

**STABILITY ANALYSIS FOR GROWTH, YIELD AND
QUALITY CHARACTERS IN TOMATO
(*Solanum lycopersicum* L.)**

Thesis

by

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(H-2020-88-D)**

submitted to



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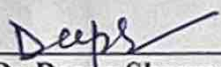
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CERTIFICATE-I

This is to certify that the thesis titled “**Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173 230 is a bonafide research work carried out by **Mr. Nikhil Thakur (H-2020-88-D)** son of Shri Dharam Paul Thakur 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 this investigation have been fully acknowledged.

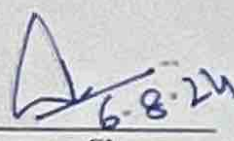
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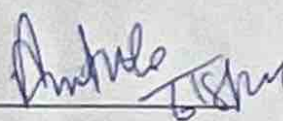
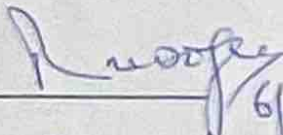
This is to certify that the thesis titled, "Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)" submitted by Mr. Nikhil Thakur (H-2020-88-D) son of Shri Dharam Paul Thakur to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) – 173 230 India in partial fulfilment of the requirements for the degree of Doctor of Philosophy 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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Gratitude is the fairest blossom which springs from the soul. - Henry Ward Beecher

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Errors and omissions are solely my responsibility.

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	AEA	average environment axis
2	AEC	average environment coordinate
3	amsl	above mean sea level
4	ANOVA	analysis of variance
7	cm	centimeter
8	df	degrees of freedom
9	E	east
10	et al.	et alii (and others)
11	Fig.	figure
12	g	gram
13	GGE	genotype+ (genotype× environment)
14	GCV	genotypic coefficient of variation
15	ha	hectare
16	<i>i.e.</i> ,	id est (that is)
17	kg	kilogram
18	L.	linnaeus
19	l	litre
20	m	meter
21	ml	milliliter
22	mg	milligram
23	mm	millimeter
24	N	north
25	PCV	phenotypic coefficient of variation
26	<i>viz.</i> ,	videlicet (namely)
27	&	and
28	@	at the rate
29	v/s	against
30	°B	degree brix
31	°C	degree celsius
32	≤	less than equal to
33	/	per
34	%	per cent

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Chapter - 1

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a true diploid ($2n=2x=24$) belongs to the family Solanaceae and it is indigenous to Peru- Ecuador region (Rick, 1965). It is a major vegetable that is widely cultivated all over the world. Although, tomatoes are mostly a day-neutral crop and a self-pollinating species, where cross-pollination upto 5% through insects has been reported by Ghadage et al. (2020). The growth habits of the plants are determinate, semi-determinate and indeterminate. Consumption of tomato has increased tremendously due to its numerous uses *i.e.* raw salads, as cooked vegetables and variety of processed products such as soup, ketchups, sauces, preserves, paste and puree (Tiwari and Upadhyay, 2011). Its soup is served as an appetizer and suggested for patients suffering from constipation. Tomato is also an important ingredient in the cocktail "Bloody Marry".

Tomato is referred to as poor man's orange in many nations because of its attractive appearance and nutritive value (Bhutani and Kallo, 1983). It is known as "protective food" since it is a crucial source of antioxidants or chemo-protective substances and is high in minerals, vitamins, essential amino acids, sugar and dietary fiber, which works to the slow growth of cancerous cells, prevents the prostate, colorectal and stomach cancers (Castagna et al. 2013). Lycopene is the primary carotenoid, which has important dietic properties as it lowers the risk of different types of cancers and heart ailments.

Tomatoes are loaded with many health supplements such as coumaric and chlorogenic acid and may restore lung damage caused by cigarette smoking. Potassium in tomato helps in lowering the blood pressure and prevents heart strokes. According to the Centers for Disease Control and Prevention, during pregnancy vitamin C in tomato helps to protect both the woman and the baby (Joye et al. 2003). Fraser et al. (1991) reported decreased risk of cancer with the intake of tomato. Tomato can be grown throughout the year. It is more flourishing where there are long sunny periods. Optimum growing temperatures are 21 °C to 24 °C. At these temperatures, good quality seeds take about seven days to emerge. Temperature also affects flowering and pollination. The hot and dry weather leads to drying of flowers and stops pollination. If temperature is below 15°C or above 29°C, pollen fails to release which results in incomplete fertilization of ovules (Peirce, 1987).

Tomatoes are planted worldwide on an area of 50,51,983 ha with the production of 1,86,821 thousand MT. In India, it is grown on an area of 789 thousand hectares with production of 19,759 thousand MT (Anonymous, 2022a). Whereas, in Himachal Pradesh, it is cultivated in about 13,795 ha area with a production of 5,77,004 MT (Anonymous, 2022b). It is an important cash crop for small and marginal vegetable growers of the hilly areas. It is grown as an off-season crop in hilly regions which fetches premium prices in the markets of surrounding states like Punjab, Haryana and Delhi during rainy season (Dishri et al. 2017). For the transport of off-season tomatoes to distant markets, they should possess oval to round fruit shape with thick pericarp, high TSS, low number of locules and smooth blossom end without any depression or scar. The tomato fruiting season in Himachal Pradesh coincides with the rainy season. High rainfall limits the fruiting season. Hence, cultivars with extended harvest seasons should be cultivated to meet the needs of farmers and consumers.

