GENETIC EVALUATION OF TOMATO (*Solanum lycopersicum* L.) GERMPLASM FOR YIELD AND QUALITY TRAITS

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis entitled, **"Genetic evaluation of tomato *(Solanum lycopersicum* L.*)* germplasm for yield and quality traits"** submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES** of Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173230 is a bonafide research work carried out by **Mr. Achal Kashyap (NH- 2017-22-M)** son of Shri Manjeet Kashyap under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

Place: Neri, Hamirpur
Dated:

(Dr Dharminder Kumar)
Chairman, Advisory Committee

CERTIFICATE-II

This is to certify that the thesis entitled, **"Genetic evaluation of tomato *(Solanum lycopersicum* L.) germplasm for yield and quality traits"** submitted by **Mr Achal Kashyap (NH-2017-22-M)** son of Shri Manjeet Kashyap to Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173230 India in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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When heart speaks in seclusion…

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Place: Neri, Hamirpur

Dated: **(Achal Kashyap)**

CONTENTS

ABBREVIATIONS

%	:	Per cent
^{o}C	:	Degree Celsius
CD	:	Critical Difference
HP	:	Himachal Pradesh
UHF	:	University of Horticulture and Forestry
COH&F	:	College of Horticulture and Forestry
cm	:	Centimeter
et al.	:	And co-worker/ and others
Fig	:	Figure
kg	:	Kilogram
ha	:	Hectare
i.e.	:	That is
m	:	Meter
RCBD	:	Randomized Complete Block Design
RH	:	Relative Humidity
mm	:	Milli Meter
/	:	Per
spp.	:	Species
TSS	:	Total Soluble Solids
viz.	:	Videlicet (namely)
ANNOVA	:	Analysis of Variance
CV	:	Coefficient of Variation
g	:	Gram
NHB	:	National Horticulture Board
SE	:	Standard Error
PCV	:	Phenotypic Coefficient of Variation
GCV	:	Genotypic Coefficient of Variation
pH	:	Pouvoir Hydrogen
ºB	:	ºBrix
=	:	Equal to
×	:	Multiplication
MT	:	Metric Tonnes

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Chapter-1

INTRODUCTION

Tomato is a very popular warm season vegetable crop grown worldwide because it has wider adaptation along with high yield potential and is suitable for fresh use as well as in processed form. It ranks second only after potato (Bose *et al*. 2002). It is designated as “Protective food” because of its nutritive value and presence of several antioxidants *viz.* carotenoids, particularly lycopene, ascorbic acid, vitamin E and phenol compounds, particularly flavonoids (Sepat *et al*. 2013). Lycopene is reported to possess dietetic properties as it reduces the risk of heart attacks and various types of cancers (Dorgan *et al*. 1998 and Clinton, 2005).

It belongs to Solanaceae family which has more than 3000 species with origins in both the Old and New World (Knapp, 2002). The classification of Solanaceae family has been recently revised and the genus *Lycopersicon* re-integrated into the *Solanum* genus. *Solanum* section *Lycopersicon* includes the cultivated tomato and 12 additional wild relatives. *Solanum lycopersicum* is the only domesticated species (Peralta *et al*. 2006).

It is native to tropical Central and South America, where it was cultivated in pre – Columbian times. Its wild proginator is thought to have been the cherry tomato, *Solanum lycopersicum* var. *cerasiforme*, which grows wild in the Peru – Ecuador area though tomatoes were probably domesticated from weedy forms which had spread as far as North Mexico (Cobley and Steele, 1976 and Purseglove, 1988). It is evident from the historical aspects that the popularity of tomato has increased rapidly from the middle of nineteenth century to the present time. It is also grown in green houses as an off-season vegetable crop. Therefore, it has become a good source of income to small and marginal farmers.

Tomato is herbaceous, annual to perennial, prostrate, day neutral and sexually propagated crop plant with bisexual flowers. There are four to eight flowers in each compound inflorescence. Tomato is mainly self-pollinated in nature but cross-pollination to certain extent also occurs (Rick, 1976). Apart from fruit characteristics, the plant habit of tomato separates them into two distinct groups, those that are determinate and indeterminate cultivars. Determinate cultivars reach a height of 1.0 to 1.2 m, at which stage the lead growth develops into a flower truss and similar things happen to all lateral branches. Indeterminate plants produce one or two stems, which grow on and on until they are stopped by removing the growing point. Indeterminate types usually have smaller fruits and reach maturity later. They bear fruits over a long period and are ideally suited to staking and pruning, both in open ground and in tunnels. They have much smaller pedicel scar than larger fruited sorts. They allow continuous production of high-quality fruits. The determinate types have a relatively concentrated fruit set which lasts only two or three weeks and the fruit ripen much faster than those from indeterminate types (Naika *et al*. 2005).

Tomatoes show a wild climatic tolerance and can be grown in the open wherever there is more than three months of frost-free weather. Tomato is more successful where there are long sunny periods. The optimum growing temperatures are 21 ºC to 24 ºC. At these temperatures good quality seeds will take about seven days to emerge. Temperature affects flowering and pollination. The hot and dry weather leads to drying of the flowers and stops pollination. If temperatures are below 15 ºC or above 29 ºC, pollen fails to release which results in incomplete fertilization of ovules. This causes collapsing of fruit walls and formation of deep indentation in the fruit, a phenomenon called catface (Peirce, 1987).

It is widely grown as an off-season vegetable in the hilly regions of Himachal Pradesh. The crop is becoming popular day by day among hill farmers due to its short duration, high market value and constant demand throughout the year on account of its popularity. Farmers fetch good income after sending their produce in the plains from June to September.

The longer harvesting period and off-season production of tomato make this crop more suitable for cultivation in mid-hills conditions. But tomato is grown in the Himachal Pradesh during rainy season, which invite many diseases, insect-pests and weeds, hence, poses serious problems in its cultivation. The productivity of tomato grown in the hilly regions is much lesser than its potential yield due to the non-availability high yielding disease and insect-pest resistant cultivar for growing in hilly areas.

In India, it is cultivated over an area of nearly 814 thousand ha with annual production of 20,515 thousand MT [Anonymous, 2018-19 (a)]. Madhya Pradesh, Andhra Pradesh, Karnataka, Odisha are the major producing states of tomato in India. It has the share of nearly 8.3% of total vegetable area and 10.3% of total vegetable production in India. Though, tomato is one of the major vegetables exported from India, per capita consumption in India is abysmally low (Srivastava *et al*. 2016). In the year 2014-15, an estimated 0.22 MT of tomato worth 44, 461.34 Lakh were exported from India.

Himachal Pradesh is a major off-season tomato growing state covering an area of 9.93 thousand hectare with an annual production of 4.13 lakh metric tonnes and productivity of 41.7 metric tonnes per hectares (Tiwari *et al*. 2014). The annual production of tomato in Himachal Pradesh is 489.36 thousand MT from an area of 11.08 thousand ha [Anonymous, 2016-17 (b)]. It is being grown as off-season vegetable, which brings profitable returns to the hilly farmers.

Considering the importance of this crop, there is an urgent need for development of new high yielding varieties/hybrids of tomato with good quality attributes. A complete knowledge pertaining to the amount of genetic variability existing for different traits is considered a prerequisite to start any crop improvement programme.

The phenotypic expression of a particular trait is mainly influenced by the genetic makeup of the plant and the environment, in which it is growing. Further, the genetic variance of any quantitative trait is comprised of additive and non-additive variance. Therefore, it become pertinent that observed phenotypic variability is sub-divided into its heritable and non-heritable components with the help of suitable parameters *viz.* coefficients of variation, heritability and genetic advance. Further, genetic advance can be used to predict the efficiency of selection.

Yield is a complex trait which is controlled by a large number of yield contributing traits and their interactions. Study of correlation between different quantitative traits reveals the interactions which are effective in formulating selection strategies to improve yield components. The selection programme becomes effective, when the relative magnitude of association of various traits with yield parameters is taken into consideration. The path coefficient technique developed by Wright in 1921 helps in estimating direct and indirect contribution of different component traits in building up the total correlation towards yield. Based on these studies the importance of individual trait is marked to facilitate the selection programme for better gains.

The F_1 hybrids are very popular in tomato and choice of appropriate parents for exploiting high heterosis is of utmost importance. Generally, diverse parents are supposed to yield higher hybrid vigour (Harrington, 1940). Hence, this necessitates the utilization of genetic divergence for identification of parents for hybridization programme. The information on genetic divergence is valuable for planning the future breeding programme. D^2 statistics developed by Mahalanobis (1936) helps to measure the magnitude of divergence among two genotypes to be compared. This technique has been applied in several crops to select genotypes for further breeding programmes. Grouping of genotypes based on D^2 analysis is useful for selection of suitable parental lines for heterosis breeding. This technique also helps in selection of suitable parents for hybridization and to choose desirable transgressive segregants in later segregating generations.

Therefore, the present investigation on "Genetic evaluation of tomato (*Solanum lycopersicum* L.) germplasm for yield and quality traits" was undertaken with the following objectives:

OBJECTIVES: -

1. To estimate the extent of genetic variability for yield and quality traits in different genotypes of tomato.

2. Determination of degree and direction of association of different horticultural traits with total marketable yield.

3. To assess the extent of genetic diversity in the available tomato germplasm.

Chapter-2

REVIEW OF LITERATURE

Vegetable breeding is mainly focused on the improvement of both qualitative and quantitative traits. The success of any vegetable breeding program depends on the extent and the magnitude of variability present in the available germplasm. Several studies have been made with regard to variability, character association and genetic divergence in tomato. A brief review of literature pertaining to present studies is presented under the following subheads:

2.1 Variability studies

2.2 Correlation and path coefficient analysis

2.3 Genetic divergence studies

2.1 Variability studies

Khanom *et al.* (2008) carried out a study on variability for yield and its contributing traits in 55 genotypes of tomato. High heritability coupled with high genetic advance was observed for the traits *viz.* number of fruits per plant, number of seeds per fruit, individual fruit weight and number of primary branches per plant.

Hazra *et al.* (2010) studied variability in 12 varieties of tomato and observed high heritability along with high genetic advance for average fruit weight and high heritability coupled with low genetic advance for rest of the traits except pericarp thickness.

Rocha *et al.* (2010) studied 40 accessions of organically grown cherry tomato and observed wide variations for colour, shape and number of locules per fruit. Fruit with different colours such as yellow, orange and brown were observed. The presence of fruits with two, three, four and even with seven locules was also detected.

Rani and Anitha (2011) assessed different genotypes of tomato and it was observed that PCV had higher values than GCV for most of the traits. GCV estimates were found high for average fruit weight, number of fruits per plant and yield per plant. Heritability estimates were high for average fruit weight, number of fruits per plant, plant height and number of branches per plant.

Tasisa *et al.* (2011) assessed 23 tomato genotypes and reported significant genotypic variations among all the genotypes for all the traits studied. The phenotypic and genotypic coefficients of variation for number of fruits per plant, number of flowers per cluster, unmarketable fruit yield per plot, number of fruit clusters per plant and plant height were observed.

Vyas *et al.* (2011) observed high genotypic and phenotypic coefficient of variation for different horticultural traits in 20 genotypes of tomato. The high heritability was found for most of the traits.

Kumar *et al.* (2012) reported 13 genotypes of tomato including their 30 crosses along with two checks and reported that the maximum variation (G and P) for plant height and minimum for fruit shape index. Further, magnitude of PCV was found higher than GCV for maximum traits. The magnitude of GCV and PCV was recorded high for number of fruits per cluster.

Shankar *et al.* (2013) found high estimates of PCV and GCV for number of fruits per cluster, average fruit weight, plant height and yield per plant for different germplasm of tomato. The characters like number of fruits per cluster, fruit length, average fruit weight, number of primary branches per plant, plant height, pericarp thickness, number of locules per fruit and shelf life reported high heritability assisted with high genetic advance.

Kumar *et al.* (2013) assessed 26 genotypes of tomato and found that the genotype 'EC- 357838' recorded maximum values for total soluble solids, number of fruits per plant and yield per plant. Genetic variability and heritability estimates with high genetic gain, were observed for number of fruits per plant, plant height, yield per plant and fruit weight. Similarly, Chernet *et al.* (2013) evaluated 36 genotypes of tomato and observed highest heritability for number of matured fruits per plant and the minimum was observed for number of primary branches.

Patel *et al.* (2013) observed significant variations for different horticultural traits in 13 tomato genotypes. Lowest PCV was reported for fruit yield per plant and number of locules and for fruit yield per plant highest GCV was recorded. At the same time Ahirwar *et al.* (2013) carried out a study in 19 tomato genotypes and observed significant difference among different genotypes for all the horticultural traits. The PCV was found higher than GCV for all the traits under study.

Reddy *et al.* (2013a) evaluated 19 genotypes of tomato for different horticultural traits and observed that the PCV was higher than GCV for all the traits under study. High heritability along with high genetic advance was recorded for maximum traits.

Khapte and Jansirani (2014a) studied different genotypes of tomato and observed high estimates of heritability for yield contributing traits. In another study Sherpa *et al*. (2014) conducted experiment on 17 exotic collections of tomato and observed high heritability coupled with high genetic advance for various traits *viz.* number of fruits and flowers per cluster, number of fruits per plant, fruit weight, pericarp thickness, plant height, polar diameter, TSS and fruit yield per plant.

Prajapati *et al.* (2015) evaluated 39 genotypes/collections of tomato and observed high heritability estimates for different characters *viz.* average fruit weight and number of secondary branches. High GG was recorded for average fruit weight and lowest was observed for days to 50 per cent fruit setting.

Solanki and Patel (2016) assessed the variability in 25 genotypes of tomato. The GCV, PCV, heritability and genetic advance were observed high for number of branches per plant at final harvest trailed by plant height at final harvest, pericarp thickness, ascorbic acid, lycopene, average fruit weight, number of fruits per plant and fruit yield per plant.

Genetic variability was estimated by Rai *et al.* (2016) among 56 genotypes of tomato and they observed that estimates of PCV were higher than the GCV as well as magnitude of heritability and genetic gain was also recorded high for maximum traits and suggested direct selection for identifying high yielding genotypes in tomato.

Bhandari *et al.* (2017) observed significant genotypic difference for all the traits studied and fruit yield per plant recorded the maximum heritability. Similarly, Ligade *et al.* (2017) conducted variability studies in 20 genotypes of tomato and data were recorded on different yield and its contributing traits. High estimates of GCV and PCV were observed for most of the horticultural traits. Also high heritability coupled with high genetic advance was noticed for the traits *viz.* plant height, number of flowers and fruit per cluster, average fruit weight, number of fruits per plant, fruit yield per plant, fruit yield, fruit shape index, TSS, pericarp thickness, number of locules per fruit which indicated the existence of additive gene action and there by improvement for these traits can be made by selection.

Singh *et al.* (2017a) evaluated 35 genotypes of tomato for different horticultural traits. High heritability coupled with high genetic advance was observed for maximum traits indicating opportunity for selection response.

Patel *et al.* (2017) evaluated 24 genotypes of tomato to study the variability among the yield and yield attributing traits. For various characters higher PCV as well as high heritability with high genetic advance was reported.

Meena *et al.* (2018) assessed genetic variability for yield and quality attributes in 15 different genotypes of tomato. The maximum phenotypic and genotypic variance, genetic advance was recorded for average fruit weight.

