maximum in genotype NT-8 (7.00), which was statistically at par with S-12 (6.67) and minimum was reported in genotypes Castle Rock and P.H.S. (3.89). The maximum and minimum polar diameter was observed in genotypes Punjab Chhuhara (6.76 cm) and Sel-7 (3.36 cm), respectively. Whereas, the maximum and the minimum equatorial diameters were observed in genotypes Castle Rock (5.35 cm) and DVRT-8 (3.47 cm). Pericarp thickness was observed to be maximum in genotype DVRT-8 (7.44 cm) and minimum in genotype Pusa Ruby (3.24 cm). These differences in growth parameters are likely attributed to the genetic variation among the genotypes. Similar findings were reported by Dadi et al. (2024), who observed variation in plant height among four tomato varieties, suggesting that genetic differences played a key role.

The yield and yield contributing characters like the maximum number of marketable fruits per plant, were found in genotype DVRT-5 (38.53) and number of unmarketable fruits per plant in genotype P.H.S. (13.22). Weight of marketable fruits per plant was observed to be maximum in genotype PNR-7 (1356.70 g) and the weight of unmarketable fruits per plant in genotype Castle Rock (660.34 g). The yield of fruits per plant and yield of fruits per hectare was recorded as maximum in genotype Castle Rock (1388.74 g and 462.91 q) and minimum was recorded in genotype S-12 (981.33 g and 327.11 q). The differences in yield and yield-contributing traits may be attributed to the genetic variability among the varieties, as each possesses a distinct genetic makeup. Similar observations were made by Hossain et al. (2014) and Dadi et al. (2024), who reported variations in fruit diameter and fruit number while assessing different tomato varieties.

**Coefficient of variation**

 **Genotypic coefficient of variation:** The highest magnitude of genotypic coefficient of variation (GCV) was observed for traits plant height (32.50%) followed by number of marketable fruits per plant (23.90%). Moderate estimates of GCV was observed for traits total number of fruits per plant (19.15%), number of branches per plant (17.86%), weight of unmarketable fruits per plant (15.49%), yield of fruits per plant (15.09%), yield of fruits per hectare 34 (14.93%), number of unmarketable fruits per plant (13.36%), weight of marketable fruits per plant (13.08%), days to 50% flowering (11.59%).

**Phenotypic coefficient of variation:** The highest estimates of phenotypic coefficient of variation (PCV) was observed for traits plant height (32.88%) followed by number of marketable fruits per plant (28.62%), total number of fruits per plant (23.02%) and polar diameter (21.81%) whereas, the moderate PCV was observed for traits number of branches per plant (19.48%), number of unmarketable fruits per plant (18.18%), weight of unmarketable fruits per plant (16.59%), yield of fruits per plant (15.36%), yield of fruits per hectare (15.16%), weight of marketable fruits per plant (13.21%), days to 50% flowering (12.55%).

From the results of the present investigation (Table 4), it is clear that it is not always necessary for high heritability to be associated with high genetic advance. Phenotypic coefficient of variation (PCV) was always higher than the corresponding genotypic coefficient of variation (GCV) for all the traits, denoting environmental factors influencing their expression to some degree or other on these traits. Shankar et al., (2013) and Meitei et al., (2014) also observed higher PCV value than GCV values for all the traits. Wide difference between PCV and GCV for some of the traits implied that they are more susceptible to environmental fluctuations than others. In the present investigation high magnitude of GCV and PCV was observed for almost all traits. Similar results were also observed by Islam et al., (2012) and Kumar et al., (2017). The efficacy of selection for any character depends not only on the magnitude of variability present for the character but also on the extent to which it can be transferred from parents to the offspring i.e. heritability of the trait.

**Heritability and Genetic Advance:** The uniformity between parents and their progeny is governed by heritability. The magnitude of heritability in the broad sense indicates the reliability with which a genotype can be recognised by its phenotypic expression. According to Burton and DeVane (1953), heritability is a measure of heritable variation and is helpful in predicting expected amount of improvement to be achieved through selection together with the genotypic coefficient of variation. Heritability acts as an index of transmissibility of a particular character to its offsprings. However, the knowledge of heritability alone does not help in formulating concrete breeding programme. Genetic advance along with heritability helps to ascertain the possible genetic control for any particular trait and provide the knowledge about the expected gain for a particular trait after selection. The nature and extent of the inherent ability of a genotype for a character is an important parameter determining the extent of improvement of any crop species. The heritability in a broad sense and genetic advance as per cent of the mean were worked out for all the characters presented in (Table 4).