The climatic conditions of Himachal Pradesh are ideal not only for the production but also for quality seed production which offers a great scope for production and export of quality seed to rest of the country. It is necessary to identify and develop varieties or hybrids having stable performance over varied soil and environmental conditions of Himachal Pradesh. Fruit yield and quality are the key traits of most tomato breeding programmes nowadays. The major fruit quality characters of interest to both fresh market and processing industries are fruit shape, size, total solids, lycopene, β -carotene, firmness, nutritional quality, flavour, titratable acidity, pH and vitamin contents (Foolad, 2007).

An insight into the magnitude of genetic diversity present in a crop provides the basis for effective selection (Chaudhari et al. 2019) and an opportunity to improve the yield and quality through strategic breeding programme (Singh et al. 2009). A huge amount of the variability increases the chance of selecting the desirable types and the response of variation. Most of the desirable traits are quantitative in nature and their expression is influenced by the environment. These traits exhibit continuous variation and are under the control of heritable and non-heritable factors (Fisher, 1918). The response of selection depends upon the relative proportion of the heritable component in the continuous variation which is due to genotype while the non-heritable portion is mainly due to the environmental factors. Hence, it is essential to partition overall variability into heritable and non-heritable components with the help of genetic parameters namely, coefficient of variation, heritability and genetic advance.

Since yield is a complex trait, indirect selection through correlated, less complex and easily measurable traits would be an advisable approach to increase the yield. Efficacy of indirect selection depends upon the magnitude of association between yield and yield contributing traits (Esposito et al. 2009). Correlation coefficient, in general, shows association among characters which is not sufficient to describe their relationship when the causal association among characters is needed (Toker and Cagiran, 2004). Direct selection of one of the characters on the basis of genetic correlation between two traits may cause change in the other. The correlation per se does not give the complete picture of their interrelationships when more than two variables are involved (Fakorede and Opeke, 1985).

The path analysis has been used by the breeders (Ali et al. 2009) to identify traits which is useful selection criteria to improve crop yield as it identifies the causes, measures the relative importance of the association and is used to determine the amount of direct and indirect effect of causal components on the yield component (Dewey and Lu, 1959). Therefore, determination of correlation and path-coefficients between yield and yield components is important for the selection of desirable plant types for tomato breeding programmes.

It has been noticed that the effectiveness of different varieties of any crop usually varies from location to location and even more markedly, from season to season. A single experiment will precisely furnish information about only one place or one season in which the experiment is conducted. It has thus, become a common practice to repeat an experiment at different places or over a number of years to obtain valid recommendations taking into account place to place variation or variation over time or both (Asilo et al. 2019). In such cases of repeated experiments, appropriate statistical procedures for a combined analysis of the data would have to be followed. Phenotypically stable lines of tomato are of great importance because the environmental conditions under which it is grown differ from zone to zone and even within the same zone having different agro-ecological situation.

In the process of developing novel varieties, genotype-environment interactions have significant consequences to the breeder. As a result, breeders generally agree that genotype-environment interaction has a significant impact on developing better varieties. Since, genotype-environment interaction has a masking effect on the performance of genotypes, the relative ranking of the genotypes does not remain the same when tested over number of environments which benefits breeders in producing stable and high yielding genotypes

(Mamta et al. 2022). Precise knowledge on the nature and magnitude of genotype $\times$ environment interactions is important in understanding the stability in yield of a particular variety or hybrid before it is recommended for a given situation.

Significant advances have been made in the measurement of contribution of genotypes to the genotype-environment interaction and in identifying stable genotypes. The model of Eberhart and Russel (1966), based on regression technique, is an important and powerful statistical procedure to measure the phenotypic stability in the performance of genotypes, where an ideal genotype is one having high mean, unit regression and least deviation from the regression slope.

Testing of genetic materials under different environments differing in unpredictable variation is an accepted approach for selecting stable genotypes (Eberhart and Russel, 1966). In order to identify stable genotypes, the genotype-environment interactions must be portioned into stability statistics that are assignable to each genotype evaluated across a range of environments. Stability indices have allowed researchers to identify widely-adapted genotypes for use in breeding programmes (Yan and Tinker, 2006). The stable genotypes may subsequently be used for cultivation on a wide range of environments and also serve as base materials for future breeding programmes. Keeping these facts in view, the study entitled “**Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)**” was proposed with following objectives:

Objectives

1. To estimate the extent of genetic variability for yield and quality traits in different genotypes of tomato
2. To find out the correlation for yield and quality traits
3. To study the genotype $\times$ environment interaction for yield and quality traits

Chapter - 2

REVIEW OF LITERATURE

The primary aim of any breeding programme is to evolve varieties with superior yield, desirable maturity, resistance to biotic and abiotic stresses and improved quality. The critical assessment of nature and magnitude of genetic variability, genetic diversity, association of characters with yield and path coefficient analysis are most important to plan effective strategies for crop improvement. The knowledge also aids in obtaining superior varieties with high yield potential and other desirable characters.