Bajpai *et al.* (2018) evaluated 46 genotypes to assess the extent of variability in tomato germplasm. The high estimates of PCV as well as GCV were observed for plant height and number of locules per fruit. High heritability along with high genetic gain was observed for number of fruits per plant, number of locules per fruit, fruit circumference, primary branches per plant and plant height.

Das *et al*. (2018) conduct an experiment in 30 genotypes of tomato and observed high PCV and GCV for acidity content, ascorbic acid, plant height and fruits per plant. The high heritability along with genetic gain was reported in case of number of fruits per plant followed by acidity and lycopene content.

Kumar *et al*. (2018a) studied genetic variability in 30 genotypes including 3 check varieties and observed highest PCV in locules per plant followed by average pericarp thickness, plant height, primary branches per plant, diameter of fruit and TSS. Heritability was recorded high for diameter of fruit followed by primary branches per plant, pericarp thickness, number of locules, fruit length and TSS.

Kumar *et al.* (2018b) carried out an experiment in 43 genotypes to assess the extent of genetic variability. PCV estimates were found higher than the GCV for all the characters studied. High heritability along with high genetic advance was observed for plant height, total number of fruits per plant, total fruit yield per plant, early fruit yield per plant and total soluble solids.

Saravanan *et al.* (2018) studied genetic variability in 18 genotypes of tomato and revealed that the phenotypic variation was high as compared to genotypic variation for all the traits. High PCV, GCV and genetic advance was observed for yield per plant, number of fruits per plant and number of locules per fruit.

Badhani *et al.* (2019) assessed 30 genotypes/cultivars of tomato for yield and quality traits. High heritability coupled with high genetic gain was observed for marketable fruit yield, lycopene content and buckeye rot incidence.

Yadav *et al*. (2019) evaluated 47 genotypes with 3 check varieties of tomato in respect of genetic variability, heritability and genetic advance for 12 horticultural traits. High value of GCV was recorded for number of fruits per plant, unmarketable and unmarketable fruit yield per plant, average fruit weight. For number of fruits per plant high heritability and genetic advance as percent of mean was observed.

2.2 Correlation and path-coefficient analysis

Rani *et al.* (2010) estimated correlation coefficients among different horticultural traits using 23 hybrids of tomato and found that fruit weight, pericarp thickness, acidity, ascorbic acid and lycopene had significantly positive correlation with yield per plant. Fruit weight showed highest positive direct effect on yield per plant, whereas number of fruits was having high positive indirect effect on yield per plant as revealed by path analysis.

Dar *et al.* (2011) evaluated 60 germplasm lines of tomato and reported that yield had positive association with lycopene content, total soluble solids, pericarp thickness, number of locules per fruit, number of fruits per plant, fruit yield per plant and average fruit weight. Path coefficient analysis revealed that fruit yield per plant had highest positive direct effect on yield per hectare, followed by average fruit weight and number of locules per fruit.

Tiwari and Upadhyay (2011) estimated correlation and path coefficient analysis in the 19 genotypes along with two checks of tomato revealed that fruit weight had highest significant correlation and direct effect on fruit yield per plant.

Al Aysh *et al.* (2012) evaluated 14 landraces of tomato and observed that average fruit weight and harvest index had significantly positive correlation with fruit yield per plant both at phenotypic and genotypic level. Highest positive direct effect on fruit yield per plant was observed via number of fruits per plant and harvest index.

According to Madhurina and Paul (2012) in tomato cultivars, fruit yield per plant had positive correlation with fruit length, fruit weight, pericarp thickness and number of fruits per plant. In path coefficient analysis fruit breadth and total acid content had significantly negative effect on the fruit yield in tomato.

Khan and Samadia (2012) studied 12 traits in 23 genotypes of tomato for correlation studies which revealed that fruit weight, fruit length, fruit diameter and number of fruits per plant had significant positive correlation with fruit yield both at the genotypic and phenotypic levels. On the other hand, negative correlation of days to flowering and days to first harvest was observed on yield per plant.

Sharma and Singh (2012) reported positive correlation of fruit yield with fruit weight per plant and days to 50 per cent flowering whereas, number of fruits per plant and flower clusters per plant had maximum direct effect on fruit weight per plant as per path analysis of 120 tomato cultivars.

Kumar *et al.* (2013a) evaluated 13 genotypes along with two checks of tomato and observed maximum PCV and GCV for plant height. Experimental results also revealed that magnitude of PCV was higher as compared to GCV for all the traits except number of primary branches per plant.

Rahaman and Bhatt (2013) assessed 34 genotypes of tomato and reported that number of pickings and number of fruits per plant had positive genotypic and phenotypic correlation with fruit weight. Based on the mean performance, 14 genotypes were identified for multi-location yield trials.

Reddy *et al.* (2013b) studied correlation and path analysis in 19 genotypes of tomato for different yield and quality traits. They observed that number of fruits per plant and fruit width had significantly positive correlation with fruit yield per plant. Path analysis studies revealed that fruit yield per plant is directly affected in positive direction by fruit length and width, number of fruits per plant, plant height and ascorbic acid content.

Kumar *et al.* (2013b) assessed 26 genotypes of tomato and reported significantly positive association of number of fruits per plant and number of fruits per cluster with fruit yield.

Meena and Bahadur (2014) observed that fruit yield per plant was positively associated with number of fruits per plant, fruit weight and polar diameter of fruit. Further, path coefficient analysis depicted that fruit weight had highest positive direct effect on fruit yield per plant.

Rahman *et al.* (2015) evaluated 48 genotypes of tomato, results depicted that number of fruits per cluster had non-significant positive association with yield per plant whereas, path analysis showed that number of fruits per cluster had the highest positive direct effect on fruit yield per plant.

Singh *et al.* (2017b) conducted an experiment to identify the potential genotypes of tomato with high productivity and good quality. The most imperative economic character, fruit yield per plant exhibited significantly high and positive phenotypic correlation with number of fruits per plant which was followed by average fruit weight and number of primary branches per plant. Path coefficient analysis revealed appreciable amount of direct positive effect of number of fruits per plant followed by average fruit weight, fruit yield per plant. On the other hand, positive indirect effect by number of fruits per plant and average fruit weight on fruits yield per plant was exerted via primary branches per plant.

Naveen *et al.* (2017) reported in 30 tomato genotypes that fruit yield had positive and significant correlation with plant height, average fruit weight and fruit yield per hectare. Maximum yield contributing traits exhibited positive direct effects on fruit yield as reported in path analysis.

Das *et al.* (2017) studied correlation and observed that number of flower clusters per plant, number of flowers and fruits per cluster and number of fruits per plant had positive significant correlation with fruit yield per plant.

Rawat *et al.* (2017) studied path coefficient analysis of 14 yield quantitative traits in 59 genotypes of tomato and found that fruit yield was positively correlated with number of fruits per plant.

Singh *et al.* (2018) conducted trials on 7 parents including one hybrid check (BSS-488) for yield and quality contributing traits of tomato. Fruit yield per plant showed positive correlation with average fruit weight. The path coefficient analysis revealed a very high positive direct effect of average fruit weight on fruit yield per plant.

Rojalin *et al.* (2018) evaluated 18 genotypes to study the correlation and path coefficient analysis in determinate tomato for fruit yield and yield attributes. Correlation studies showed that marketable fruit yield per plant was positive and significantly correlated with plant height and primary branches per plant at both genotypic and phenotypic level. Path analysis revealed that traits like average fruit weight, number of locules, fruit length, % of fruit set, flowers per cluster, days to fruit set, fruits per plant, primary branches per plant and plant height at final harvest had positive direct effect on marketable fruit yield per plant.

Anuradha *et al.* (2018) studied the correlation and path coefficient analysis in 40 genotypes of tomato and observed high significant positive correlations with fruit yield per plant, average fruit weight, yield per hectare, beta carotene and lycopene. Positive direct effects on fruit yield were observed due to number of fruits per plant and average fruit weight.

Namdev and Dongre (2018) assess 33 genotypes for correlation and path analysis in tomato and revealed positive association of fruit yield per plant with number of plant height, fruit per plant, fruit yield per hectare and fruit yield per plot. Path analysis showed that number of fruits per cluster, fruit yield per hectare, days to 50% flowering, plant height and number of fruits per plant had positive direct effect for fruit yield.

Roy *et al.* (2018) evaluated 23 genotypes for association of fruit yield and yield contributing traits in tomato. Correlation analysis revealed that the genotypic correlation coefficient was higher than phenotypic one and average yield per plant showed highest positive association with flower per plant and lowest association with plant height.

Kumar and Singh (2018) studied correlation and path analysis in 28 genotypes of tomato. Correlation studies revealed that various fruit and yield parameters were positive correlated with fruit yield per plant.

2.3 Genetic divergence studies

Prashanth *et al.* (2008) studied 67 tomato genotypes to know the value and magnitude of genetic divergence using Mahalanobis D^2 statistics. A wide genetic diversity was observed among the genotypes and was grouped into seven clusters. The maximum inter cluster distance was observed between cluster V and VI, cluster IV and VII, cluster VI and VII and cluster V and VII.

Shashikanth *et al.* (2010) studied 30 tomato genotypes and Mahalanobis D^2 statistics helped in grouping the 30 genotypes into 10 diverse clusters. The composition of clusters of heterogenous geographic origin indicated that the strains were distributed among the different clusters randomly irrespective of their geographical origin. This indicated that there was no parallelism between genetic diversity and geographical divergence in tomato.

Sharma *et al.* (2011) evaluated 126 genotypes of tomato and formed 10 groups or clusters of the exotic gene pool. Cluster I accommodated 20 genotypes, followed by cluster II accommodating 18 genotypes. Cluster III and IV, V and VI and VII and VIII had equal number of genotypes i.e., 16, 12 and 11 respectively. Cluster X contained only 3 genotypes. Cluster V had genotypes with desirable features of higher average fruit weight, more pericarp thickness and more locules per fruit. Cluster III followed the cluster V in economical features. Based on genetic distance, clusters V and X and VIII and X were more diverse.

Pathak and Kumar (2011) studied genetic divergence among 6 varieties of tomato. Genetic distances were measured following D^2 statistics and grouped into three distinct constellations. The inter and intra-constellation distance represents the index of genetic diversity among the constellations. The constellation II showed the highest divergence from constellation III.

Narolia and Reddy (2012) studied 55 genotypes of tomato and based on D^2 values of 13 characters, genotypes were grouped into 12 highly divergent clusters. Out of that eight clusters viz., III, VI, VII, VIII, IX, X, XI and XII were solitary with one genotype in each cluster and the remaining four clusters were having maximum number of genotypes. Cluster II was biggest with 20 genotypes followed by cluster I (14 genotypes), while the other two clusters IV and V comprised six and seven genotypes, respectively. The maximum genetic divergence was observed between clusters IX and XII followed by between clusters V and IX. The maximum intra-cluster distance was shown by cluster V.

Mulge *et al.* (2012) evaluated 67 genotypes of tomato collected from different sources and lines developed through pedigree method of breeding and grouped these genotypes into 7 clusters where, maximum of 44 genotypes entered in cluster I, followed by 11 genotypes in cluster II, 7 genotypes in cluster IV, two genotypes in cluster III and the clusters V, VI and VII had solitary genotype each.

Kumar *et al.* (2013c) conducted study on 40 genotypes of tomato and observed wide genetic diversity among the genotypes which were grouped into 4 clusters based on 14 important characters. The cluster III was the largest containing 17 genotypes followed by cluster I with 11 genotypes. The clustering pattern indicated that the geographic distribution need not necessarily be related to genetic diversity. The maximum inter-cluster distance was observed between cluster III and IV.

Khapte and Jansirani (2014b) conducted a study on genetic diversity in 24 tomato genotypes. The genotypes were grouped into eight clusters based on yield contributing traits. Cluster VI contained maximum number of genotypes followed by cluster V and VII having three genotypes each and remaining clusters were having two genotypes each. The highest inter cluster distance was observed between cluster V and VIII, followed by cluster V and VII and cluster III and V, revealing that the enormous diversity between genotypes belonging to respective pairs of the clusters. The genotypes from clusters V and VI having oblong fruits with thick pericarp, high fruit firmness and high yielding.

Nalla *et al.* (2014) conducted an experiment to study the genetic diversity for quantitative and qualitative traits in 27 genotypes of tomato by using Mahalanobis D^2 statistics. The maximum inter cluster distance was recorded within cluster III and the maximum inter cluster distance between cluster VI and VII.

Srivastava *et al.* (2014) evaluated 30 genotypes of tomato to study the genetic diversity for yield and quality traits. Maximum inter cluster distance was observed between cluster IV and X. The maximum contribution towards divergence was showed by plant height, seed index, yield per plant, fruits per plant, juice pulp ratio, pericarp thickness and flowers per cluster.

Dar *et al*. (2015) evaluated 60 genotypes which were grouped into 20 clusters. The maximum inter cluster D^2 values were between clusters XII and XX, followed by clusters XI and XX, clusters VII and XX and clusters XV and XX.

Singh *et al.* (2016) evaluated 35 genotypes of tomato for the extent of diversity for utilization in breeding program. The data recorded on 13 quantitative characters were subjected to analysis of variance revealed significant differences. D^2 analysis was conducted to measure the genetic diversity among the genotypes. High genetic divergence was observed among Cluster III, Cluster II (Maximum intra-cluster distance) and cluster V and VI followed by IV and V (Maximum inter-cluster distance) among genotypes of these groups. The genotypes of cluster IV and cluster V constitute high cluster mean for different traits along with fruit yield per plant.

Kumar *et al.* (2016) evaluated 40 genotypes which were grouped into seven clusters. Cluster II had maximum of 24 genotypes followed by cluster I and VII. The maximum inter cluster distance was observed in cluster VII followed by cluster IV.

Spaldon and Kumar (2017) conducted an experiment in 25 genotypes of tomato to study genetic diversity and these genotypes were grouped into six divergent clusters. Among the six clusters, cluster VI was the largest, comprising of nine genotypes followed by cluster I, cluster II and cluster IV with four genotypes in each cluster whereas cluster III and cluster V consisted of two genotypes each. The clustering pattern did not show any relationship between genetic diversity and geographic diversity. The intra and inter cluster D^2 values among 25 genotypes revealed that maximum intra-cluster D^2 value was recorded in cluster III whereas, cluster III, cluster IV and cluster V showed minimum intra-cluster D^2 value followed by cluster I and cluster II indicated that genotypes included in this cluster are very diverse and was due to both natural and artificial selection forces among the genotypes.

Mishra *et al.* (2018) evaluated 55 genotypes to assess the genetic divergence using Mahalanobis D^2 statistics. Cluster V had maximum of 11 genotypes followed by cluster I. The maximum inter cluster distance was between cluster XIII and XVII followed by cluster XI and cluster XVII.

Babu *et al.* (2018) evaluated 60 tomato genotypes to study the genetic diversity and these genotypes were grouped into eight cluster. Genetic diversity studied for twenty attributes revealed that average fruit weight contributed maximum towards divergence. Highest inter cluster distance was between cluster V and VII, while the lowest was between cluster I and VI.

Badhani *et al.* (2019) conducted an experiment in 30 genotypes in tomato to study the genetic diversity for yield and quality traits and genotypes were grouped into four clusters. Cluster IV had maximum genotypes followed by cluster III, cluster II and cluster I. Highest inter cluster distance was obtained between cluster I and III.