Based on above characterization, it was evaluated from Table 4 that the high magnitude of heritability (broad sense) was noticed in almost all characters like weight of marketable fruits per plant (98.11%) followed by plant height (97.72%), yield of fruits per hectare (97.04%), yield of fruits per plant (96.48%), days to 50% flowering (85.22%), number of branches per plant (84.06%), equatorial diameter (76.71%), weight of unmarketable fruits per plant (71.24%), number of marketable fruits per plant (69.75% and total number of fruits per plant (69.24%) whereas, the moderate heritability was observed for total soluble solids (57.24%), number of unmarketable fruits per plant (54.03%).

In the present investigation, the magnitude of genetic advance as percentage of mean was observed high for plant height (66.19%) followed by polar diameter (42.45%), number of marketable fruits per plant (41.12%), number of branches per plant (33.74%), total number of fruits per plant (32.84%), yield of fruits per plant (31.28%) and yield of fruits per hectare (30.30%). It was recorded as moderate for weight of marketable fruits per plant (28.11%), days to 50% flowering (22.03%), weight of unmarketable fruits per plant (29.36%), number of unmarketable fruits per plant (20.20%) and equatorial diameter (19.36%).

 Heritability estimates together with genetic advance is more important than heritability alone to predict the effects of selection. In reality, heritability and genetic advance are two complementary aspects of crop improvement through selection. In the present investigation, high heritability coupled with high genetic advance as percent of mean and high GCV was observed for yield attributing traits. These results are in accordance with the findings of Sahanur et al., (2011); Madhurina and Paul (2012) and Tasisa et al., (2012). It may be due to the presence of additive gene action for these characters and hence, simple selection would be the most appropriate breeding method for their improvement. Traits like plant height, number of marketable fruits per plant and polar diameter revealed high heritability associated with high genetic advance as percent of the mean and moderate GCV indicated lesser variability but they can be improved through selection. Similar findings were also observed by Dar and Sharma (2011); Mohamed et al., (2012) and Saleem et al., (2013).

**Conclusion**

The current study demonstrated considerable genetic variability among the assessed tomato genotypes in terms of growth, yield, and associated traits. Significant differences were found in characteristics such as plant height, number of branches, fruit size, and pericarp thickness, reflecting a wide genetic base. Genotypes like Pusa Ruby, NT-8, DVRT-8, and Castle Rock excelled in specific traits, with 'Castle Rock' achieving the highest yield per plant and per hectare, and DVRT-5 recording the greatest number of marketable fruits per plant. High genotypic and phenotypic coefficients of variation, especially for plant height and marketable fruit number, indicated strong genetic diversity. Most traits showed high heritability and genetic advance, particularly those related to yield and plant architecture, suggesting the presence of additive gene action and good potential for genetic improvement through selection. These results underline the importance of exploiting superior genotypes for enhancing tomato productivity in breeding programs.

**Disclaimer (Artificial intelligence)**

Option 1:

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

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**References:**

1. Al-Jibouri, H.A., Miller, P.A. and Robinson, H.F. (1958). Genotypic and environmental variances and co-variances in upland cotton crosses of inter specific origin. *Agronomy Journal*, **50**: 633-637.
2. Burton, G.W. and Devane, E.H. (1953). Estimating heritability in tall fescue (*Festuca arundi-nancea*) from replicated clonal materials. *Agronomy Journal,* **45:** 478-481.
3. Dadi, T.L., Dejene, T.B., Habtamu G.M. and Damtew A. (2024). Evaluation and participatory variety selection of tomato (*Lycopersicum esculentum* Mill.) for yield and related traits. *Cross Current International Journal of Agriculture and Veterinary Sciences*. **6(1):** 1-5.
4. Dar, R.A. and Sharma, J.P. (2011). Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicum* L.). *International Journal of Plant Breeding and Genetics*, **5:** 168-174.
5. Dewey, D.R. and Lu, K.H. (1959). A correlation and path coefficient analysis of yield components of the crested wheat grass seed production. *Agronomy Journal*, **51:** 515-518.
6. Fischer, R.A. and Yates, F. (1963). Statistical Tables for Biological, Agricultural and Medical Research, Oliver and Boyd Edinburgh. pp. 55-57.
7. Gautham, S.S.P., Shashikanth, E., Fakrudin B., Raveendra, J., Vasudeva, KR, Basavarajappa, M.P.and Vinay, K.M.M. (2024). Exploring genetic variability in tomato for yield and quality traits. *International Journal of Research in Agronomy*, **7(12)**: 321-325.
8. Goulden, C.H. (1954). Methods of statistical analysis. John Wiley and Sons. Inc., New York, 2nd Edition.
9. Hanson, C.H., Robinson, H.F. and Comstock, R.E. (1956). Biometrical studies of yield in segregating population of Korean Lespedeza. *Agronomy Journal,* **48:** 268-272.
10. [Hossain, M.F.](https://ageconsearch.umn.edu/search?f1=author&as=1&sf=title&so=a&rm=&m1=e&p1=Hossain%2C%20M.F.&ln=en), [Ara, N.](https://ageconsearch.umn.edu/search?f1=author&as=1&sf=title&so=a&rm=&m1=e&p1=Ara%2C%20N.&ln=en), [Islam, M.R.](https://ageconsearch.umn.edu/search?f1=author&as=1&sf=title&so=a&rm=&m1=e&p1=Islam%2C%20M.R.&ln=en), [Hossain, J.](https://ageconsearch.umn.edu/search?f1=author&as=1&sf=title&so=a&rm=&m1=e&p1=Hossain%2C%20J.&ln=en) and [Ahkter, B.](https://ageconsearch.umn.edu/search?f1=author&as=1&sf=title&so=a&rm=&m1=e&p1=Ahkter%2C%20B.&ln=en) (2014). Effect of different sowing dates on yield of tomato genotypes. *International Journal Of Agricultural Research Innovation and Technology,* **4(1):** 40-43.
11. Islam, M.S., Mohanta, H.C., Rafii, M.Y. and Malek, M.A. (2012). Genetic variability and trait relationship in cherry tomato (*Solanum lycopersicum* L.). *Bangladesh Journal Botany*, **41(2):** 163-167.
12. Johnson, H.W., Robinson, H.F. and Comstock, R.E. (1955). Estimates of genetic and environmental variability in soybean. *Journal of Agronomy*, **47:** 314-318.
13. Kumar, V., Sahay, S., Nirgude, V., Kumari, A., Singh, R.S., Mir, H., Mahesh, S.S., Kumar, V. (2017). Assessment of genetic variability among different genotypes of Cape gooseberry (*Physalis peruviana* L.) in India. *Journal of Applied and Natural Science*, **9(3):** 1735-1739.
14. Madhurina, M. and Paul, A. (2012). Studies on genetic variability and characters association of fruit quality parameters in tomato. *Horticulture Flora Research Spectrum*, **1(2):** 110-116.
15. Meitei, K.M., Bora, G.C., Senjam, J.S. and Anjan, K.S. (2014). Morphology based genetic variability analysis and identification of important characters for tomato (*Solanum lycopersicum* L.) crop improvement. *American Eurasian Journal of Agricultural and Environmental Sciences*, **14(10):** 1105-1111.
16. Mohamed, S.M., Ali, E.E. and Mohamed, T.Y. (2012). Study of heritability and genetic variability among different plant and fruit characters of tomato (*Solanum lycopersicum* L.). *International Journal of Science and Technology Research*, **1(2):** 55-58.
17. Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorous in soils by extraction with sodium bicarbonate. *Circulation from United States Department of Agriculture*, 939. USDA, Washington, D.C.
18. Omoyeni D.I., Fayeun, L.S., Odiyi, A.C., Olatunji, O.S. and Oluwadare, L.V. (2024). Genetic diversity studies for quantitative traits of twenty six tomato (*Solanum lycopersicon* M.) genotypes using principal component analysis and single linkage cluster analysis. *Nigerian Journal of Horticultural Science*, **28(3):** 1118-2733.
19. Panse, V.G. and Sukhatme, P.V. (1967). Statistical methods for agricultural workers. ICAR, New Delhi.
20. Patel, P. and Kumar, U. (2021). Studies on correlation and path coefficient analysis for yield and quality traits in tomato. *The Pharma Innovation Journal*, **10(9):** 1914-1918.
21. Piper, C.S. (1950). Soil and water analysis. Published by University Adelaide, Australia.
22. Robinson, H.F. (1966). Quantitative genetics in relation to breeding on centennial of Mendelism. *Indian Jounal of Genetics*. **26:** 171-187.
23. Romesburg, H.C. (1990). Cluster Analysis for Researchers. Krieger Publishing Co., Malabar, Florida.
24. Sahanur R., Lakshman, S.S. and Maitra, N.J. (2012). Genetic variability and heritability studies in tomato (*Lycopersicon esculentum* Mill.). *International Journal of Plant Science,* (Muzaffarnagar), **7(1):** 58-62.
25. Saleem, M.Y., Iqbal, Q. and Asghar, M. (2013). Genetic variability, heritability, character association and path analysis in F1 Hybrids of tomato. *Pakistan Journal of Agricultural Sciences,* **50(4):** 649-653.
26. Sekhar, L., Prakash, B.G., Salimath, P.M., Sridevi, O. and Patil, A.A. (2008). Genetic diversity among some productive hybrids of tomato (*Lycopersicon esculentum* Mill.). *Karnataka Journal of Agricultural Science,* **21(2):** 264-265.
27. Shankar, A., Reddy, R.V.S.K., Sujatha, M. and Pratap, M. (2013). Genetic variability studies in F1 generation of tomato (*Solanum lycopersicum* L.). *IOSR Journal of Agriculture and Veterinary Science,* **4(5):** 31-34.
28. Sivasubramanium, J. and Madhavamenon, P. (1973). Genotypic and phenotypic variability in rice. *Madras Agriculture Journal,* **12:** 15-16.
29. Subbaiah, B.V. and Asija, G.L. (1956). A rapid procedure for the determination of available nitrogen in the soil. *Current Science*, **25**: 259-260.
30. Tasisa, J., Belew, D. and Bantte, K. (2011). Variability, heritability and genetic advance in tomato (*Lycopersicon esculentum* Mill.). genotypes in West Shoa, Ethiopia, American- Eurasian. *Journal of Agriculture and Environment Science*, **11(1):** 87-94.
31. Walkley, A. and Black C.A. (1934). An examination of the digtjareff method for determination of soil organic matter and a proposed modification of chronic acid titration method. *Soil Science*, **37**: 29-39.
32. Wright, S. (1921). Correlation of causation. *Journal of Agriculture Research*, **20:** 257-287.
33. Zannat, A., Hussain, M. A., Abdullah, A. H. M., Hossain, M. I., Saifullah, M., Safhi, F. A., ... & Hossain, M. S. (2023). Exploring genotypic variability and interrelationships among growth, yield, and quality characteristics in diverse tomato genotypes. Heliyon, 9(8).
34. Akhter, S., & Najnine, F. (2022). Variability of tomato (Lycopersicon esculentum L.) genotypes for higher yield and yield contributing traits. North American Academic Research, 5(2), 48-64.