Stability analysis for growth, earliness, yield and yield attributing traits are very important from the point of stable production of tomatoes and to avoid glut or scarcity in the market. Yielding capacity of any crop depends upon the genetic make-up of the plant as well as suitable environment for the genotype to express its yield potential. Genotype $\times$ environment interactions play a significant role in the development of improved plant varieties that can withstand the unpredictable changing conditions. It is only possible when we possess knowledge about past research undertaken in the relevant field.

Extensive work had been done in field crops on these aspects which is very useful in getting an understanding of the nature and magnitude of varieties and genotype $\times$ environment interaction. The relevant literature available on major aspects of present study has been reviewed briefly under the following subheadings:

2.1 Genetic variability

2.2 Heritability and Genetic advance

2.3 Correlation studies

2.4 Path coefficient analysis

2.5 Stability analysis studies

2.1 Genetic variability

Genetic variability is considered as an essential prerequisite for plant improvement programme for obtaining high yielding progenies. Sufficient genetic variability, if present, can be exploited for developing superior cultivars. Fisher (1918) was the first to divide genetic variance into three components i.e., additive, dominance and epistatic variances and partitioned

the continuous variation exhibited by a quantitative character into heritable and non-heritable components. The heritable component is a consequence of genotypic constitution while the non-heritable portion is the result of environmental influence. Johanssen (1909) revealed that variation within the pure lines was environmental (non-heritable) while that between the lines was heritable. In plant improvement, only the genotypic component of variation is important to plant breeders as only this component is transmitted to the next generation. Since phenotype is the result of interaction between genotype and environment and selection pressure is exercised on the phenotype, therefore it is important to score the phenotypic variability expressed in population for yield and other contributing traits.

Genetic variability is a measure of the tendency of individual genotypes in a population to vary from one another. Genetic variability for yield and yield components is essential in the base population for successful crop improvement (Allard, 1960). Variability is different from genetic diversity which is the amount of variation seen in a particular population. Genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (h^2) and genetic advance are commonly used in describing the variability and genetics of a character.

Asati et al. (2008) observed significant variations among various genotypes in tomato for all traits examined, with phenotypic coefficients of variation generally surpassing genotypic coefficients of variation. The variation between the accessions based on coefficient of variability was greater in traits for number of fruits per plant followed by number of flowers per plant with coefficient of variability and yield per plant.

Madhurina and Amitava (2012) studied genetic variability and characters association of different fruit quality parameters in fifteen tomato genotypes grown in a two-year field experiment. High and moderate to high GCV and PCV were recorded for number of locules per fruit, fruit weight, total acid, number of fruits per plant, vitamin C, fruit yield per plant, fruit length and pericarp thickness.

Ahirwar et al. (2013) studied nineteen genotypes of tomato. Significant differences were observed among the genotypes for all the traits. The phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the traits.

Shankar et al. (2013) studied thirty five genotypes to study the genetic variability indicated that genetic material in the present investigation possessed variability which provides

sufficient basis for selection by breeder. High estimates of PCV and GCV were obtained for plant height, number of fruits per cluster, average fruit weight, yield per plant, titrable acidity, ascorbic acid and lycopene indicated a good deal of variability in those characters signifying the effectiveness of selection of desirable types for improvement. Hence, simple selection based on phenotypic performance of these traits would be more effective.

Kumar et al. (2013) conducted experiment on thirteen genotypes along with two checks of tomato. The maximum genotypic and phenotypic variation was for plant height and minimum for fruit shape index, respectively. Analysis of coefficient of variation revealed that magnitude of phenotypic coefficient was higher than genotypic coefficient of variation for all the characters except primary branches per plant under study. The magnitude of genotypic and phenotypic coefficient of variation was higher for number of fruits per cluster and lycopene content, respectively.

Sidhya et al. (2014) carried out investigation for six cultivars of tomato. Analysis of variance studies indicates significant differences among all the genotypes for all the characters under study. Majority of the characters like plant height, fruits per plant, fruit weight, equatorial fruit diameter, polar fruit diameter, fruit yield per plant exhibit moderate PCV, GCV values and seeds per fruit exhibits higher GCV and PCV values indicating greater variation for these traits and greater scope for further improvement by genetic manipulation.

Madhukar et al. (2015) evaluated thirty-nine tomato genotypes for ten quantitative traits to observe the nature and magnitude of variability. Analysis of variance revealed that the differences among thirty-nine genotypes were significant for all the traits. The parameters such as days to flowering, days to ripening, plant height, number of branches per plant, number of fruits per cluster, fruit length, fruit width, number of locules per fruit, number of fruits per plant and fruit weight per plant exhibited minor disparities between the genotypic coefficient of variation (GCV) and the phenotypic coefficient of variation (PCV).