Bajpai *et al.* (2019) evaluated 46 genotypes of tomato to study the genetic divergence using Mahalanobis D^2 analysis. Genotypes were grouped into seven clusters and maximum genotypes were contained in cluster VI. The maximum intra and inter was recorded in cluster V and between cluster II and VII.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled "**Genetic Evaluation of Tomato (*Solanum lycoersicum* L.) Germplasm for Yield and Quality Traits"** was carried out during 2018 at Regional Horticultural Research and Training Station, Dr YS Parmar University of Horticulture and Forestry, Jachh (Nurpur), District-Kangra, Himachal Pradesh. The details of experiment materials used and procedures followed during the course of investigation have been described below:

3.1 SITE OF EXPERIMENT

3.1.1 Location

The Regional Horticultural Research Station, Jachh is situated on Pathankot-Mandi National Highway (NH-22) at an altitude of 428 m above mean sea level, lying between $32^{0}16^{'}54.02''$ N latitude and $75^{0}51^{'}4.38''$ E longitude under sub-mountain and low hill sub-tropical agro-climatic zone of Himachal Pradesh, India.

3.1.2 Climate

The climate of Jassur area is subtropical. The summers here have a good deal of rainfall, whereas the winters have very little. The summer and winter temperature averages at 29.30 ºC and 13.60 ºC, respectively. The mean annual rainfall received by the area is 1500 mm.

3.1.3 Soil

The soil structure of the experimental farm is sandy loam to clay loam with the pH ranging from 6.8-7.0.

3.2 EXPERIMENTAL MATERIAL

Experimental material comprised of 25 diverse genotypes of tomato comprising of 11 varieties, 10 exotic lines while 3 local collections along with one standard check Solan Lalima for conducting the present investigation. The complete lists of genotypes along with their source of collection have been presented in Table 3.1.

Table 3.1 List of different genotypes of tomato and their source of collection.

Sr. No.	Genotype	Source
1	EC-802554	AVRDC, Taiwan
2	EC-802555	AVRDC, Taiwan
3	EC-802556	AVRDC, Taiwan
4	EC-802557	AVRDC, Taiwan
5	EC-802558	AVRDC, Taiwan
6	EC-802559	AVRDC, Taiwan
7	EC-802560	AVRDC, Taiwan
8	EC-802561	AVRDC, Taiwan
9	EC-802562	AVRDC, Taiwan
10	EC-802563	AVRDC, Taiwan
11	Pusa Ruby	IARI, New Delhi
12	Pusa Uphar	IARI, New Delhi
13	Pusa Sadabahr	IARI, New Delhi
14	Pusa-120	IARI, New Delhi
15	Pusa Sheetal	IARI, New Delhi
16	Pusa Rohini	IARI, New Delhi
17	Arka Alok	IIHR, Banglore
18	Arka Abha	IIHR, Banglore
19	Arka Vikas	IIHR, Banglore
20	Punjab Chhuhara	PAU, Ludhiana
21	Pant T-3	GBPUAT, Pantnagar
22	LC-1	Bilaspur
23	LC-2	Solan
24	LC-3	Jachh
25	Solan Lalima (Check)	UHF, Nauni

3.3 SEED SOWING AND RAISING IN NURSERY

The seed sowing of all the genotypes were carried out during March, 2018 in raised nursery bed. Recommended cultural practices were followed for raising the healthy nursery.

3.4 EXPERIMENT DESIGN AND LAYOUT

The experiment was laid out in the Randomized Complete Block Design (RCBD) with three replications during April, 2018. The details of experimental layout are given below:

Design	:	Randomized Complete Block Design (RCBD)
Replication (s)	:	3
Genotypes	:	25 (Including one check cultivar).
Plot size	:	1.8 m x 1.8 m
Spacing	:	60 cm x 45 cm
Planting Year	:	Summer, 2018

3.5 OBSERVATIONS RECORDED

3.5.1 Growth and fruit yield characteristics

3.5.1.1 Days to first fruit harvesting (number)

Data on the days to first fruit harvesting in number was recorded from the date of transplanting to the date of first fruit harvest of fruits at breaker stage or turning stage.

3.5.1.2 Plant height (cm)

Plant height was measured in cm from the soil base to the top of the plant at last harvest of fruits.

3.5.1.3 Fruit length (cm)

Length was measured in cm from the base of calyx to tip of fruit using measuring scale.

3.5.1.4 Fruit breadth (cm)

Fruit breadth was measured by using Digital Vernier Calliper at the widest point of fruit.

3.5.1.5 Average fruit weight (g)

Total weight of fruits from five randomly selected plants at every picking will be recorded and was divided by total number of fruits of all the harvests to compute the mean fruit weight in grams.

3.5.1.6 Number of fruit clusters per plant

Total number of fruit clusters harvested from each selected plant was counted to work out the mean value.

3.5.1.7 Number of fruits per cluster

Numbers of fruits in each cluster of five plants were counted to work out mean number of fruits per cluster in each entry.

3.5.1.8 Number of fruits per plant

The marketable fruits harvested from randomly taken plants were counted and summed up at each harvest and were averaged to obtain numbers of fruit per plant.

3.5.1.9 Number of locules per fruit

Ten fruits were selected randomly and each fruit was cut transversely into two halves to count the number of locules and then average values were worked out.

3.5.1.10 Harvest duration (days)

Numbers of days were counted between first picking to final harvest of marketable fruits in each entry to record the data on harvest duration.

3.5.1.11 Marketable fruit yield per plant (kg) & per hectare (q)

The pickings were made at half ripe stage or breaker stage for recording fruit yield per plant. Fruit yield was recorded at every picking in grams and added up for all the pickings to arrive at the total yield per plant. The total yield per plant was multiplied with total number of plants accommodated per hectare to obtain yield per hectare.

3.5.2 Fruit quality characteristics

3.5.2.1 Shelf life (days)

Shelf life of fruits were estimated by keeping the fruits at ambient room temperature conditions till they shrunk and become unfit for consumption.

3.5.2.2 Pericarp thickness (mm)

Pericarp thickness of five randomly taken fruits of second harvest in each entry was measured after cutting the fruits transversely. Measurement was done with Digital Vernier Callipper in millimeters and mean value was worked out.

3.5.2.3 Total soluble solids (^{o}Brix):-

The ripe fruits were crushed and their juice passed through a double layer of fine mesh cheese cloth. Further, a drop of juice was placed on the plate of Hand Refractometer and the reading was noted. A mean of five readings was taken in every replication in each entry.

3.5.3 Incidence/severity of economically important insect-pests and diseases

The incidence of buckeye rot under natural epiphytotic conditions in each genotype was recorded periodically by using the following formula:

$$(\%)\ \text{Disease incidence} = \frac{\text{Number of diseased fruits per plant}}{\text{Total number of fruits per plant}} \times 100$$

The disease reaction was categorized as per the scale given by Dodan, 1995.

Scale/grade	Disease incidence (%)	Reaction
1.	Nil	Resistant
2.	0.1-10.0	Moderately Resistant (MR)
3.	10.1-25.0	Moderately Susceptible (MS)
4.	25.1-45.0	Susceptible (S)
5.	45.1 and above	Highly Susceptible (HS)

3.6 STATISTICAL ANALYSIS

The following statistical analysis was subjected to the mean of the various observations to draw conclusions from the present investigation. For each observed character, the statistical analysis was performed by using MS-Excel, OPSTAT and SPAR 1.0 packages.

3.6.1 Analysis of variance (ANOVA)

The statistical analysis for all the characters studied was done by the method recommended by Gomez and Gomez (1983) for Randomized Complete Block Design (RCBD) for adopted:

Source of Variation	Degree of Freedom	Sum of Square	Mean Sum of Square	Variation Ratio
Replication (r)	r-1	Sr	$Mr = \frac{Sr}{r-1}$	$\frac{Mr}{Me}$
Genotypes (g)	g-1	Sg	$Mg = \frac{St}{g-1}$	$\frac{Mg}{Me}$
Error (e)	(r-1) (g-1)	Se	$Me = \frac{Se}{(r-1)(g-1)}$	

Where,

r = Number of replications

g = Number of genotypes

Sr = Sum of squares due to replications

Sg = Sum of squares due to genotypes

Se = Sum of squares due to error

Mr = Mean sum of squares due to replications

Mg = Mean sum of squares due to genotypes

Me = Mean sum of square due to error

The calculated ‘F’ values were compared with tabulated ‘F’ value for test of significance. Standard Error (SE), Critical Difference (CD) and Coefficient of Variation (CV) were calculated to find out the superiority of one genotype over the others with the help of following formulae:

SE (m) ± = $\sqrt{\frac{Me}{r}}$

SE (d) ± = $\sqrt{\frac{2Me}{r}}$

$CD_{0.05}$ = S.E. (d) x t $_{(0.05)}$ (r-1) (g-1) df

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference

$CD_{0.05}$ = Critical difference at 5 per cent level of significance

All the characters which showed significant differences among genotypes were further subjected to analysis for the following parameters.

- Coefficients of variability (phenotypic and genotypic)
- Heritability
- Genetic advance
- Genetic gain
- Correlation coefficients
- Path coefficient analysis
- Genetic divergence

3.6.2 Parameters of variability

Variability for different characters was estimated as suggested by Burton and De-Vane (1953). The coefficient of variability at genotypic (GCV) and phenotypic (PCV) levels were estimated as follows:

A) Genotypic Coefficient of Variability (GCV)

$$\text{GCV (\%)} = \frac{\sqrt{\text{Genotypic Variance (Vg)}}}{\text{General Mean of population } (\mu)} \times 100$$

B) Phenotypic Coefficient of Variability (PCV)

$$\text{PCV (\%)} = \frac{\sqrt{\text{Phenotypic Variance (Vp)}}}{\text{General Mean of population } (\mu)} \times 100$$

Where,

Ve = Me

Vg = Genotypic Variance (Mt-Me)/r

Vp= Phenotypic Variance (Vg+Ve)

PCV and GCV were classified as shown below (Cherian, 2000)

Less than 10 %	=	Low
10-20 %	=	Moderate
More than 20 %	=	High

3.6.3 Heritability:

Heritability in broad sense was estimated as per the formulae suggested by Allard (1960).

$$H (\%) = \frac{Vg}{Vp} \times 100$$

Where,

H	=	Heritability (%)
Vg	=	Genotypic variance, [$V_g = (M_t – M_e) / r$]
Vp	=	Phenotypic variance ($V_g + V_e$)

The heritability was categorised as suggested by Johnson *et al.* (1955):

0-30%	=	Low
31-60%	=	Medium
61% and above	=	High

3.6.4 Genetic advance

The expected genetic advance (GA) resulting from selection of five percent superior individuals was calculated as per Allard (1960).

GA = H x rp x K

Where,

H	=	Heritability (%)
rp	=	Phenotypic standard deviation
K	=	Selection differential at 5% selection intensity K = 2.06

3.6.5 Genetic gain

Genetic gain expressed as per cent ratio of genetic advance and population mean was calculated by the method given by Johnson *et al*. (1955).

GG = (GA/GM) x 100

Where,

GG = Genetic gain

GA = Genetic advance

GM = Population mean

The genetic advance as per cent over mean was categorized as mentioned below (Johnson *et al.*, 1955):

Less than 10%	= Low
10-20%	= Moderate
More than 20 %	= High

3.6.6 Correlations

The genotypic and phenotypic correlations were calculated as per Al-Jibouri *et al.* (1958) by using analysis of variance and covariance matrix in which total variability split into replications, genotypes and errors. All the components of variance were estimated from the analysis of covariance as given below:

3.6.6.1 Analysis of variance and co variance

Source of variance	**Degree of freedom**	**Mean sum of squares**		**Mean sum of products**	**Variance**
		X	**Y**		
Replications (r)	r-1				
Genotypes (g)	g-1	Mg X	Mg Y	Mg XY = MP_1	MP_1/MP_2
Error (e)	(r-1) (g-1)	Me X	Me Y	Me XY = MP_2	

Genotypic, phenotypic and environmental covariances between X and Y characters were worked out as under:

Ve XY = MP_2

Vg XY = $(MP_1-MP_2) / r$

Vp XY = Vg XY + Ve XY

Where

Ve XY = Environmental covariance between X and Y

Vg XY = Genetic covariance between X and Y

Vp XY = Phenotypic covariance between X and Y

3.6.6.2 Coefficients of correlations

a) Genotypic correlation coefficient between X and Y.

$$r_g = \frac{\text{Vg XY}}{\sqrt{\text{Vg X Vg Y}}}$$

Where,

Vg XY	=	Genotypic covariance between X and Y
Vg X	=	Genotypic variance of X
Vg Y	=	Genotypic variance of Y

b) Phenotypic correlation coefficient between X and Y

$$r_p = \frac{\text{Vp XY}}{\sqrt{\text{Vp X Vp Y}}}$$

Where,

Vp XY	=	Phenotypic covariance between X and Y
Vp X	=	Phenotypic variance of X
Vp Y	=	Phenotypic variance of Y
Genotypic variance (Vg)	=	(Mg - Me) / r
Phenotypic variance (Vp)	=	(Vg + Ve)

The calculated correlation coefficients (r) values were compared with ‘r’ tabulated values as given by Fisher and Yates (1963) at (n-2) degrees of freedom to test their significance, where ‘n’ denotes number of genotypes. If calculated ‘r’ value at 5 per cent level of significance was greater than tabulated value of ‘r’, the correlation was said to be significant.

3.6.7 Path Coefficients of analysis

The coefficients genotypic and phenotypic correlations were used to determine their direct and indirect contribution towards marketable fruit yield per plant.

The direct and indirect paths were obtained by following Dewey and Lu (1959). The path coefficients were obtained by simultaneous selection of the following equations, which expresses the basic relationship between genotypic correlation ‘r’ and path coefficients (P):

r_{14} : $P_{14} + P_{24} r_{12} + P_{34} r_{13}$

r_{24} : $P_{14} r_{21} + P_{24} + P_{34} r_{23}$

r_{34} : $P_{14} r_{31} + P_{24} r_{32} + P_{34}$

Where,

r_{14}, r_{24} and r_{34} are genotypic correlations of component characters with marketable fruit yield per plant (dependent variable) and r_{12}, r_{13} and r_{23} are the genotypic correlations among component characters (independent variables).

The direct effects were calculated by the following set of equations:

P_{14} = $C_{11}\ r_{14} + C_{12}\ r_{24} + C_{13} r_{34}$

P_{24} = $C_{21}\ r_{14} + C_{22}\ r_{24} + C_{23}\ r_{34}$

P_{34} = $C_{31}\ r_{14} + C_{32}\ r_{24} + C_{33r}\ r_{34}$

Where,

C_{11}, C_{22}, C_{23} and C_{33} are constants derived by using abbreviated Doulittle's technique as explained by Goulden (1959).

$r_{12}\ P_{24}$, $r_{13}\ P_{34}$, $r_{21}\ P_{14}$, $r_{23}\ P_{34}$, $r_{31}\ P_{14}$, $r_{32}\ P_{24}$ are indirect effects.

3.6.7.1 Residual effect

The variation in the dependent variable which remained undetermined by including all the variables was assumed to be due to variable (s) not included in the present investigation. The degree of determination of such variable (s) on dependent variable was calculated as follows:

$$1 = P^2x4 + P14^2 + P_{24}{}^2 + P_{34}{}^2 + 2P14\ r12\ P24 + 2P14\ r13\ P34 + 2P24\ r23\ P34$$

3.6.8 Genetic divergence

The genetic divergence in 25 genotypes was estimated by Mahalanobis 'D^2' statistics (generalized distance as suggested by (Rao, 1952) and canonical variate analysis. The calculation of D^2 values involved following steps (Murty and Arunachalam, 1967).