**Table 1** Detailed description of Mechanical, and chemical analysis of soil and cropping history

|  |
| --- |
| **Mechanical analysis of the soil** |
| Sr. No. | Soil parameters | Proportion in percentage | Methods and reference |
| 1 | Sand | 56 | International pipette method (Piper, 1950) |
| 2 | Silt | 32 |
| 3 | Clay | 12 |
| 4 | Soil texture | Sandy - loam |
| **Chemical analysis of the soil at the start of the experiment** |
| S. No. | Soil Parameters | Value | Methods and reference |
| 1 | pH(1:2 soil: water suspension) | 7.86 | Potentiometric method(Jackson, 1973) |
| 2 | EC (ds/m) at 250C(1:2 soil: water suspension) | 0.12 | Conductometric method(Jackson, 1973) |
| 3 | Organic Carbon (%) | 0.40 | Wet oxidation method (Walkley and Black, 1934) |
| 4 | Available nitrogen (kg/ha) | 158 | Kjeldhal- distillation method(Subbiah and Asija, 1956) |
| 5 | Available phosphorus (kg/ha) | 11 | NaHCO3 extraction and colorimetry method (Olsen *et al.*, 1954) |
| 6 | Available potassium (kg/ha) | 197 | N NH4OAC extraction and Flame photometry method, (Jackson 1973) |

**Table2** List of germplasm lines and standard released varieties included in the research programme

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No.** |  **Genotype** | **Sr. No.** |  **Genotype** |
| 1. | DVRT-1 | 13. | PNR-7 |
| 2. | DVRT-2 | 14. | Palam Pink |
| 3. | DVRT-3 | 15. | Punjab Ratta |
| 4. | DVRT-5 | 16. | Pusa Ruby |
| 5. | DVRT-6 | 17. | Punjab Tropics |
| 6. | DVRT-8 | 18. | Pusa Uphar |
| 7. | Arka Vikas | 19. | Punjab Upma |
| 8. | Castle Rock | 20. | Sel-7 |
| 9. | NT-8 | 21. | S-12 |
| 10. | Punjab Chhuhara | 22. | H-86  |
| 11. | P.H.S | 23. | Pusa Sadabahar (C) |
| 12. | Punjab Kesari |  |  |