Singh et al. (2015) evaluated thirty-five genotypes of tomato for yield and various yield attributing characters. The experiment was laid out in Randomized Complete Block Design with three replications. Observations were recorded on thirteen quantitative characters viz., days to 50 per cent flowering, plant height, number of primary branches per plant, fruit diameter, fruit length, number of locules per fruit, pericarp thickness, average fruit weight, total soluble solids, number of fruits per plant, number of unmarketable fruits per plant, number of marketable fruits per plant and fruit yield per plant. High amount of GCV and

PCV were observed for all the traits except days to 50 per cent flowering, which showed very low variability.

Kumar et al. (2015) conducted investigation on thirteen genotypes and their thirty crosses along with two checks of tomato. The maximum genotypic and phenotypic coefficients of variation was for plant height and minimum for titratable acidity, respectively. Analysis of coefficient of variation revealed that magnitude of phenotypic coefficient was higher than genotypic coefficient of variation for all the yield and quality characters. The magnitude of genotypic and phenotypic coefficient of variation was higher for pericarp thickness, respectively.

Amarjeet et al. (2016) studied genetic variability among fifty-six genotypes of tomato with three replications. Analysis of coefficient of variation revealed that the magnitude of phenotypic coefficient of variation was slightly higher than the genotypic coefficient of variation for all the traits.

Shweta et al. (2016) carried out investigation with thirty-six genotypes to study the genetic variability and diversity for quantitative traits in tomato during summer and late seasons of 2014. Analysis of variance revealed considerable amount of variability for the sixteen and nineteen quantitative characters in summer and late seasons, respectively. High GCV and PCV was observed for most of the yield attributing characters in both seasons. It appears to be containing most potential genotypes and these can be utilized in further crop improvement programme.

Singh and Janeja (2018) evaluated fifteen genotypes of tomato in randomized complete block design for fruit yield and yield contributing traits. Observations were recorded for important fruit and agronomic traits viz., number of clusters per plants, number of flower per cluster, number of fruits per plant, fruit yield per plant, fruit length, fruit width, average fruit weight, plant height, number of primary branches in a plant, days to 50% flowering, days taken to first harvest and days taken to last harvest. Relatively high magnitude of significant variation was observed for all characters. Phenotypic coefficient of variance was higher than genotypic coefficient of variance except days to last harvest. Most of the characters showed high percentage of PCV and GCV.

Meena et al. (2018) carried out experiment at Lucknow consisting fifteen genotypes of tomato and reported that maximum phenotypic and genotypic variance was observed for average fruit weight. The highest of PCV and GCV was estimated for fruit yield per plant.

Namdey et al. (2018) reported high genetic variability for number of fruits per plant, fruit yield per plant, fruit weight, number of flowers per cluster, number of locules per fruit and TSS, while the lowest value recorded for days to first picking, percentage of fruit set, days to first fruit set, days to 50% flowering and plant height 60 days after transplanting.

Mishra and Pandey (2018) revealed that the phenotypic coefficient of variation was higher than the corresponding genotypic coefficient of variation for all the traits. A high phenotypic and genotypic coefficient of variation was recorded for fruit yield per plant followed by the number of fruits per plant, number of flowers cluster, number of flower clusters per plant and number of fruits per cluster.

Sinha et al. (2019) evaluated fourteen genotypes at Sabour to assess the genetic variability and character association for yield attributing traits in tomato genotypes for protected conditions and recorded data for 16 morphological and 5 biochemical traits. The results revealed considerable differences among the genotypes for all the traits except titratable acidity and Beta-carotene. Higher PCV and GCV were observed for number of flowers truss, number of locules per fruit, number of fruits per truss, fruit yield per plant, number of fruits per plant, average weight of fruit, plant height at final stage of harvesting, titratable acidity, ascorbic acid and Beta-carotene indicating phenotypic selection. Genetic variation is not only due to genotypic but also due to the influence of environmental factors.

Chaudhari et al. (2019) reported that the magnitude of the phenotypic coefficient of variability was higher than the corresponding genotypic coefficient of variability for all the traits studied. High phenotypic and genotypic coefficient of variability values were recorded for the traits such as number of fruits per plant, test seed weight, average fruit weight, yield per plant, plant height and number of locules per fruit.

Maurya et al. (2020) studied thirty genotypes of tomato and revealed that these genotypes exhibited a wide range of variability for all the characters and PCV was higher than GCV for all the characters studied.

Rawat et al. (2020) studied fifty-nine genotypes to determine the extent of variability present in the experimental material for yield and yield attributing traits. Analysis of variance revealed the presence of high variability for all the fourteen characters studied. High magnitude of PCV and GCV were found for number of fruits per plant, average fruit weight, fruit yield and ascorbic acid.