1. A set of uncorrelated linear combinations (Y's) was obtained by pivotal condensation of the common dispersion matrix (Rao, 1952) of a set of correlated variable (X's) and this matrix was arranged with the help of error mean sum of square and sum of products.
2. Using the relationship between Y's and X's the mean value of different genotypes for different characters (X_1 to X_{16}) were transformed into the mean values of asset of uncorrelated linear combinations (Y_1- Y_{16}).
3. The D^2 values between i^{th} and j^{th} genotypes for P^{th} characters was calculated as under:

$$D^2ij = \sum_{i=1}^{k}(Yit - Yjt)^2$$

Where,

Yit	=	uncorrelated mean value of i^{th} genotype for 't' characters.
Yjt	=	uncorrelated mean value of j^{th} genotype for 't' characters.
D^2ij	=	D^2 between i^{th} and j^{th} accessions.

In all combinations each character was ranked based on their contribution towards divergence between two entries (di= Yit- Yjt). Rank 1 is given to the highest mean difference and rank P to the lowest difference, where, P is the total number of characters.

i. The 'P' component and D^2 for each combination were ranked in descending order of magnitude.

ii. The ranks were added up for each component D^2 over all combination and the rank totals were obtained.

3.6.8.1 Group constellation

Varieties have been grouped into a number of clusters. D^2 is treated as the square of generalized distance, according to the method described by Tocher (Rao, 1952). The criterion used in clustering by this method is that any two genotypes belonging to the same cluster should, at least on an average, show a smaller D^2 value than those belonging to two different clusters. In other words, if variety V_1 and V_2 are close together and variety V_3 is distinct from both shown by this generalized distance than V_1 and V_2 from one cluster.

The average D^2 values of all possible genotypes combinations in one cluster with those in the other were computed and its square root was used to represent the 'statistical distance' between two clusters.

3.6.8.2 Intra and inter cluster genetic distances

For the analysis of intra-cluster D^2 values, the following formula was used:

Intra and Inter cluster $D^2 = \frac{\sum Di^2}{N}$

$N = n\,(n-1)/2$

Where,

$\sum Di^2$ is the sum of D^2 values between all possible combinations (N) within and between clusters, respectively.

n = number of populations included in a cluster

Intra and inter cluster genetic distances (d) where computed square root of average intra-and inter cluster D^2 values *i.e.*, $d = \sqrt{D^2}$

Chapter-4

RESULTS AND DISCUSSION

The present investigation entitled, **"Genetic evaluation of tomato (*Solanum lycopersicum* L.) germplasm for yield and quality traits"** was conducted at RHR & TS, Jachh, Kangra, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during the year 2018. Eleven varieties, ten exotic lines and three local collections of tomato along with one standard check (Solan Lalima) were evaluated for different attributes traits. The experimental results so obtained are documented under the following sub-heads:

4.1 Variability studies

4.2 Correlation studies

4.3 Path coefficient analysis

4.4 Genetic divergence

4.1 VARIABILITY STUDIES

4.1.1 Mean performance of genotypes

A highly significant difference was observed among the genotypes for all the traits studied (Appendix-I), which indicated the existence of enough variability in the germplasm under study. The mean performance of twenty-five genotypes along with parameters of variability for different horticultural traits are described and discussed below:

4.1.1.1 Days to first fruit harvesting (number)

A statistical significant variation was observed among all the genotypes under study for days to first fruit harvesting (Appendix - I). Its value ranged from (62.00 – 81.33 days) with a grand mean of 69.69 days (Table 4.1). Thirteen genotypes including check were earlier in days to first fruit harvesting than the total population mean. Minimum number of days to first fruit harvesting was recorded in LC-2 (62.00 days) which was statistically at par with Pusa Ruby (64.00 days), Pusa Sadabahar (64.33 days), Punjab Chhuhara (62.33 days) and EC-802562 (63.33 days). Maximum number of days to first fruit harvesting was recorded in Pusa Rohini took (81.33 days). Nine genotypes took lesser number of days to first fruit harvesting than the standard check cultivar Solan Lalima (67.33 days) in all the genotypes under study. Considerable variability regarding this trait was found in accordance with the findings of Rai *et al.* (2016), Patel *et al*. (2013), Kumar *et al.* (2013b) and Reddy *et al.* (2013a)

4.1.1.2 Plant height (cm)

As shown in Appendix – I, the data observed for plant height showed wide variation among all the genotypes. The overall mean value for the trait was 71.57 cm (Table 4.1). It varied from 55.73 to 98.87 cm. Ten genotypes including check had more plant height than the population mean (71.57 cm). Maximum plant height was recorded in Pusa Ruby (98.87 cm) whereas minimum plant height was recorded in Arka Alok (55.73 cm). Two genotypes *viz.* Pusa Ruby (98.87 cm) and LC-2 (87.96) acquired more plant height than the standard check cultivar Solan Lalima (86.95 cm). Considerable variation for this trait was also observed by Meena *et al.* (2018), Singh *et al.* (2017a), Ligade *et al*. (2017), Bhandari *et al.* (2017), Rai *et al.* (2016), Prajapati *et al*. 2015 and Khapte *et al.* (2014a).

4.1.1.3 Fruit length (cm)

A significant variation was observed among all the genotypes under study for fruit length (Appendix- I). It ranged from 3.53 to 5.89 cm (Table 4.1). Sixteen genotypes including standard check (Solan Lalima) produced longer fruits than population mean (4.97 cm). EC- 802562 (5.89 cm) reported the maximum fruit length and was found statistically at par with 5 genotypes *viz.* EC-802563 (5.87 cm), EC-802561 (5.63 cm), EC-802557 (5.57 cm), Punjab Chhuhara (5.61 cm) and Arka Vikas (5.63cm) whereas, minimum fruit length was observed in EC-802555 (3.53 cm) and was found statistically at par with Pant T-3 (3.79 cm) and Pusa Ruby (3.58 cm). Among all the genotypes under study, seven genotypes had larger fruit length than standard check Solan Lalima (5.43 cm). Meena *et al.* (2018), Prajapati *et al*. 2015, Khapte *et al.* (2014a), Shankar *et al.* (2013), Kumar *et al.* (2013b) and Reddy *et al.* (2013a) reported a wide variations for fruit length.

Table 4.1 Mean performance of tomato genotypes for days to first fruit harvesting, plant height (cm), fruit length (cm) and fruit breadth (cm).

Genotypes	Days to first fruit harvesting	Plant height (cm)	Fruit length (cm)	Fruit breadth (cm)
EC-802554	66.00	63.25	5.17	5.33
EC-802555	65.33	76.87	3.53	3.40
EC-802556	66.33	64.63	5.16	5.25
EC-802557	75.00	69.90	5.57	5.70
EC-802558	71.00	68.67	5.24	5.29
EC-802559	73.00	66.08	5.20	4.70
EC-802560	74.00	69.28	5.09	4.67
EC-802561	71.67	74.07	5.63	5.44
EC-802562	63.33	67.60	5.89	5.65
EC-802563	72.33	77.83	5.87	5.55
Pusa Ruby	64.00	98.87	3.58	4.97
Pusa Uphar	68.00	65.93	4.90	5.33
Pusa Sadabhar	64.33	63.14	4.84	5.01
Pusa-120	76.33	72.27	4.06	5.10
Pusa Sheetal	64.67	61.13	4.42	5.12
Pusa Rohini	81.33	65.90	5.23	4.80
Arka Alok	68.67	55.73	5.52	5.96
Arka Abha	74.67	75.27	5.20	5.26
Arka Vikas	74.33	70.40	5.63	5.32
Punjab Chhuhara	62.33	67.63	5.61	4.23
Pant T-3	73.67	73.00	3.79	4.66
LC-1	73.67	71.63	4.33	4.39
LC-2	62.00	87.96	5.09	5.75
LC-3	69.00	75.31	4.18	2.64
Solan Lalima (Check)	67.33	86.95	5.43	5.23
Mean	**69.69**	**71.57**	**4.97**	**4.99**
Range	**62.00 - 81.33**	**55.73 – 98.87**	**3.53 – 5.89**	**2.64 – 5.96**
± SE(m)	**0.932**	**1.385**	**0.123**	**0.107**
CV (%)	**2.317**	**3.351**	**4.293**	**3.721**
C.D. (0.05)	**2.659**	**3.950**	**0.351**	**0.306**

4.1.1.4 Fruit breadth (cm)

Fruit breadth ranged from 2.64 to 5.96 cm (Table 4.1) and varied significantly among all the genotypes under study (Appendix-I). Sixteen genotypes including standard check had higher fruit breadth than population mean (4.99 cm). Highest breadth was observed in Arka Alok (5.96 cm) and was statistically at par with 3 genotypes *viz.* LC-2 (5.75 cm), EC-802557 (5.70 cm) and EC-802562 (5.65 cm). Minimum fruit breadth was recorded in LC-3 (2.64 cm). Twelve genotypes under study had greater fruit breadth than standard check Solan Lalima (5.23 cm). Similar findings were also reported by Meena *et al.* (2018), Prajapati *et al*. 2015, Khapte *et al.* (2014a), Shankar *et al.* (2013), Kumar *et al.* (2013b) and Reddy *et al.* (2013a).

4.1.1.5 Average fruit weight (g)

Average fruit weight ranged from 25.37 to 76.65 g (Table 4.2) and varied significantly among all the genotypes under study (Appendix-I). Fourteen genotypes including standard check produced fruits with more average fruit weight than population mean. Highest average fruit weight was observed in EC-802562 (76.65 g) and was statistically at par with Arka Alok (75.62 g) and EC-802563 (74.91 g). Minimum average fruit weight was recorded in LC-3 (25.37 g) and was statistically at par with EC-802555 (30.08 g). Seven genotypes viz., EC- 802563 (74.91 g), EC-802562 (76.65 g), EC-802561 (70.44 g), EC-802557 (70.17 g), Arka Vikas (68.85g), Arka Alok (75.62 g) and LC-2 967.35 g) gave higher fruit weight than the standard check cultivar Solan Lalima (65.32 g). It is one of the major yields contributing character. Wide genetic variation with respect to this character was also reported by Meena *et al.* (2018), Singh *et al.* (2017a), Ligade *et al*. (2017), Bhandari *et al.* (2017), Rai *et al.* (2016) Prajapati *et al*. 2015, Khapte *et al.* (2014a), Patel *et al*. (2013), Dar and Sharma (2011) and Reddy *et al.* (2013a).

4.1.1.6 Number of fruit clusters per plant

The number of fruit cluster per plant varied from 3.60 to 7.20 (Table 4.2) and varied significantly among all the genotypes under study (Appendix-I). Eleven genotypes had more number of fruits per cluster than population mean. EC-802563 (7.20) reported the maximum number of fruits per cluster and was found statistically at par with EC-802562 (6.87) while Pusa Uphar (3.60) reported the minimum number of fruit cluster per plant. Twenty-one genotypes produced more number of fruit cluster per plant than the standard check cultivar Solan Lalima (5.10). Results of the present study were in line with the findings of Meena *et al.* (2018) and Reddy *et al.* (2013a).

4.1.1.7 Number of fruits per cluster

The number of fruits per cluster varied from 2.31 to 5.65 with the overall mean 3.76 (Table 4.2) and varied significantly among all the genotypes under study (Appendix-I). Twelve genotypes including standard check had more number of fruits per cluster than population mean. Maximum number of fruits per cluster was observed in Pusa Uphar (5.65) while EC-802563 (2.31) reported the minimum number of fruits per cluster and was found statistically at par with EC-802559 (2.58). More number of fruits per cluster than the standard check cultivar Solan Lalima (4.43) was observed in three genotypes *viz.* EC-802555 (5.05), Pusa Uphar (5.65) and Pusa Ruby (4.48). Results of the present study were in line with the findings of Meena *et al.* (2018), Ligade *et al*. (2017), Bhandari *et al.* (2017), Rai *et al.* (2016), Prajapati *et al*. (2015), Shankar *et al.* (2013) and Kumar *et al.* (2013b).

4.1.1.8 Number of fruits per plant

The number of fruits per plant ranged from 15.53 to 30.60 and varied significantly among all the genotypes under study (Appendix-I). Including standard check twelve genotypes produced more number of fruits per plant than the population means (20.93). Maximum number of fruits per plant was observed in genotype EC-802555 (30.60) while LC- 1 (15.53) recorded in minimum number of fruits per plant and was statistically at par with LC- 3 (17.07), EC-802558 (17.57), EC-802559 (17.02), EC-802561 (15.84) and EC-802563 (16.62). Eleven genotypes among study produced more number of fruits per plant than the standard check (Solan Lalima, 22.58). Results of the present study were in line with the findings of Meena *et al.* (2018), Singh *et al.* (2017), Rai *et al.* (2016), Patel *et al*. (2013), Kumar *et al.* (2013), Dar and Sharma (2011), Sidhya *et al*. (2014) and Reddy *et al.* (2013a).

Table 4.2 Mean performance of tomato genotypes for average fruit weight (g), number of fruit clusters per plant, number of fruits per cluster and number of fruits per plant.

Genotypes	Average fruit weight (g)	Number of fruit clusters per plant	Number of fruits per cluster	Number of fruits per plant
EC-802554	63.39	5.37	4.03	21.64
EC-802555	30.08	6.07	5.05	30.60
EC-802556	62.34	6.40	3.72	23.80
EC-802557	70.17	6.43	3.73	24.00
EC-802558	63.77	5.93	2.96	17.57
EC-802559	56.18	6.60	2.58	17.02
EC-802560	54.69	5.67	3.18	18.01
EC-802561	70.44	5.40	2.93	15.84
EC-802562	76.65	6.87	2.92	20.03
EC-802563	74.91	7.20	2.31	16.62
Pusa Ruby	40.90	5.57	4.48	24.90
Pusa Uphar	60.07	3.60	5.65	20.27
Pusa Sadabhar	55.82	5.40	3.80	20.53
Pusa-120	47.70	5.47	3.64	19.83
Pusa Sheetal	52.08	5.43	3.63	19.70
Pusa Rohini	57.74	5.70	4.29	24.43
Arka Alok	75.62	5.17	4.06	21.00
Arka Abha	62.97	5.60	4.07	22.60
Arka Vikas	68.85	5.37	3.78	20.27
Punjab Chhuhara	59.40	5.53	4.27	23.60
Pant T-3	40.61	5.70	3.84	21.90
LC-1	43.76	4.47	3.48	15.53
LC-2	67.35	6.50	3.67	23.87
LC-3	25.37	4.73	3.60	17.07
Solan Lalima (Check)	65.32	5.10	4.43	22.58
Mean	**57.85**	**5.65**	**3.76**	**20.93**
Range	**25.37 – 76.65**	**3.60 – 7.20**	**2.31 – 5.65**	**15.53 – 30.60**
± SE(m)	**1.946**	**0.153**	**0.162**	**0.740**
CV (%)	**5.826**	**4.691**	**7.466**	**6.126**
C.D. (0.05)	**5.550**	**0.437**	**0.463**	**2.111**

4.1.1.9 Number of locules per fruit

Number of locules ranged from 2.33 to 5.67 (Table 4.3) and varied significantly among all the genotypes under study (Appendix-I). Fourteen genotypes under study had reduced locules number per fruit than population mean. EC-802555 (2.33) recorded the minimum number of locules per fruit which was statistically at equivalence with Pusa Ruby (3.00), Pusa Uphar (3.00), Pusa- 120 (3.00), Pusa Sheetal (3.00), Pusa Rohini (3.00), EC-802554 (3.00), EC-802562 (3.00) and EC-802560 (2.67) whereas maximum number of locules per fruit was observed in Arka Abha (5.67) which was statistically at par with Arka Vikas (5.00). Eighteen genotypes had reduced number of locules per fruit than the check cultivar Solan Lalima (4.33). Similar results have also been obtained by Meena *et al.* (2018), Singh *et al.* (2017a), Ligade *et al*. (2017), Bhandari *et al.* (2017), Rai *et al.* (2016), Prajapati *et al*. (2015) and Khapte *et al.* (2014a).