**Table 3: Mean performance of different genotypes for various traits in tomato**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  **Observations** **Treatments** | **Plant height****(cm)** | **Number of branches per plant** | **Days to 50% flowering** | **Polar diameter****(cm)** | **Equatorial diameter****(cm)** | **Number of marketable fruits per plant** | **Weight of marketable fruits per plant (g)** | **Number of un-marketable fruits per plant** | **Yield of fruit per plant (g)** | **Yield of fruit per plant (g)** |
| **DVRT-1** | 64.22 | 4.33 | 52.00 | 4.36 | 4.30 | 17.71 | 849.89 | 11.85 | 1191.63 | 1191.63 |
| **DVRT-2** | 73.67 | 4.44 | 56.33 | 4.49 | 5.11 | 20.76 | 1117.05 | 10.53 | 1549.28 | 1549.28 |
| **DVRT-3** | 61.67 | 6.33 | 50.67 | 3.76 | 3.65 | 30.73 | 931.68 | 12.33 | 1157.78 | 1157.78 |
| **DVRT-5** | 70.78 | 5.00 | 47.33 | 3.55 | 3.63 | 38.53 | 1100.78 | 16.82 | 1421.14 | 1421.14 |
| **DVRT-6**  | 68.55 | 4.45 | 46.67 | 5.67 | 4.60 | 18.49 | 1126.87 | 11.24 | 1590.71 | 1590.71 |
| **DVRT-8** | 65.33 | 4.56 | 45.00 | 5.37 | 3.47 | 20.11 | 1047.69 | 11.98 | 1493.97 | 1493.97 |
| **Arka Vikas** | 81.11 | 5.23 | 40.00 | 4.10 | 4.67 | 20.18 | 958.93 | 11.36 | 1311.44 | 1311.44 |
| **Castle Rock** | 62.33 | 3.89 | 43.00 | 5.61 | 5.35 | 13.11 | 1139.72 | 8.98 | 1800.06 | 1800.06 |
| **NT-8** | 64.33 | 7.00 | 45.00 | 3.99 | 4.29 | 19.78 | 1151.15 | 11.07 | 1512.38 | 1512.38 |
| **Punjab Chhuhara** | 70.44 | 4.44 | 44.33 | 6.76 | 3.64 | 24.62 | 1066.01 | 10.71 | 1336.84 | 1336.84 |
| **P.H.S** | 66.22 | 3.89 | 39.33 | 3.50 | 4.15 | 22.47 | 911.14 | 13.22 | 1224.29 | 1224.29 |
| **Punjab Kesari** | 63.55 | 4.89 | 53.67 | 3.60 | 4.38 | 25.29 | 988.75 | 12.98 | 1297.13 | 1297.13 |
| **PNR-7** | 144.66 | 5.00 | 52.33 | 4.01 | 5.05 | 19.02 | 1356.70 | 10.45 | 1756.57 | 1756.57 |
| **Palam Pink** | 67.22 | 4.00 | 37.67 | 4.43 | 4.52 | 15.02 | 801.79 | 11.40 | 1144.41 | 1144.41 |
| **Punjab Ratta** | 80.22 | 4.33 | 49.00 | 5.44 | 4.56 | 17.44 | 1093.54 | 9.62 | 1465.26 | 1465.26 |
| **Pusa Ruby** | 145.22 | 5.00 | 36.67 | 3.41 | 4.20 | 25.76 | 932.14 | 12.31 | 1283.38 | 1283.38 |
| **Punjab Tropics** | 70.56 | 4.56 | 45.67 | 3.51 | 4.44 | 23.22 | 916.35 | 12.98 | 1333.52 | 1333.52 |
| **Pusa Uphar** | 131.00 | 4.78 | 43.00 | 3.44 | 3.93 | 26.20 | 1036.81 | 10.00 | 1331.75 | 1331.75 |
| **Punjab Upma** | 60.78 | 4.56 | 51.67 | 5.40 | 4.59 | 17.40 | 1067.39 | 12.13 | 1477.76 | 1477.76 |
| **Sel-7** | 66.29 | 6.41 | 38.00 | 3.36 | 4.08 | 19.46 | 835.64 | 11.53 | 1177.02 | 1177.02 |
| **S-12** | 66.89 | 6.67 | 44.00 | 3.66 | 3.99 | 18.51 | 745.59 | 7.90 | 981.33 | 981.33 |
| **H-86**  | 76.89 | 4.11 | 41.67 | 4.20 | 4.68 | 16.98 | 1169.79 | 12.27 | 1733.43 | 1733.43 |
| **Pusa Sadabahar (C)** | 69.22 | 4.11 | 46.33 | 4.25 | 4.60 | 21.69 | 1045.71 | 10.98 | 1369.96 | 1369.96 |
| **General mean** | 77.88 | 4.87 | 45.62 | 4.34 | 4.34 | 21.41 | 1017.00 | 11.51 | 1388.74 | 1388.74 |
| **C.D. @ 5%** | 6.38 | 0.63 | 3.64 | 0.37 | 0.42 | 5.56 | 32.10 | 2.33 | 65.41 | 65.41 |
| **SE(m)** | 2.23 | 0.22 | 1.27 | 0.13 | 0.15 | 1.95 | 11.23 | 0.82 | 22.87 | 22.87 |
| **SE(d)** | 3.16 | 0.31 | 1.80 | 0.18 | 0.21 | 2.75 | 15.88 | 1.15 | 32.34 | 32.34 |
| **C.V.** | 4.96 | 7.78 | 4.83 | 5.10 | 5.91 | 15.74 | 1.91 | 12.27 | 2.85 | 2.85 |