Bamaniya et al. (2020) conducted an experiment to study the growth and yield parameters of twelve hybrids of tomato. Observations on traits related to plant morphology, maturity and yield components were recorded to develop, evaluate, identify and recommend high yielding hybrids of tomato. The assessments indicated significant PCV and GCV values for parameters such as fruit yield per hectare, plant height, number of flower clusters per plant, fruit yield per plot (kg) and days to fruit initiation.

Anuradha et al. (2020) conducted an experiment on forty tomato genotypes and observed significant differences among genotypes in all characters studied. High genetic variability was observed for the number of primary branches per plant, number of fruits per plant, average fruit weight, fruit yield per plant and yield per hectare revealing the significance of these characters for being used for selecting superior genotypes.

Eppakayala et al. (2021) showed high PCV and GCV for fruit weight, yield and total soluble solids due to the existence of wider genetic variability in the genotypes and a narrow range of genetic variability having low PCV and GCV in fruit set, days to first harvest and ascorbic acid content.

Maurya et al. (2022) studied the genetic variability and character association among important yield and attributing traits was studied in twenty genotypes of tomato. The magnitude of the phenotypic coefficient of variation (PCV) for all characteristics was higher than the magnitude of the genotypic coefficient of variation (GCV).

Sahoo et al. (2022) conducted a study examined genetic variability of forty-six advanced tomato lines to determine the association between yield and morphological traits. Most of the traits studied under this experiment had higher phenotypic coefficient values than genotypic coefficient values indicating the expression of environmental influences.

Pooja et al. (2022) conducted a study on forty-one genotypes of tomato to study genetic variability. The analysis of variance revealed highly significant variation among the genotypes for all the characters studied indicating considerable amount of variability among the genotypes. High genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for average fruit weight, fruit volume, number of fruits per plant, number of locules per fruit, yield per plant, yield per plot, yield per hectare, ascorbic acid, pericarp thickness and titratable acidity.

Thakur et al. (2022) studied twenty-three diverse genotypes of tomato which were replicated thrice to ascertain the extent of variability for yield and other horticultural traits among the genotypes. Analysis of coefficient of variation revealed that the magnitude of the phenotypic coefficient of variation was slightly higher than the genotypic coefficient of variation for all the studied traits.

2.2 Heritability and Genetic advance

Heritability may be defined as the ratio of genotypic variance to the phenotypic variance. If heritability of a character is very high, a selection for the character is easy. This is because as there would be a closure correspondence between genotype and phenotype due to a relatively smaller contribution of environment to the phenotype but for the character with low heritability, a selection may be considerably difficult due to masking effect of environment on the genotype Hanson et al. (1956). Improvement in the mean genotype value of selected plants over the parental population is known as genetic advance. Therefore, the components of variance, heritable components with genetic parameters such as GCV, PCV, heritability and genetic advance as per cent mean are important tools of plant breeding.

Golani et al. (2007) evaluated twenty genotypes of tomato and revealed that high heritability with high genetic gain was observed for fruit weight, number of locules per fruit and fruit yield which could be improved by simple selection.

Dar and Sharma (2011) investigated on sixty diverse genotypes of tomato. The observations were recorded on yield and quality traits to generate information regarding the extent of genetic variability, heritability and expected genetic advance. High heritability was recorded for most of the characters namely pericarp thickness, polygalacturonase activity and alcohol insoluble solids.

Mohamed et al. (2012) studied thirty tomato genotypes. The highest heritability was recorded on plant height, while the lowest was for fruit yield per plant. High heritability (broad senses) estimates were observed for all the tested characters indicating that these characters are controlled by additive gene action which is very useful in selection.

Rahaman et al. (2012) reported high heritability coupled with high genetic advance expressed in percentage of mean for selection of primary and secondary branches, plant

height, fruits per plant, fruit length, fruit diameter, and fruit weight indicating that these traits were mainly governed by additive gene action and responsive for further improvement of these traits.

Reddy et al. (2013) reported high heritability combined with high genetic advance for the characters plant height, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, fruit length, fruit weight, fruit yield per plant, ascorbic acid, acidity, shelf life and TSS.

Sajjan et al. (2016) studied the genetic parameters to elucidate heritability and genetic advance in tomato (*Solanum lycopersicum* L.). Field evaluation of F₆ recombinant inbred lines was done. High heritability combined with high genetic advance was observed for the characters average fruit weight, number of branches per plant, number of fruits per plant, plant height, fruit yield per plant, total soluble solid, number of locules per fruit and pericarp thickness which indicates that additive gene action plays a major role in governing these traits and these traits can be improved by simple selection.

Bhandari et al. (2017) studied ten yield traits in sixty six genotypes of tomato. Fruit yield per plant recorded the maximum heritability followed by number of fruits per cluster. Important yield contributing traits namely average fruit weight, number of fruits per plant, number of seeds per fruit and fruit yield per plant revealed high heritability coupled with high genetic advance as percentage of mean. Simple selection or pure line selection following hybridization may be effective for improvement of these traits.