4.1.1.10 Harvest duration (days)

Harvest duration ranged from 21.33 to 46.67 days with the overall mean of 31.08 days (Table 4.3) and varied significantly among all the genotypes under study (Appendix-II). Eleven genotypes including standard check had the longer harvest duration than population mean among all the genotypes under study. Genotype EC-802555 (46.67 days) recorded the maximum harvest duration whereas, EC-802563 (21.25 days) reported the minimum harvest duration which was found statistically at par with EC-802561 (23.00 days), Arka Alok (21.33 days) and Pusa Sadabahar (23.33 days). Four genotypes viz., EC-802556 (41.33 days), EC-802555 (46.67 days), Pusa Rohini (42.00 days) and Pusa Ruby (39.33 days) had longer harvest duration than standard check cultivar Solan Lalima (39.00 days). Similar results were also reported by Rai *et al.* (2016), Kumar *et al.* (2013b) and Bajpai *et al.* (2018) for this attribute.

4.1.1.11 Shelf life (days)

Statistical analysis revealed that genotypes showed significant variations for shelf life (Appendix-I). It ranged from 14.00 to 31.33 days (Table 4.3). Overall mean for the character was 22.13 days. Ten genotypes were found to have longer shelf life than population mean. Maximum shelf life was recorded in genotype EC-802562 (31.33 days) which was found statistically at equivalence with EC-802557 (30.33 days), whereas, minimum shelf life was observed in LC-3 (14.00 days) which was found statistically at par with Pant T-3 (16.00 days). Ten genotypes had longer shelf life than standard check cultivar Solan Lalima (22.00 days). Results of the present study were in accordance with the findings of Reddy *et al.* (2013a) and Yogendra and Gowda (2013).

4.1.1.12 Pericarp thickness (mm)

Pericarp thickness ranged from 4.24 to 7.85 mm with the mean value 6.46 mm (Table 4.3) and varied significantly among all the genotypes under study (Appendix-I). Fourteen genotypes including standard check had higher pericarp thickness than population mean Maximum pericarp thickness was recorded in EC-802562 (31.33 days) which was statistically at par with EC-802557 (7.78 mm), EC-802554 (7.37 mm), Punjab Chhuhara (7.42 mm), Pusa Uphar (7.27 mm) and LC-2 (7.63 mm). Minimum pericarp thickness was observed in LC-3 (4.24 mm). Nine genotypes under study had more pericarp thickness than standard check cultivar Solan Lalima (6.67 mm). Results of the present study were in line with the findings of Singh *et al.* (2017a), Rai *et al.* (2016), Prajapati *et al*. (2015), Khapte *et al.* (2014a), Patel *et al*. (2013) and Kumar *et al.* (2013b).

4.1.1.13 Total soluble solids (°Brix)

Total soluble solids ranged from 3.65- 5.10 °B (Table 4.4) and varied significantly among all the genotypes under study (Appendix-I). Fourteen genotypes including standard check obtained maximum value for total soluble solids than the population mean (4.52 °B). LC-2 (5.10 °B) reported with maximum value for total soluble solids which was statistically at par with Pusa Rohini (4.83 °B), Arka Abha (5.00 °B), Punjab chhuhara (4.77 °B), Pant T-3 (4.80 °B), EC-802554 (4.77 °B), EC-802555 (4.87°B) and EC-802557 (5.03 **°**B). Pusa Ruby (3.65 °B) recorded in minimum value for total soluble solids which was statistically at equivalence with LC-1 (3.90 °B), Pusa Uphar (3.77 °B) and Arka Vikas (3.93 °B). Ten genotypes recorded maximum value for total soluble solids than the standard check cultivar Solan Lalima (4.73 °B). Results of the present study were in line with the findings of Meena *et al.* (2018), Singh *et al.* (2017a), Ligade *et al*. (2017), Rai *et al* . (2016), Khapte *et al.* (2014a), Patel *et al*. (2013), Kumar *et al.* (2013b), Meena *et al.* (2015) and Reddy *et al.* (2013a).

Table 4.3 Mean performance of tomato genotypes for number of locules per fruit, harvest duration (days), shelf life (days) and pericarp thickness (mm).

Genotypes	Number of locules per Fruit	Harvest duration (days)	Shelf life (days)	Pericarp thickness (mm)
EC-802554	3.00	38.00	24.33	7.37
EC-802555	2.33	46.67	28.00	7.18
EC-802556	3.67	41.33	25.00	6.41
EC-802557	4.33	34.00	30.33	7.78
EC-802558	4.33	26.00	22.00	6.67
EC-802559	3.67	27.00	19.33	5.86
EC-802560	2.67	29.67	20.67	6.26
EC-802561	3.33	23.00	22.00	6.67
EC-802562	3.00	35.00	31.33	7.85
EC-802563	3.67	21.33	22.67	6.87
Pusa Ruby	3.00	39.33	21.67	6.57
Pusa Uphar	3.00	30.00	24.00	7.27
Pusa Sadabhar	3.33	23.33	22.67	6.87
Pusa-120	3.00	26.00	20.33	6.16
Pusa Sheetal	3.00	29.33	21.67	6.56
Pusa Rohini	3.00	42.00	21.33	6.46
Arka Alok	3.67	21.33	20.33	6.16
Arka Abha	5.67	25.00	19.00	5.76
Arka Vikas	5.00	31.67	16.33	4.95
Punjab Chhuhara	4.67	32.33	23.00	7.42
Pant T-3	3.33	27.67	16.00	4.85
LC-1	3.33	27.67	16.33	4.95
LC-2	4.33	36.33	29.00	7.63
LC-3	3.33	24.00	14.00	4.24
Solan Lalima (Check)	4.33	39.00	22.00	6.67
Mean	**3.60**	**31.08**	**22.13**	**6.46**
Range	**2.33 – 5.67**	**21.33 – 46.67**	**14.00 – 31.33**	**4.24 – 7.85**
± SE(m)	**0.303**	**0.888**	**0.711**	**0.210**
CV (%)	**14.596**	**4.950**	**5.565**	**5.626**
C.D. (0.05)	**0.865**	**2.534**	**2.028**	**0.598**

4.1.1.14 Buckeye rot incidence (%)

In the mid hills zones of Himachal Pradesh, buckeye rot of tomato is one of the most destructive disease. The incidence ranged from 20.05 to 33.41 % (Table 4.4) and varied significantly among all the genotypes under study (Appendix-I). Buckeye rot incidence was minimum in LC-2 (20.05 %) which was statistically at par with Arka Vikas (22.32 %). The values were rated as moderately susceptible as per the scale given by Dodan *et al.* (1995). The buckeye rot incidence was comparatively less (20.05-24.10 %) in eight genotypes than the standard check cultivar Solan Lalima (24.18 %), whereas, maximum incidence of disease was observed in LC-1 (33.41%). Similar findings were also reported by Kumar *et al*. (2006) and Kumar *et al*. (2018c).

4.1.1.15 Marketable fruit yield per plant (kg) and per hectare (q)

Range for fruit yield (kg/plant and q/ha) varied from 0.44 – 1.68 kg/plant and128.83–498.90q/ha (Table4.4) and varied significantly among all the genotypes under study (Appendix-I). General average for this attribute was 1.20kg/plant and 356.29 q/ha. Thirteen genotypes including standard check gave higher yield (kg/plant and q/ha) than population mean. EC-802557 (1.68 kg/plant and 498.90 q/ha) reported the maximum fruit yield and it was found statistically at equivalence with genotypes Arka Alok (1.59 kg/plant and 470.77 q/ha) and LC-2 (1.61 kg/plant and 476.27 q/ha). Minimum fruit yield was recorded in LC-3 (0.44 kg/plant and 128.83 q/ha). Five genotypes recorded higher yield (kg/plant and q/ha) than the standard check cultivar Solan Lalima (1.47 kg/plant and 436.42 q/ha). Similar observations were made by Meena *et al.* (2018), Singh *et al.* (2017a), Ligade *et al*. (2017), Khapte *et al.* (2014a), Patel *et al*. (2013), Kumar *et al.* (2013b) and Dar and Sharma (2011).

Table4.4 Mean performance of tomato genotypes for total soluble solids (°Brix), buckeye rot incidence (%)* and marketable fruit yield per plant (kg) & per hectare (q).

Genotypes	Total soluble solids (°Brix)	Buckeye rot incidence (%)*	Marketable fruit yield per plant (kg)	Marketable fruit yield per hectare (q)
EC-802554	4.77	23.61 (23.61)	1.37	406.42
EC-802555	4.87	26.42 (26.43)	0.92	272.40
EC-802556	4.67	24.10 (24.11)	1.48	438.68
EC-802557	5.03	23.81 (23.82)	1.68	498.90
EC-802558	4.43	28.30 (28.31)	1.12	332.19
EC-802559	4.70	29.62 (29.63)	0.96	283.68
EC-802560	4.80	26.45 (26.46)	0.98	291.26
EC-802561	4.37	28.13 (28.14)	1.12	330.21
EC-802562	4.43	26.91 (26.92)	1.54	454.84
EC-802563	4.80	28.51 (28.53)	1.25	369.07
Pusa Ruby	3.65	27.27 (27.28)	1.02	301.76
Pusa Uphar	3.77	27.22 (27.23)	1.21	360.18
Pusa Sadabhar	4.10	27.50 (27.51)	1.15	339.93
Pusa-120	4.53	24.44 (24.45)	0.95	279.87
Pusa Sheetal	4.37	24.09 (24.10)	1.02	303.32
Pusa Rohini	4.83	23.88 (23.89)	1.41	417.98
Arka Alok	4.47	27.06 (27.07)	1.59	470.77
Arka Abha	5.00	24.05 (24.06)	1.42	421.79
Arka Vikas	3.93	22.32 (22.33)	1.39	412.87
Punjab Chhuhara	4.77	24.20 (24.21)	1.40	415.09
Pant T-3	4.80	30.03 (30.04)	0.89	263.38
LC-1	3.90	33.41 (33.42)	0.68	201.02
LC-2	5.10	20.05 (20.06)	1.61	476.27
LC-3	4.07	33.04 (33.05)	0.44	128.83
Solan Lalima (Check)	4.73	24.18 (24.19)	1.47	436.42
Mean	**4.52**	**26.34 (26.35)**	**1.20**	**356.29**
Range	**3.65 – 5.10**	**20.06 – 33.41**	**0.44 – 1.68**	**128.83 – 498.90**
± SE(m)	**0.144**	**0.796**	**0.050**	**14.91**
CV (%)	**5.517**	**5.230**	**7.237**	**7.25**
C.D. (0.05)	**0.410**	**2.269**	**0.143**	**42.52**

*** Figures in the parenthesis are Arc-Sine transformed values**

4.1.2 PARAMETERS OF VARIABILITY

To assess the prevailing variation in the studied genotypes of tomato, the estimates of variability were worked out for various characters after analyzing the data recorded for different horticultural characters. It was observed that the major variation was because of the effect of genotype and environment. To determine the magnitudes of genotypic and phenotypic variability in term of genotypic and phenotypic coefficients were presented in Table 4.5.

4.1.2.1 Coefficients of variability

For all the characters studied, phenotypic coefficients of variation were higher in magnitude than the corresponding genotypic coefficients of variation, though the difference was less in majority of cases thus, indicating that environmental factors have played less influence on the expression of these characters.

4.1.2.1.1 Phenotypic and genotypic coefficients of variation

The perusal of data (Table 4.5) revealed marked extent of variation for all the characters studied. It ranged from 7.54% - 26.42% at phenotypic level and 7.18% - 25.41% at genotypic level. The phenotypic and genotypic coefficients of variability were high for average fruit weight (23.94% and 23.22%), number of locules per fruit (24.91% and 20.19%), harvest duration (23.10% and 22.57%) and marketable fruit yield per plant (26.42% and 25.41%). Similar findings have been reported by Rai *et al.* (2016) for average fruit weight and marketable fruit yield per plant. Further, they recorded high PCV for harvest duration. Bhandari *et al.* (2017) for number of locules per fruit, Meena *et al.* (2018) for marketable fruit yield per plant.

Moderate coefficients of variability both at phenotypic and genotypic level were observed for plant height (13.19% and 12.75%), fruit length (14.53% and 13.88%), fruit breadth (15.02% and 14.55%), number of fruit clusters per plant (14.19% and 13.40%), number of fruits per plant (17.35% and 16.23%), pericarp thickness (15.40% and 14.33%) and buckeye rot incidence (12.71% and 11.58%). Similar findings were reported by Bhandari *et al.* (2017) for plant height, Meena *et al.* (2018) for pericarp thickness, number of fruit clusters per plant and number of fruits per plant, Singh *et al.* (2015a) for fruit length and fruit breadth.

Low coefficients of variability was observed for days to first fruit harvesting (7.54% and 7.18%) as also confirmed from the findings of Reddy *et al.* (2018).

High coefficients of variability at phenotypic level along with moderate coefficients of variability at genotypic level were recorded for number of fruits per cluster (20.48% and 19.07%) and shelf life (20.08% and 19.29%). Moderate coefficient of variability at phenotypic level along with low coefficient of variability at genotypic level was recorded for total soluble solids (10.11% and 8.47%) as also confirmed from the findings of Meena *et al.* (2018)

4.1.2.2 Heritability

Heritability in broad sense is a measure of the proportions of phenotypic variance resulting due to genetic factors. Heritability (broad sense) estimates ranged from 65.68-95.41% (Table 4.5). High heritability was recorded for harvest duration (95.41%), average fruit weight (94.08%), fruit breadth (93.87%), plant height (93.54%), marketable fruit yield per plant (92.50%), shelf life (92.32%), fruit length (91.27%), days to first fruit harvesting (90.57%), pericarp thickness (86.65%), buckeye rot incidence (83.06%), total soluble solids (70.20%) and number of locules per fruit (65.68%) which were in accordance with the findings of Rai *et al.* (2016) for marketable fruit yield per plant, harvest duration, days to first fruit harvesting, total soluble solids, number of locules per fruit, pericarp thickness, plant height, average fruit weight. Similarly Reddy *et al.* (2018) reported for number of fruits per plant, total soluble solids, number of fruit clusters per plant and marketable fruit yield per plant. Singh *et al.* (2015a) recorded similar results for fruit breadth.

Table 4.5 Estimates of phenotypic and genotypic coefficients of variation, heritability, genetic advance and genetic gain for various characters in tomato.