**Table 4: Range, mean, coefficient of variations, heritability and genetic advance as % of mean for 21 characters in tomato**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Characters** | **Mean** | **Range** | **Variance** | **Coefficient of variation** | **Heritability% (broad sense)** | **Genetic advance** |
| **Min** | **max** | **Genotypic** | **Phenotypic** | **Genotypic** | **Phenotypic** | **As *percent* of mean** |
| **Plant height (cm)** | 77.88 | 60.78 | 145.22 | 640.80 | 655.74 | 32.50 | 32.88 | 97.72 | 66.19 |
| **Number of branches per plant** | 4.87 | 3.89 | 7.00 | 0.76 | 0.90 | 17.86 | 19.48 | 84.06 | 33.74 |
| **Days to 50% flowering** | 45.62 | 36.67 | 56.33 | 27.94 | 32.78 | 11.59 | 12.55 | 85.22 | 22.03 |
| **Days to first picking** | 101.55 | 92.33 | 109.44 | 21.82 | 29.89 | 4.60 | 5.38 | 73.01 | 8.10 |
| **Days to last picking**  | 136.62 | 127.33 | 144.33 | 22.02 | 30.01 | 3.43 | 4.01 | 73.38 | 6.06 |
| **Polar diameter (cm)** | 4.34 | 3.36 | 6.76 | 0.85 | 0.90 | 21.20 | 21.81 | 94.53 | 42.45 |
| **Equatorial diameter (cm)** | 4.34 | 3.47 | 5.35 | 0.22 | 0.28 | 10.73 | 12.26 | 76.71 | 19.36 |
| **Pericarp thickness (mm)** | 5.33 | 3.24 | 7.44 | 1.11 | 1.16 | 19.76 | 20.23 | 95.42 | 40.10 |
| **Number of marketable fruit per plant** | 21.41 | 13.11 | 38.53 | 26.19 | 37.54 | 23.90 | 28.62 | 69.75 | 41.12 |
| **Weight of marketable fruits per plant (g)** | 1071.00 | 745.59 | 1356.70 | 19630.37 | 20007.92 | 13.08 | 13.21 | 98.11 | 28.11 |
| **Number of unmarketable fruits per plant** | 11.51 | 7.90 | 16.82 | 2.37 | 4.38 | 13.36 | 18.18 | 54.03 | 20.20 |
| **Weight of unmarketable fruits per plant (g)** | 371.74 | 226.11 | 660.34 | 9696.05 | 9770.21 | 26.49 | 26.59 | 99.24 | 54.36 |
| **Total number of fruits per plant** | 32.92 | 22.09 | 55.36 | 39.76 | 57.43 | 19.15 | 23.02 | 69.24 | 32.84 |
| **Yield of fruit per plant (g)** | 1388.74 | 981.33 | 1800.06 | 43928.62 | 45530.16 | 15.09 | 15.36 | 96.48 | 31.28 |
| **Yield of fruit per hectare (q)** | 462.91 | 327.11 | 600.01 | 4777.50 | 4923.07 | 14.93 | 15.16 | 97.04 | 30.30 |