Somraj et al. (2017) investigated genetic variability in twenty genotypes of tomato for yield and quality traits. High heritability coupled with high genetic advance as per cent of mean indicates operation of additive gene action which was observed in characters plant height, root to shoot ratio, number of primary branches per plant, number of flowers per cluster, number of clusters per plant, fruit set, number of fruits per cluster, number of fruits per plant, fruit length, fruit width, average fruit weight, fruit yield per plant, number of locules per fruit, ascorbic acid, lycopene content, stomatal diffusive resistance, relative water content and chlorophyll content. Hence, directional selection for the above characters could be effective for desired genetic improvement.

Kavyashree et al. (2017) reported high heritability coupled with high genetic advance as percent mean for characters viz., number of flowers per cluster, number of fruits per

cluster, number of fruits per plant, average fruit weight, pericarp thickness, dry matter content and fruit yield per plant.

Dixit and Pandey (2017) estimated high heritability (broad sense) and genetic advance for number of fruits per plant, early yield per plant and total yield per plant showing additive gene action for expression of these traits.

Panchbhैया et al. (2018) carried out investigation in thirty-six treatments (28 F₁'s and 8 parents) and observed moderate to high heritability and genetic advance as percent of mean for majority of the characters under study.

Savithamma et al. (2018) studied different genotypes of tomato and revealed that high heritability coupled with high genetic advance as per cent of mean was observed for fruits per plant, plant height, and clusters per plant and fruit yield indicating the involvement of additive gene action for expression of these traits.

Mohamed et al. (2018) showed highest heritability recorded for plant height, while the lowest was for fruit yield per plant. High heritability (broad sense) estimates are observed for all the tested characters indicating that characters are controlled by additive gene action.

Pandey et al. (2018) revealed high heritability coupled with high expected genetic advance in per cent of mean for fruit yield per plant, fruit weight per plant, plant height and days to maturity.

Khuntia et al. (2019) observed high heritability combined with high genetic advance estimates for plant height, number of fruits per cluster and per plant, fruit setting percentage, individual fruit weight, yield for plant, flesh thickness, number of locules per fruit, lycopene and beta-carotene.

Saravanan et al. (2019) reported high heritability coupled with high genetic advance for yield per plant, number of fruits per plant and number of locules per fruit indicating the additive genetic effect.

Kumar et al. (2020) recorded highest heritability for fruits per plant and lowest for number of branches. Highest genetic advance as per cent of mean was highest for fruit yield per plant.

Kherwa et al. (2020) estimated highest heritability (broad senses) for titratable acidity and total antioxidant capacity while the lowest was for the TSS. Highest genetic advance as percent of mean was recorded for total antioxidant capacity and lowest for TSS.

Maurya et al. (2020) showed high heritability combined with high genetic advance for the characters plant height, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, fruit length, fruit weight, fruit yield per plant, ascorbic acid and TSS.

Rawat et al. (2020) found that the heritability coupled with genetic advance as per cent of mean were high for ascorbic acid, number of fruits per plant, average fruit weight, fruit yield, number of locules per fruit, pericarp thickness and number of fruits cluster which suggests that these characters could be improved by selection.

Singh et al. (2021) observed high heritability coupled with genetic advance for pericarp thickness, plant height, number of fruits per cluster, fruit length and fruit yield per hectare.

Maurya et al. (2022) studied the genetic variability and character association among important yield and attributing traits was studied in twenty genotypes of tomato. High heritability accompanied by high genetic advance as per cent of mean was recorded for number of fruits per plant, average fruit weight, number of flower clusters per plant, number of fruits per cluster, plant height, number of flowers per cluster, locule number, polar diameter, equatorial diameter, pericarp thickness and fruit yield per plant.

Sahoo et al. (2022) conducted a study on forty-six advanced tomato lines to determine the association between yield and morphological traits. Among nine different characters studied, fruit number per plant showed high heritability and genetic advance with the highest yield per plant.

Pooja et al. (2022) conducted a study on forty-one genotypes of tomato and found that high heritability coupled with high genetic advance over mean were observed for fruit length, fruit diameter, average fruit weight, fruit volume, number of locules per fruit, number of fruits per cluster, number of fruits per plant, yield per plant, yield per plot, yield per hectare, TSS, ascorbic acid content of fruit, lycopene content, titratable acidity, pericarp thickness and firmness.

Thakur et al. (2022) observed high heritability along with high estimates of genetic gain the number of flowers per cluster, number of fruits per cluster, fruit length, number of locules per fruit, pericarp thickness, shelf life and fruit yield per plot.