Characters	Range	Mean± SE(d)	Coefficients of Variability (%)		Heritability (%)	Genetic advance	Genetic gain (%)
			Genotypic	Phenotypic			
Days to first fruit harvesting (number)	62.00 - 81.33	69.69± 1.32	7.18	7.54	90.57	9.81	14.08
Plant height (cm)	55.73 - 98.87	71.57± 1.96	12.75	13.19	93.54	18.18	25.41
Fruit length (cm)	3.53 - 5.89	4.97± 0.17	13.88	14.53	91.27	1.36	27.32
Fruit breadth (cm)	2.64 - 5.96	4.99± 0.15	14.55	15.02	93.87	1.45	29.04
Average fruit weight (g)	25.37 – 76.65	57.85± 2.75	23.22	23.94	94.08	26.83	46.39
Number of fruit clusters per plant	3.60 – 7.20	5.65± 0.22	13.40	14.19	89.07	1.47	26.04
Number of fruits per cluster	2.31 – 5.65	3.76± 0.23	19.07	20.48	86.71	1.38	36.59
Number of fruits per plant	15.53 – 30.60	20.93± 1.05	16.23	17.35	87.53	6.55	31.29
Number of locules per fruit	2.33 – 5.67	3.60± 0.43	20.19	24.91	65.68	1.21	33.71
Harvest duration (days)	21.33 – 46.67	31.08± 1.26	22.57	23.10	95.41	14.11	45.41
Shelf life (days)	14.00 – 31.33	22.13± 1.01	19.29	20.08	92.32	8.45	38.19
Pericarp thickness (mm)	4.24 – 7.85	6.46± 0.30	14.33	15.40	86.65	1.78	27.48
Total soluble solids (°Brix)	3.65 – 5.10	4.52± 0.20	8.47	10.11	70.20	0.66	14.61
Buckeye rot incidence (%)	20.06 – 33.41	26.34± 1.12	11.58	12.71	83.06	5.73	21.75
Marketable fruit yield per plant (kg)	0.44 – 1.68	1.20± 0.07	25.41	26.42	92.50	0.61	50.35

4.1.2.3 Genetic advance and genetic gain

The genetic gain ranged from 14.08 to 50.35% (Table 4.5) and was moderate to high in nature. High genetic gain was recorded for marketable fruit yield per plant (50.35%), average fruit weight (46.39%), harvest duration (49.41%), shelf life (38.19%), number of fruits/cluster (36.59%), number of locules/fruit (33.71%), number of fruits/plant (31.29%), fruit breadth (29.04%), pericarp thickness (27.48%), fruit length (27.32%), number of fruit clusters/plant (26.04%), plant height (25.41%) and buckeye rot incidence (21.75%), while it was moderate for total soluble solids (14.61%) and days to first fruit harvesting (14.08%) which were in accordance with the findings of Singh *et al.* (2017) and Kumar *et al.* (2013) for number of fruits /cluster, number of fruits/plant, fruit length, fruit breadth, number of locules/ fruit and pericarp thickness. Reddy *et al.* (2018) for harvest duration, marketable fruit yield per plant. Shankar *et al*. (2013) for shelf life, number of fruits per cluster. Bajpai *et al.* (2018) and Al-Aysh *et al*. (2012) for total soluble solids. Prajapati *et al.* (2015) and Sureshkumara *et al.* (2018) for number of fruit clusters per plant.

4.2 Correlation studies

Correlation coefficients for genotypic and phenotypic have been presented in Tables 4.6 and 4.7. In general, the magnitude of genotypic correlation coefficient was higher than phenotypic correlation coefficients.

4.2.1 Genotypic Correlations

The perusal of data from table 4.6 revealed the genotypic correlation coefficients among different traits. The genotypic correlation coefficients revealed that marketable fruit yield per plant had positive and significant correlation with fruit length and breadth (0.706 and 0.759), average fruit weight (0.833), number of fruit clusters /plant (0.351), number of fruits / plant (0.373), number of locules /fruit (0.506), harvest duration (0.289), shelf life (0.627), pericarp thickness (0.647) and total soluble solids (0.456). Negative and significant correlation of marketable fruit yield per plant was observed with incidence of buckeye rot (- 0.781).

Average fruit weight had positive and significant correlation with fruit length and breadth (0.908 and 0.867) and had negative and significant correlation with plant height (- 0.253).

A positive and significant correlation of number of fruits per plant with plant height (0.249) and number of fruits per cluster (0.670) were observed while it was negative and significantly correlated with days to first fruit harvesting (-0.293) and fruit length (-0.281). Number of fruits per cluster had negative and significant correlation with days to first fruit harvesting (- 0.236), fruit length (-0.392), average fruit weight (-0.310) and number of fruit clusters per plant (-0.598). Number of fruit clusters per plant had positive and significant correlation with fruit length (0.315), fruit breadth (0.264) and average fruit weight (0.345). Number of locules per fruit had positive and significant correlation with fruit length (0.538), fruit breadth (0.315) and average fruit weight (0.476).

Total soluble solids had positive and significant correlation with fruit length (0.283), average fruit weight (0.259), number of fruit clusters per plant (0.672), number of fruits/plant (0.390), number of locules/fruit (0.251), harvest duration (0.232), shelf life (0.383) and pericarp thickness (0.325). Pericarp thickness had positive and significant correlation with fruit length (0.376), fruit breadth (0.482), average fruit weight (0.508), number of fruit clusters/plant (0.370), number of fruits/ plant (0.409), harvest duration (0.398) and shelf life (0.922) while it had negative and significant correlation with days to first fruit harvesting (-0.485). Shelf life had positive and significant correlation with fruit length (0.296), fruit breadth (0.414), average fruit weight (0.430), number of fruit clusters/ plant (0.501), number of fruits /plant (0.492) and harvest duration (0.507) while it had negative and significant correlation with days to first fruit harvesting (-0.463).

Positive and significant correlation of harvesting duration with plant height (0.292), number of fruits/cluster (0.509) and number of fruits/plant (0.799) was observed while it had negative and significant correlation with days to first fruit harvesting (-0.255) and number of locules per fruit (-0.227).

Incidence of buckeye rot had negative and significant correlation with fruit length (- 0.336), fruit breadth (-0.511), average fruit weight (-0.476), number of fruit clusters/plant (-0270), number of fruits/ cluster (-0.271), number of fruits/ plant (-0.578), number of locules/fruit (-0.382), harvest duration (-0.501), shelf life (-0.529), pericarp thickness (-0.570), TSS (-0.500). Naveen *et al*. (2017) and Rani *et al*. (2010) reported the similar findings for these attributes.

Table 4.6 Genotypic coefficients of correlation among different traits in tomato

	DTFFH	PH	FL	FB	AFW	NFCPP	NFPC	NFPP	NLPF	HD	SL	PT	TSS	IBER	MFYPP
DTFFH	1														
PH	-0.162	1													
FL	0.074	-0.334**	1												
FB	0.003	-0.113	0.593**	1											
AFW	-0.002	-0.253*	0.908**	0.867**	1										
NFCPP	-0.027	0.123	0.315**	0.264*	0.345**	1									
NFPC	-0.236*	0.106	-0.392**	-0.184	-0.310**	-0.598**	1								
NFPP	-0.293**	0.249*	-0.281*	-0.078	-0.169	0.156	0.670**	1							
NLPF	0.116	0.124	0.538**	0.315**	0.476**	0.120	-0.111	-0.013	1						
HD	-0.255*	0.292**	-0.184	-0.112	-0.150	0.165	0.509**	0.799**	-0.227*	1					
SL	-0.463**	0.044	0.296**	0.414**	0.430**	0.501**	0.097	0.492**	-0.126	0.507**	1				
PT	-0.485**	0.009	0.376**	0.482**	0.508**	0.370**	0.144	0.409**	-0.105	0.398**	0.922**	1			
TSS	0.159	-0.055	0.283*	0.141	0.259*	0.672**	-0.192	0.390**	0.251*	0.232*	0.383**	0.325**	1		
IBER	0.164	-0.039	-0.336**	-0.511**	-0.476**	-0.270*	-0.271*	-0.578**	-0.382**	-0.501**	-0.529**	-0.570**	-0.500**	1	
MFYPP	-0.149	-0.117	0.706**	0.759**	0.833**	0.351**	0.095	0.373**	0.506**	0.289*	0.627**	0.647**	0.456**	-0.781**	1

*Significant at 5% level of significance

**Significant at 1% level of significance

Where,

DTFFH = Days to first fruit harvesting, PH = Plant height, FL = Fruit length, FB = Fruit breadth, AFW = Average fruit weight, NFCPP = Number of fruit clusters per plant, NFPC = Number of fruits per cluster, NFPP = Number of fruits per plant, NLPF = Number of locules per fruit, HD = Harvest duration, SL = Shelf life, PT = Pericarp thickness, TSS = Total soluble solids, IBER = Incidence of buckeye rot and MFYPP = Marketable fruit yield per plant

4.2.2 Phenotypic correlations

The data presented in table 4.7 recorded the phenotypic correlation coefficients among different traits. The phenotypic correlation coefficients revealed that marketable fruit yield per plant had positive and significant correlation with fruit length (0682), fruit breadth (0.739), average fruit weight (0.818), number of fruit clusters/plant (0.336), number of fruits/plant (0.396), number of locules/fruit (0.405), harvest duration (0.267), shelf life (0.576), pericarp thickness (0.577) and total soluble solids (0.380). Negative and significant correlation of marketable fruit yield per plant was observed with severity of buck eye rot (- 0.693).

Average fruit weight had positive and significant correlation with fruit length and breadth (0.896 and 0.856) while had negative and significant correlation with plant height (- 0.237).

A positive correlation was observed among the number of fruits per plant with plant height (0.225) and number of fruits/cluster (0.677), whereas days to first fruit harvest (-0.259) and fruit length (-0.273) possessed the negative correlation. Number of fruits/cluster had negative and significant correlation with fruit length (-0.370), average fruit weight (-0.295) and number of fruit clusters/plant (-0.581). Number of fruit clusters per plant had positive and significant correlation with fruit length (0.283), fruit breadth (0.237) and average fruit weight (0.314). A positive and significant correlation was observed in number of locules/fruit with fruit length (0.417), fruit breadth (0.254) and average fruit weight (0.381).

Total soluble solids had positive and significant correlation with fruit length (0.281), average fruit weight (0.253), number of fruit clusters/plant (0.492), number of fruits/ plant (0.271), shelf life (0.369) and pericarp thickness (0.332). Pericarp thickness had positive and significant correlation with fruit length (0.327), fruit breadth (0.435), average fruit weight (0.454), number of fruit clusters/plant (0.317), number of fruits/plant (0.358), harvest duration (0.365) and shelf life (0.926) while it had negative and significant correlation with days to first fruit harvesting (-0.420).

Table 4.7 Phenotypic coefficients of correlation among different traits in tomato

	DTFFH	PH	FL	FB	AFW	NFCPP	NFPC	NFPP	NLPF	HD	SL	PT	TSS	IBER	MFYPP
DTFFH	1														
PH	-0.140	1													
FL	0.075	-0.302**	1												
FB	0.025	-0.113	0.554**	1											
AFW	0.017	-0.237*	0.896**	0.856**	1										
NFCPP	-0.049	0.103	0.283*	0.237*	0.314**	1									
NFPC	-0.188	0.096	-0.370**	-0.169	-0.295**	-0.581**	1								
NFPP	-0.259*	0.225*	-0.273*	-0.078	-0.168	0.165	0.677**	1							
NLPF	0.072	0.094	0.417**	0.254*	0.381**	0.099	-0.070	0.009	1						
HD	-0.237*	0.268*	-0.183	-0.105	-0.146	0.159	0.460**	0.729**	-0.164	1					
SL	-0.418**	0.026	0.267*	0.384**	0.396**	0.448**	0.092	0.444**	-0.104	0.478**	1				
PT	-0.420**	-0.011	0.327**	0.435**	0.454**	0.317**	0.13	0.358**	-0.085	0.365**	0.926**	1			
TSS	0.131	-0.030	0.281*	0.138	0.253*	0.492**	-0.160	0.271*	0.210	0.183	0.369**	0.332**	1		
IBER	0.121	-0.052	-0.293**	-0.456**	-0.424**	-0.203	-0.257*	-0.501**	-0.287*	-0.423**	-0.431**	-0.439**	-0.361**	1	
MFYPP	-0.120	-0.110	0.682**	0.739**	0.818**	0.336**	0.127	0.396**	0.405**	0.267*	0.576**	0.577**	0.380**	-0.693**	1

*Significant at 5% level of significance

**Significant at 1% level of significance

Where,

DTFFH = Days to first fruit harvesting, PH = Plant height, FL = Fruit length, FB = Fruit breadth, AFW = Average fruit weight, NFCPP = Number of fruit clusters per plant, NFPC = Number of fruits per cluster, NFPP = Number of fruits per plant, NLPF = Number of locules per fruit, HD = Harvest duration, SL = Shelf life, PT = Pericarp thickness, TSS = Total soluble solids, IBER = Incidence of buckeye rot and MFYPP = Marketable fruit yield per plant.

Shelf life had positive and significant correlation with fruit length (0.267), fruit breadth (0.384), average fruit weight (0.396), number of fruit clusters/plant (0.448), number of fruits/plant (0.444) and harvest duration (0.478) while it had negative and significant correlation with days to first fruit harvesting (-0.418).

Positive as well as significant correlation was observed between harvest duration and; plant height (0.268), number of fruits/cluster and number of fruits/plant (0.460 and 0.729) while it had negative and significant correlation with days to first fruit harvesting (-0.237).

Incidence of buck eye rot had negative and significant correlation with fruit length and breadth (-0.293 and -0.456), average fruit weight (-0.424), number of fruits/cluster (-0.257), number of fruits/plant (-0.501), number of locules/fruit (-0.287), harvest dur ation (-0.423), shelf life (-0.431), pericarp thickness (-0.439) and total soluble solids (- 0.361). Both at Genotypic and phenotypic level similar results have also been reported by Naveen *et al*. (2017), Rani *et al.* (2010), Khapte and Jansirani (2014b) and Meena and Bahadur (2014).

4.3 Path coefficient analysis

Although correlation studies are useful in governing important yield contributing traits, but when we include more number of variables in the correlation studies the association becomes more complicated. In such cases, path coefficient analysis method devised by Dewey and Lu (1959) helps in partitioning the correlation coefficients under direct and indirect effects. In order to understand such effects of different independent characters or in combinations with other yield contributing characters, path coefficient analysis were used to determine the estimates of direct and indirect effects and results obtained have been presented in table4.8.

4.3.1 Path coefficient analysis at genotypic level

Maximum positive direct effect towards marketable fruit yield per plant (Table 4.8) was contributed by average fruit weight (4.740) followed by fruit length (2.787), number of locules/fruit (1.388), harvest duration (1.355), pericarp thickness (1.150), fruit breadth (0.295), TSS (0.255) and days to first fruit harvesting (0.228). Further, maximum negative direct effect on marketable fruit yield per plant was shown by incidence of buckeye rot (-1.499) followed by number of fruits/plant (-0.901), plant height (-0.610), shelf life (-0.320), number of fruit clusters/plant (-0.169) and number of fruits/cluster (-0.097).

On the other hand, fruit length (4.307), fruit breadth (4.110), number of fruit clusters/plant (1.634), number of locules/fruit (2.256), shelf life (2.037), pericarp thickness (2.407) and TSS (1.226) recorded maximum positive indirect effect via average fruit weight on marketable fruit yield per plant. Similarly, plant height (1.263), number of fruits/cluster (1.483) and buckeye rot incidence (1.272) recorded maximum positive indirect effect via fruit length on marketable fruit yield/plant. Number of fruits per plant had maximum positive indirect effect via harvest duration (1.082) whereas days to first fruit harvesting had maximum positive indirect effect via number of fruits/plant (0.264) on marketable fruit yield/plant.

Further, days to first fruit harvesting had maximum negative indirect effect via pericarp thickness (-0.557) similarly, plant height (-1.201), number of fruits per cluster (-1.469) and incidence of buckeye rot (-2.255) recorded maximum negative indirect effect via average fruit weight on marketable fruit yield per plant. Average fruit weight (-3.440), number of fruit clusters/plant (-1.191), number of locules/fruit (-2.038), shelf life (- 1.120), pericarp thickness (-1.424) and TSS (-1.072) recorded maximum negative indirect effect via fruit length on marketable fruit yield/plant. Harvest duration had maximum negative indirect effect via number of fruits/plant (-0.719). Fruit breadth had maximum negative indirect effect via incidence of buck eye rot (-2.255) on marketable fruit yield per plant and fruit length had maximum negative indirect effect via number of fruits per cluster (-3.038) on marketable fruit yield per plant. At genotypic level, the residual effect was recorded to be 0.02134.

Table 4.8 Path coefficient analysis showing the direct and indirect effect of fourteen characters on marketable fruit yield per plant at genotypic level

	DTFFH	PH	FL	FB	AFW	NFCPP	NFPC	NFPP	NLPF	HD	SL	PT	TSS	IBER	GCCMFYPP
DTFFH	**0.228**	0.099	-0.280	-0.005	-0.010	0.004	0.023	0.264	0.161	-0.346	0.148	-0.557	0.040	0.082	-0.149
PH	-0.037	**-0.610**	1.263	0.192	-1.201	-0.021	-0.010	-0.224	0.172	0.396	-0.014	0.011	-0.014	-0.020	-0.117
FL	0.017	0.203	**2.787**	-1.011	4.307	-1.053	-3.038	0.253	0.747	-0.747	-1.095	0.432	0.072	-1.168	0.706**
FB	0.001	0.069	-2.247	**0.295**	4.110	-0.045	0.018	0.070	0.437	-0.152	-0.132	0.554	0.036	-2.255	0.759**
AFW	0.000	0.155	-3.440	-1.477	**4.740**	-0.058	0.030	0.152	0.660	-0.203	-0.138	0.584	0.066	-0.238	0.833**
NFCPP	-0.006	-0.075	-1.191	-0.450	1.634	**-0.169**	0.058	-0.141	0.167	0.224	-0.160	0.425	0.171	-0.136	0.351**
NFPC	-0.054	-0.064	1.483	0.313	-1.469	0.101	**-0.097**	-0.603	-0.153	0.689	-0.031	0.166	-0.049	-0.137	0.095
NFPP	-0.067	-0.152	1.063	0.133	-0.800	-0.026	-0.065	**-0.901**	-0.018	1.082	-0.158	0.470	0.099	-0.287	0.373**
NLPF	0.026	-0.075	-2.038	-0.537	2.256	-0.020	0.011	0.011	**1.388**	-0.308	0.040	-0.121	0.064	-0.191	0.506**
HD	-0.058	-0.178	0.695	0.192	-0.709	-0.028	-0.049	-0.719	-0.315	**1.355**	-0.162	0.457	0.059	-0.251	0.289*
SL	-0.106	-0.027	-1.120	-0.705	2.037	-0.085	-0.009	-0.443	-0.174	0.686	**-0.320**	1.060	0.097	-0.264	0.627**
PT	-0.111	-0.006	-1.424	-0.821	2.407	-0.062	-0.014	-0.368	-0.146	0.539	-0.295	**1.150**	0.083	-0.285	0.647**
TSS	0.036	0.033	-1.072	-0.241	1.226	-0.114	0.019	-0.351	0.348	0.315	-0.122	0.373	**0.255**	-0.249	0.456**
IBER	0.436	0.024	1.272	0.871	-2.255	0.046	0.026	0.520	-0.530	-0.679	1.169	-0.055	-0.127	**-1.499**	-0.781**

*Significant at 5% level of significance

**Significant at 1% level of significance

Where,

DTFFH = Days to first fruit harvesting, PH = Plant height, FL = Fruit length, FB = Fruit breadth, AFW = Average fruit weight, NFCPP = Number of fruit clusters per plant, NFPC = Number of fruits per cluster, NFPP = Number of fruits per plant, NLPF = Number of locules per fruit, HD = Harvest duration, SL = Shelf life, PT = Pericarp thickness, TSS = Total soluble solids, IBER = Incidence of buckeye rot and GCCMFYPP = Genotypic correlation coefficient with marketable fruit yield per plant.

Residual effect 0.02134

Diagonal figures represent the direct effect.

Naveen *et al*. (2017) reported that maximum positive direct effect towards marketable fruit yield per plant was contributed by average fruit weight. Manna and Paul (2012) reported a positive direct effect towards marketable fruit yield per plant by fruit length, fruit weight, number of locules per fruit and pericarp thickness. Namdev and Dongre (2018) also reported positive direct effect of fruit diameter towards marketable fruit yield per plant. Kumar and Singh (2018) reported positive direct effect towards marketable fruit yield by fruit breadth, fruit length and number of locules per plant. Walia *et al.* (2018) also obtained positive direct effect by total soluble solids and average fruit weight towards marketable fruit yield per plant. Singh *et al.* (2015b) also obtained similar results for fruit breadth, pericarp thickness, number of fruits per plant, average fruit weight and TSS towards marketable fruit yield/plant.

4.3.2 Path coefficient analysis at phenotypic level

Maximum positive direct effect towards marketable fruit yield/plant (Table 4.9) was contributed by fruit length (0.856) followed by fruit breadth (0.691), number of fruits/plant (0.651), average fruit weight (0.423), shelf life (0.124), number of locules/fruit (0.028) and total soluble solids (0.018). Further, maximum negative direct effect on marketable fruit yield/plant was shown by incidence of buckeye rot (-0.212) followed by pericarp thickness (-0.152), number of fruit clusters/plant (-0.091), days to first fruit harvesting (-0.060), number of fruits/cluster (-0.048), harvest duration (-0.021), plant height (-0.016).

On the other hand, days to first fruit harvesting had maximum positive indirect effect via fruit length (0.064) and pericarp thickness (0.064) on marketable fruit yield /plant. Plant height (0.147), number of fruits/cluster (0.441), harvest duration (0.474) and shelf life (0.289) recorded maximum positive indirect effect via number of fruits/plant on marketable fruit yield/ plant. Average fruit weight (0.767), number of fruit clusters/ plant (0.242), number of locules fruit (0.357) and total soluble solids (0.240) recorded maximum positive indirect effect via fruit length on marketable fruit yield per plant. Pericarp thickness had maximum positive indirect effect via fruit breadth (0.301) on marketable fruit yield per plant. Incidence of buckeye rot had maximum positive indirect effect via plant height (0.199) on marketable fruit yield per plant.

Further, days to first fruit harvesting (-0.169) and severity of buckeye rot (-0.326) recorded maximum negative indirect effect via number of fruits/plant on marketable fruit yield per plant. Similarly, plant height (-0.259), number of fruits/cluster (-0.316), number of fruits/plant (-0.234) and harvest duration (-0.156) recorded maximum negative indirect effect via fruit length on marketable fruit yield/plant. Fruit length (- 0.379), fruit breadth (-0.362), number of fruit clusters/plant (-0.133), number of locules/fruit (-0.161), shelf life (-0.168), pericarp thickness (-0.192) and total soluble solids (- 0.107) recorded maximum negative indirect effect via average fruit weight on marketable fruit yield/plant. Average fruit weight had maximum negative indirect effect via incidence of buckeye rot (-0.841) on marketable fruit yield/plant. At phenotypic level, the residual effect was recorded to be0.01676.

Naveen *et al*. (2017) reported that, maximum positive direct effect on marketable fruit yield per plant via number of fruit per plant and average fruit weight whereas maximum negative direct effect on marketable fruit yield per plant was shown by plant height. Singh *et al.* (2015b) also obtained similar results for fruit breadth, pericarp thickness, number of fruits/plant, average fruit weight, TSS and number of locules/fruit towards marketable fruit yield/ plant. Walia *et al.* (2018) reported similar results for pericarp thickness, number of locules/fruit, TSS, plant height, average fruit weight towards marketable fruit yield/plant. Kumar and Singh (2018) also reported similar findings for days to first fruit harvest, fruit diameter, average fruit weight, number of fruits/plant, number of locules/fruit, pericarp thickness and total soluble solids.

Table 4.9 Path coefficient analysis showing the direct and indirect effect of fourteen characters on marketable fruit yield per plant at phenotypic level

	DTFFH	PH	FL	FB	AFW	NFCPP	NFPC	NFPP	NLPF	HD	SL	PT	TSS	IBER	PCCMFYPP
DTFFH	**-0.060**	0.002	0.064	0.017	-0.007	0.005	0.009	-0.169	0.002	0.005	-0.052	0.064	0.002	-0.002	-0.120
PH	0.008	**-0.016**	-0.259	-0.078	0.100	-0.009	-0.005	0.147	0.003	-0.006	0.003	0.002	-0.001	0.001	-0.110
FL	-0.004	0.005	**0.856**	0.383	-0.379	-0.026	0.018	-0.178	0.012	0.004	0.033	-0.050	0.005	0.003	0.682**
FB	-0.001	0.002	0.475	**0.691**	-0.362	-0.022	0.008	-0.051	0.007	0.002	0.048	-0.066	0.002	0.006	0.739**
AFW	-0.001	0.004	0.767	0.592	**0.423**	-0.029	0.014	-0.110	0.011	0.003	0.049	-0.069	0.005	-0.841	0.818**
NFCPP	0.003	-0.002	0.242	0.164	-0.133	**-0.091**	0.028	0.107	0.003	-0.003	0.056	-0.048	0.009	0.001	0.336**
NFPC	0.011	-0.002	-0.316	-0.117	0.125	0.053	**-0.048**	0.441	-0.002	-0.010	0.011	-0.020	-0.003	0.004	0.127
NFPP	0.016	-0.004	-0.234	-0.054	0.071	-0.015	-0.032	**0.651**	0.000	-0.016	0.055	-0.054	0.005	0.007	0.396**
NLPF	-0.004	-0.002	0.357	0.176	-0.161	-0.009	0.003	0.006	**0.028**	0.004	-0.013	0.013	0.004	0.005	0.405**
HD	0.014	-0.004	-0.156	-0.073	0.062	-0.015	-0.022	0.474	-0.005	**-0.021**	0.060	-0.056	0.003	0.006	0.267*
SL	0.025	0.000	0.228	0.265	-0.168	-0.041	-0.004	0.289	-0.003	-0.010	**0.124**	-0.141	0.007	0.005	0.576**
PT	0.025	0.000	0.280	0.301	-0.192	-0.029	-0.006	0.233	-0.002	-0.008	0.115	**-0.152**	0.006	0.006	0.577**
TSS	-0.008	0.000	0.240	0.095	-0.107	-0.045	0.008	0.176	0.006	-0.004	0.046	-0.051	**0.018**	0.006	0.380**
IBER	-0.007	0.199	-0.250	-0.315	0.179	0.019	0.012	-0.326	-0.008	0.009	-0.054	0.067	-0.006	**-0.212**	-0.693**

*Significant at 5% level of significance
**Significant at 1% level of significance

Where,

DTFFH = Days to first fruit harvesting, PH = Plant height, FL = Fruit length, FB = Fruit breadth, AFW = Average fruit weight, NFCPP = Number of fruit clusters per plant, NFPC = Number of fruits per cluster, NFPP = Number of fruits per plant, NLPF = Number of locules per fruit, HD = Harvest duration, SL = Shelf life, PT = Pericarp thickness, TSS = Total soluble solids, IBER = Incidence of buckeye rot and PCCMFYPP = Phenotypic correlation coefficient with marketable fruit yield per plant.

Residual effect 0.01676

Diagonal figures represent the direct effect.

4.4 Genetic Divergence

Cluster analysis to get the overview of the 25 diverse genotypes of tomato has been presented in the table 4.10 for different attributes. Total 5 clusters were observed for all the genotypes. Maximum numbers of genotype were accommodated in cluster V (12) followed by cluster I (5), cluster III (4), cluster II (2) and cluster IV (2) respectively.

Table 4.10 Clustering pattern of twenty-five genotypes on the basis of genetic divergence

Cluster	Number of Genotypes	Genotypes along with their sources
I	**5**	Arka Alok (IIHR, Banglore), EC-802557 (AVRDC, Taiwan), EC-802561 (AVRDC, Taiwan), EC-802562 (AVRDC, Taiwan) and EC-802563 (AVRDC, Taiwan).
II	**2**	LC-2 (Solan) and Solan Lalima (UHF Nauni).
III	**4**	LC-1 (Bilaspur), LC-3 (Jachh), Pusa-120 (IARI, New Delhi) and Pant T-3 (GBPUAT, Pantnagar).
IV	**2**	Pusa Ruby (IARI, New Delhi) and EC-802555 (AVRDC, Taiwan).
V	**12**	Pusa Uphar (IARI, New Delhi), Pusa Sadabahar (IARI, New Delhi), Pusa Sheetal (IARI, New Delhi), Pusa Rohini (IARI, New Delhi), Arka Abha (IIHR, Banglore), Arka Vikas (IIHR, Banglore), Punjab Chhahara (PAU, Ludhiana), EC-802554 (AVRDC, Taiwan), EC-802556 (AVRDC, Taiwan), EC- 802558, (AVRDC, Taiwan), EC-802559 (AVRDC, Taiwan) and EC-802560 (AVRDC, Taiwan).

Group constellation of tomato genotypes through genetic divergence has also been reported by Kumar *et al.* (2016), Singh *et al*. (2016), Khapte *et al.* (2014b) and Prashanth *et al.* (2008).

Average intra (Diagonal) and inter- cluster (Lower half diagonal) distance (D^2) values have been presented in the table 4.11 which represents the intra cluster distance, which was maximum in cluster IV (5.782) followed by cluster III (5.017), cluster I (4.970) and cluster II (4.743) whereas, minimum in cluster V (4.006). The maximum inter cluster distance (6.827) was recorded between IV and I and minimum (3.910) was observed between cluster V and I.

Table 4.11: Average intra (Diagonal) and inter- cluster (Lower half diagonal) distance (D^2).