2.3 CORRELATION STUDIES:

Knowledge of genetic association of yield and various component characters are of economic worth in formulating and executing the breeding programme (Singh and Sharma 2007). To raise the genetic potential of a crop, the information on nature and magnitude of association among different characters is of immense value to any breeding programme and forms a basis for selection (Robinson et al. 1951). Correlation coefficient is the measure of the degree of association between two traits (Hayes et al. 1955). Yield is a very complex entity, polygenically controlled and subject to the fluctuating environment and hence, the selection of superior genotypes based on the performance of yield as such is usually not effective. The correlation among the different pair of characters and their influence on yield assume special significance because selection for any character invariably affects number of other associated characters while bringing out improvement. Johnson et al. (1955) stressed the importance of both phenotypic and genotypic correlation among the characters in planning and evaluating breeding programmes as most of the characters of economic importance are complex in nature. They are of immense value to indicate the degree to which various morpho-physiological characters are associated with economic productivity.

Joshi and Kohli (2005) recorded that shelf life of tomato was positively and significantly associated with average fruit weight, whole fruit firmness, pericarp thickness and stem-end scar size, but it was negatively and significantly correlated with number of locules per fruit.

Makesh et al. (2006) observed a positive and significant correlation of yield per plant with number of fruits per plant, plant height, number of laterals per plant and fruits per cluster, but number of locules per fruit and flesh thickness was negatively correlated with yield.

Singh and Cheema (2006) reported that fruit yield per plant had positively correlated with plant height, number of branches per plant, number of fruits per plant, average fruit weight, fruit length, number of locules, TSS and ascorbic acid content. Pericarp thickness and acidity percentage was negatively correlated with yield.

Sharma et al. (2006) reported significant and positive correlation of yield with plant height, number of branches per plant and fruiting duration indicating that selection strategies must be focus on plant canopy, modification, fruiting duration and individual fruit weight to achieve higher level of fruit yield.

Golani et al. (2007) reported that fruit yield was significantly and positively correlated with fruit weight, fruit diameter, TSS and number of locules per fruit and negatively correlated with plant height.

Prassana et al. (2007) reported that yield per plant is important economic trait for positive association with average fruit weight and number of fruits per plant while negative association was observed for number of fruits per plant with average fruit weight, number of locules per fruit and flesh thickness.

Singh et al. (2007) conducted an experiment on correlation study and revealed that yield was positively correlated with number of fruits per plant, average fruit weight, fruit diameter and number of locules per fruit while, significant positive correlation was observed between plant height and number of branches. Further, lycopene was highly correlated with total carotenoids and pH. However, negative association was observed with pH and vitamin C contents.

Asati et al. (2008) revealed that fruit yield was positively correlated with days to fifty per cent flowering and fruit yield, fruit diameter and pericarp thickness. Hidayatullah et al. (2008) recorded that fruit weight showed high and positive genotypic and phenotypic correlation with number of pickings and number of fruits, thus indicating that these traits were the most important yield components.

Sharma and Thakur (2008) recorded that yield per plant was positively and significantly associated with number of fruits per plant, average fruit weight, pericarp thickness and total soluble solids. Anjum et al. (2009) observed that the economically important trait fruit yield per plant exhibited high positive significant correlation with fruit size, plant height, number of fruits per plant and number of primary branches per plant at both phenotypic as well as genotypic levels.

Rani et al. (2010) recorded that these traits viz. fruit weight, pericarp thickness, acidity, ascorbic acid and lycopene were positively and significantly associated with yield per plant, while number of fruits per plant was associated negatively with yield per plant.

Sharma et al. (2010) recorded that fruit yield was significantly and positively correlated with average fruit weight, number of fruits per plant, number of locule per fruits, pericarp thickness, days to fifty per cent flowering, number of branches per plant with plant height and number of fruits per plant.

Ghosh et al. (2010) observed significant positive genotypic and phenotypic correlation between plant height at first flowering, flowers per plant, fruits per cluster, fruit clusters per plant and fruits per plant with fruit yield per plant.

Dar et al. (2011) recorded that fruit yield per hectare was positively correlated with lycopene content, fruit pH, total soluble solids, number of fruits per plant, fruit yield per plant, pericarp thickness, number of locules per fruit and average fruit weight at genotypic as well as phenotypic level. However negative correlation was observed with beta-carotene, ascorbic acid and polygalacturonase activity at genotypic as well as phenotypic level.

Kumar and Dudi (2011) observed that total fruit yield per plant was correlated significantly and positively with number of fruits per plant, fruit weight and total sugar. The correlation of yield with most of the quality traits indicated that simultaneous improvement of yield and quality traits was not possible because of negative correlation of yield with such quality traits.

Ahirwar and Prashad (2013) reported that plant height after 120 DAT, days to 50 per cent flowering, leaf curl incidence and intensity showed negative correlation at both phenotypic and genotypic levels while, number of branches, number of fruits per plant, average fruit weight, number of clusters per plant, per cent of fruit set, radial and polar diameter, ascorbic acid and total soluble solids showed positive correlation with fruit yield.

Kumar et al. (2013) assessed twenty-six genotypes of tomato and reported that yield had significant positive association with number of fruits per plant and number of fruits per cluster. Sharma and Jaipaul (2014) recorded that yield and its contributing characters has significant positive association with the harvest duration, plant height, number of fruits per cluster but interestingly they found that fruit number was negatively associated with fruit weight.