Clusters	I	II	III	IV	V
I	4.970				
II	4.899	4.743			
III	5.996	6.018	5.017		
IV	6.827	5.668	5.238	5.782	
V	3.910	4.893	4.838	5.965	4.006

A wide range of intra and inter cluster genetic distance among the different cluster of tomato genotypes have also been reported by Spaldon and Kumar (2017) and Ullah *et al.* (2015)

Table 4.12 is representing the cluster means for various horticultural traits. Minimum days taken to first fruit harvesting were recorded in cluster II (64.66) and cluster IV (64.66) followed by cluster V (70.00), cluster I (70.20) and Cluster III (73.17). Maximum plant height was recorded in cluster IV (87.87) followed by cluster II (87.46), cluster III (73.05), cluster I (69.03) and cluster V (66.78). Maximum fruit length was observed in cluster I (5.70) followed by cluster II (5.26), cluster V (5.14), cluster III (4.09) and cluster IV (3.55). Maximum fruit breadth was observed in cluster I (5.66) followed by cluster II (5.49), cluster V (5.03), cluster III (4.20) and cluster IV (4.18). For average fruit weight highest mean was observed in cluster I (73.56) followed by cluster II (66.34), cluster V (59.78), cluster III (39.36) and cluster IV (35.49). Maximum number of fruit clusters /plant was observed in cluster I (6.21) followed by cluster IV (5.82), cluster II (5.80), cluster V (5.55) and cluster III (5.09). Maximum number of fruits/cluster was observed in cluster IV (4.77) followed by cluster II (4.05), cluster V (3.83), cluster III(3.64) and cluster I (3.19). For number of fruits per plant highest mean was observed in cluster IV (27.75) followed by cluster II (23.22), cluster V (20.79), cluster I (19.50) and cluster III (18.58). Maximum number of locules per fruit was observed in cluster II (4.33) followed by cluster V (3.75), cluster I (3.60), cluster III (3.25) and cluster IV (2.66). For harvest duration, highest mean was observed in cluster IV (43.00) followed by cluster II (37.66), cluster V (31.30), cluster I (26.93) and cluster III (26.34). For shelf life highest mean was observed in cluster II (25.50) followed by cluster I (25.33), cluster IV (24.84), cluster V (21.61) and cluster III (16.66).

Maximum pericarp thickness was observed in cluster II (7.15) followed by cluster I (7.07), cluster IV (6.88), cluster V (6.49) and cluster III (5.05). For total soluble solids highest mean was observed in cluster II (4.92) followed by cluster I (4.62), cluster V (4.51), cluster III (4.32) and cluster IV (4.26). For incidence of buckeye rot lowest mean was observed in cluster II

(22.12) followed by cluster V (25.44), cluster IV (26.84), cluster I (26.89) and cluster III (30.23). Maximum marketable fruit yield per plant was observed in cluster II (1.54) followed by cluster I (1.44), cluster V (1.24), cluster IV (0.97) and cluster III (0.74). Similar findings had also been reported by Kumar *et al.* (2016), Nalla *et al.* (2014), Spaldon and Kumar (2017) and Singh *et al.* (2016).

Table 4.12 Cluster means for different characters among twenty-five genotypes of tomato

Characters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Days to first fruit harvesting (number)	70.20	64.66	73.17	64.66	70.00
Plant height (cm)	69.03	87.46	73.05	87.87	66.78
Fruit length (cm)	5.70	5.26	4.09	3.55	5.14
Fruit breadth (cm)	5.66	5.49	4.20	4.18	5.03
Average fruit weight (g)	73.56	66.34	39.36	35.49	59.78
Number of fruit clusters per plant	6.21	5.80	5.09	5.82	5.55
Number of fruits per cluster	3.19	4.05	3.64	4.77	3.83
Number of fruits per plant	19.50	23.22	18.58	27.75	20.79
Number of locules per fruit	3.60	4.33	3.25	2.66	3.75
Harvest duration (days)	26.93	37.66	26.34	43.00	31.30
Shelf life (days)	25.33	25.50	16.66	24.84	21.61
Pericarp thickness (mm)	7.07	7.15	5.05	6.88	6.49
Total soluble solids (°Brix)	4.62	4.92	4.32	4.26	4.51
Buckeye rot incidence (%)	26.89	22.12	30.23	26.84	25.44
Marketable fruit yield per plant (kg)	1.44	1.54	0.74	0.97	1.24

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled **"Genetic evaluation of tomato (*Solanum lycopersicum* L.) germplasm for yield and quality traits"** was conducted at the RHR & TS, Jachh, Kangra, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during the year 2018. Twenty-five diverse genotypes of tomato comprising of eleven varieties, ten exotic lines and three local collections along with one standard check Solan Lalima were evaluated.

The characters studied during the evaluation of germplasm were days to first fruit harvesting, plant height (cm), fruit length (cm), fruit breadth (cm), average fruit weight (g), number of fruit clusters/plant, number of fruits/cluster, number of fruits/plant, number of locules/fruit, harvest duration (days), shelf life (days), pericarp thickness (mm), total soluble solids (°B), buckeye rot incidence (%) and marketable fruit yield per plant (kg) & per hectare (q).

MEAN PERFOMANCE

Parameters of variability, correlation, path coefficient analysis and genetic divergence were carried out. Analysis of variance revealed highly significant variations among all the genotypes for all the horticultural characters under study. Genotype LC-2 took minimum number of days to first fruit harvesting followed by Pusa Ruby, Pusa Sadabahar and Punjab Chhuhara whereas genotype Pusa Rohini took maximum days. Maximum plant height was recorded in Pusa Ruby whereas minimum plant height was recorded in Arka Alok. Maximum fruit length was recorded in EC-802562 followed by EC-802563, EC-802561, EC-802557, Punjab Chhuhara and Arka Vikas whereas minimum fruit length was observed in EC- 802555. Maximum fruit breadth was observed in Arka Alok followed by LC-2, EC-802557 and EC-802562 however, minimum was recorded in LC-3. Average fruit weight was observed highest in EC-802562 followed by Arka Alok and EC-802563 whereas minimum was recorded in LC-3. Maximum number of fruit clusters/plant was observed in EC-802563 followed by EC-802562 while minimum number of fruit clusters/plant was observed in Pusa Uphar. Maximum number of fruits/cluster was observed in Pusa Uphar while minimum number of fruits/cluster was observed in EC-802563 followed by EC-802559. Genotype EC-802555 recorded maximum number of fruits/plant while minimum number of fruits/plant was observed in LC-1. Genotype EC-802555 recorded minimum number of locules/fruit whereas maximum number of locules/fruit was observed in Arka Abha. Longest harvesting duration was recorded in genotype EC-802555 while, shortest harvest duration was observed in EC-802563 followed by EC-802561, Arka Alok and Pusa Sadabahar. Longest shelf life was recorded in genotype EC-802562 followed by EC-802557 (30.33 days), whereas, shortest shelf life was observed in LC-3. Maximum value for pericarp thickness was recorded in EC-802562 while minimum was observed in LC-3. Maximum value for total soluble solids was recorded in LC-2 while minimum value was recorded in Pusa Ruby. LC-2 and Arka Vikas were observed moderately susceptible to buckeye rot incidence while LC-1 was found susceptible. Maximum fruit yield was recorded in EC-802557 followed by Arka Alok and LC-2 while, minimum fruit yield was recorded in LC-3.

PARAMETERS OF VARIABILITY

Among various parameters of variability, the phenotypic and genotypic coefficients of variability were high for average fruit weight, number of locules per fruit, harvest duration and marketable fruit yield per plant. The magnitude of PCV was slightly higher than the magnitude of GCV for all the characters under study. High heritability estimates were recorded for all the characters among all genotypes under study. While high heritability coupled with high genetic gain was observed for marketable fruit yield/plant, average fruit weight, harvest duration, shelf life, number of fruits/cluster, number of locules/fruit, number of fruits/plant, fruit breadth, pericarp thickness, fruit length, number of fruit clusters/plant and plant height. High heritability coupled with high genetic advance indicates that additive gene action plays an important role in governing these traits and these traits can be improved by simple selection.

CORRELATION STUDIES

Correlation coefficients were high at genotypic level than phenotypic level. Results indicated that marketable fruit yield per plant had positive and significant correlation with fruit length, fruit breadth, average fruit weight, number of fruit clusters/plant, number of fruits/plant, number of locules/fruit, harvest duration, shelf life, pericarp thickness and total soluble solids. Hence, there is a wide scope of selection for these characters. However, negative and significant correlation of marketable fruit yield per plant was observed with incidence of buckeye rot.

Table 5.1 Best three genotypes with respect to different traits in tomato

Characters	Genotypes	Mean
Days to first fruit harvesting (number)	LC-2	62.00
	Punjab Chhuhara	62.33
	Pusa Ruby	64.00
Plant height (cm)	Pusa Ruby	98.87
	LC-2	87.96
	Solan Lalima	86.95
Fruit length (cm)	EC-802562	5.89
	EC-802563	5.87
	EC-802561	5.63
Fruit breadth (cm)	Arka Alok	5.96
	LC-2	5.75
	EC-802557	5.70
Average fruit weight (g)	EC-802562	76.65
	Arka Alok	75.62
	EC-802563	74.91
Number of fruit clusters per plant	EC-802563	7.20
	EC-802562	6.87
	EC-802559	6.60
Number of fruits per cluster	Pusa Uphar	5.65
	EC-802555	5.05
	Pusa Ruby	4.48
Number of fruits per plant	EC-802555	30.60
	Pusa Ruby	24.90
	Pusa Rohini	24.43
Number of locules per fruit	EC-802555	2.33
	EC-802560	2.67
	EC-802562	3.00
Harvest duration (days)	EC-802555	46.67
	Pusa Rohini	42.00
	EC-802556	41.33
Shelf life (days)	EC-802562	31.33
	EC-802557	30.33
	LC-2	29.00
Pericarp thickness (mm)	EC-802562	7.85
	EC-802557	7.78

	LC-2	7.63
Total soluble solids (°B)	LC-2	5.10
	EC-802557	5.03
	Arka Abha	5.00
Buckeye rot incidence (%)	LC-2	20.05
	Arka Vikas	22.32
	EC-802554	23.61
Marketable fruit yield per plant (kg)	EC-802557	1.68
	LC-2	1.61
	Arka Alok	1.59

PATH COEFFICIENT ANALYSIS

Maximum positive direct effect towards marketable fruit yield/plant was contributed by average fruit weight followed by fruit length, number of locules/fruit, fruit breadth and total soluble solids as observed using the path coefficient analysis. Thus, indicating direct selection for these traits as criteria for improvement in tomato.

GENETIC DIVERGENCE

In the present studies, on the basis of genetic divergence, 25 genotypes were grouped in to five clusters and maximum inter cluster distance was recorded between cluster I and IV and lowest was observed between cluster I and V. Therefore, the hybridization among the genotypes of cluster I and IV can be utilized to obtain superior hybrids or recombinants in segregating generations.

CONCLUSION

- On the basis of overall performance, out of 25 genotypes, EC-802557, LC-2 and Arka Alok were found superior for marketable fruit yield and other important characters.
- The estimates of PCV and GCV were high for marketable fruit yield/plant, number of locules/fruit, average fruit weight, harvest duration, shelf life and number of fruits/cluster.
- High heritability was observed for all the characters among all genotypes.
- Genetic advance was observed high for marketable fruit yield per plant, average fruit weight, harvest duration, shelf life, number of fruits/cluster, number of locules/fruit, number of fruits/plant, fruit breadth, pericarp thickness, number of fruit cluster/plant, fruit length and plant height.
- A positive and significant correlation coefficient of marketable fruit yield per plant at genotypic and phenotypic level was observed for fruit length, fruit breadth, average fruit weight, number of fruit clusters/plant, number of fruits/plant, number of locules/fruit, harvest duration, shelf life, pericarp thickness and total soluble solid whereas it was negatively and significantly correlated with incidence of buckeye rot.

- In path coefficient analysis at genotypic level, average fruit weight, fruit length, number of locules/fruit, harvest duration, pericarp thickness, fruit breadth, total soluble solids and days to first fruit harvesting had positive and direct effects on marketable fruit yield per plant.

- In path coefficient analysis at phenotypic level, fruit length followed by fruit breadth, number of fruits/plant, average fruit weight, shelf life, number of locules/fruit and total soluble solids had positive and direct effects on marketable fruit yield/plant.

- The intra-cluster distance was recorded maximum in cluster IV and minimum in cluster V. The inter cluster distance was maximum to the tune of between cluster I and IV. The minimum inter cluster distance was observed for cluster I and V.

- For quality traits like shelf life, pericarp thickness and TSS, genotypes EC-802557 and LC-2 were found significantly superior to all other genotypes.

- Therefore, two genotypes *viz.* EC-802557 and LC-2 with high marketable fruit yield and good quality traits after multi location testing can be recommended for commercial cultivation in Himachal Pradesh.

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APPENDIX-I

Analysis of variance for various horticultural traits in tomato

Source	**Mean sum of squares**			
Character	**Replications**	**Genotypes**	**Errors**	**Total**
Df	**2**	**24**	**48**	**74**
Days to first fruit harvesting (number)	7.547	77.720	2.607	1,997.947
Plant height (cm)	15.473	255.647	5.753	6,427.155
Fruit length (cm)	0.036	1.471	0.045	37.521
Fruit breadth (cm)	0.010	1.617	0.034	40.479
Average fruit weight (g)	6.462	552.404	11.359	13,809.408
Number of fruit clusters per plant	0.021	1.789	0.070	46.328
Number of fruits per cluster	0.004	1.626	0.079	42.811
Number of fruits per plant	0.022	36.267	1.644	949.342
Number of locules per fruit	0.080	1.861	0.276	58.000
Harvest duration (days)	5.040	149.952	2.367	3,717.520
Shelf life (days)	0.507	56.222	1.517	1,422.667
Pericarp thickness (mm)	0.029	2.702	0.132	71.207
Total soluble solids (□B)	0.213	0.501	0.062	15.205
Buckeye rot incidence (%)	3.381	29.833	1.899	810.513
Marketable fruit yield per plant (kg)	0.013	0.288	0.008	7.283

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Abstract

The present investigation entitled **“Genetic evaluation of tomato (*Solanum lycopersicum* L.) germplasm for yield and quality traits”** was conducted at the experimental farm of RHR&TS, Jachh, Kangra, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during the year 2018. Twenty five diverse genotypes of tomato comprising of eleven varieties, ten exotic lines and three local collections along with one standard check Solan Lalima were evaluated in Randomized Complete Block Design with three replications to ascertain extent of variability, heritability, genetic advance and gain, correlation and path coefficient analysis for yield and other horticultural traits along with the estimation of genetic divergence among the genotypes. Analysis of variance revealed significant differences among all the genotypes for all the characters under study. On the basis of overall performance, EC-802557, LC-2 and Arka Alok were found superior for marketable fruit yield and other important horticultural traits. They could be the promising parents for utilization in further breeding programmes. The estimates of PCV and GCV were high for marketable fruit yield per plant, number of locules per fruit, average fruit weight, harvest duration, shelf life and number of fruits per cluster. High heritability estimates were observed for all the traits among all genotypes while high estimates of genetic gain were observed for marketable fruit yield per plant, average fruit weight, harvest duration, shelf life, number of fruits per cluster, number of locules per fruit, number of fruits per plant, fruit breadth, pericarp thickness, number of fruit cluster per plant, fruit length and plant height. The correlation studies revealed that marketable fruit yield per plant had positive and significant correlation with fruit length, fruit breadth, average fruit weight, number of fruit clusters per plant, number of fruits per plant, number of locules per fruit, harvest duration, shelf life, pericarp thickness and total soluble solids. The path coefficient analysis revealed that maximum positive direct effect towards marketable fruit yield per plant was contributed by average fruit weight followed by fruit length, number of locules per fruit, fruit breadth and total soluble solids. Under genetic divergence studies, 25 genotypes were grouped in to five clusters and maximum inter cluster distance was recorded between cluster I and IV and lowest was observed between cluster I and V. Therefore, hybridization among the genotypes of cluster I and IV can be utilized to obtain superior hybrids or recombinants in later segregating generations.

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