Meena and Bahadur (2015) revealed that fruit yield was significantly and positively correlated with number of flowers per plant followed by number of fruits per plant and fruit

weight at genotypic and phenotypic levels, respectively and strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield.

Rahman et al. (2015) evaluated forty-eight genotypes of tomato for character association analysis among yield and yield contributing characters and the results revealed that in most of cases the genotypic correlation coefficient was higher than the respective phenotypic correlation coefficient. Fruits per cluster showed non-significant positive association with yield per plant at genotypic and phenotypic level but individual weight of fruit had significant negative association at phenotypic level with yield per plant.

Naveen et al. (2017) recorded that yield had positive and significant correlation with plant height, fruit yield per hectare, average fruit weight, lycopene and beta carotene.

Singh et al. (2017) observed highly significant and positive correlation with number of fruits per plant followed by average fruit weight and number of primary branches per plant.

Jogi et al. (2018) reported positive correlation of yield per plot with number of branches per plant, fruit diameter, pericarp thickness, number of fruits per plant, average fruit weight and firmness indicating the possibility of simultaneous improvement of these traits in improving total fruit yield per plant.

Singh and Singh (2018) recorded highly significant and positive phenotypic and genotypic correlation for fruit yield with number of fruits per cluster, plant height, number of fruits per plant and average fruit weight and strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield.

Ritonga et al. (2018) revealed a significant positive correlation coefficient for fruit weight and number of fruits per plant. As a result, it is suggested that when developing a shade tolerance tomato variety, the fruit weight and number of fruits per plant must be given special consideration.

Kumar and Dongre (2019) stated that estimation of genetic correlation of thirty-three genotypes revealed positive significant association of fruit yield per plant with number of fruits per plant, plant height at 90 DAT, fruit yield per hectare and fruit yield per plot at the genotypic and phenotypic levels.

Sharma et al. (2019) reported that for most traits, genotypic correlations were higher than phenotypic correlations. The number of marketable fruits per plant, plant height, internodal length and average fruit weight were the primary traits that exhibited a significant positive relationship with marketable yield per plant indicating that these traits can be used to select for increased yield.

Yadav et al. (2020) reported that total fruit yield per plant was significantly and positively correlated with number of fruits per plant, average fruit weight, equatorial diameter, and unmarketable fruits per plant, while days to 50 per cent flowering and plant height were significantly and negatively correlated with total fruit yield per plant.

Sushma et al. (2020) stated that the correlation coefficient studies showed positive association of fruit yield per plant with plant height, number of primary branches per plant, number of fruits per plant, days to last harvest, fruit length, fruit width, average fruit weight, ascorbic acid, total soluble solids and lycopene content.

Srinivasulu et al. (2020) studies revealed that the fruit yield had positive and significant association with fruit yield per plot, number of fruits per plant, days to first flowering, average fruit weight, number of primary branches per plant, days to 50 per cent flowering, 1000 seed weight.

Sahoo et al. (2022) in a study examined that there is a positive correlation between the number of flowers per plant and yield per plant in part due to the indirect positive effect of plant height, branches, number of branches per plant, number of fruits per plant, locule counts and of the TSS, despite the negative effect of the direct relationship between the number of flowers and yield per plant.

2.3 Path coefficient analysis:

For rational improvement of yield and its components, the understanding of correlation has been very useful. However, the estimates of correlation coefficients provide only the inter-relationship of the characters and do not furnish information on the cause and effect. In contrast, path coefficient analysis of yield and related parameters specifies the causes and measures along with relative importance of each variable. It splits the correlation coefficients into the measures of direct and indirect effects of a set of independent variables on the dependent variable and thus, provide the solution in cases where indirect association

become complex and important. Due to mutual association, the development of dependent variable is determined by the degree of the direct effect of independent variables and direct effects exerted via other characters, arising inevitably as an integral part of the growth pattern. Dewey and Lu (1959) were the first to demonstrate the utility of path coefficient analysis in breeding programme.

Harer et al. (2002) observed that number of fruits per cluster, average fruit weight and number of fruits per plant had maximum direct effect on fruit yield. The total soluble solids content had positive but low direct effect on yield, whereas ascorbic acid content had negative direct effect association with fruit yield.

Kant and Mani (2004) revealed that fruit weight had the maximum and direct positive effect on fruit yield per plant, followed by total number of fruit clusters per plant, number of branches per plant, titratable acidity, plant height and number of days to fifty per cent flowering in tomato.

Joshi and Kohli (2005) observed that maximum positive direct effect towards shelf life of fruits was contributed by whole fruit firmness followed by average fruit weight. However, average fruit weight exhibited the highest negative indirect effect via stem-end scar size on shelf life of tomato fruits.

Dhankhar and Dhankhar (2006) reported that number of fruits per plant had the maximum positive direct effect on yield. Makesh et al. (2006) observed that number of fruits per plant, total soluble solids and acidity had positive and direct influence on yield, while the number of laterals per plant, number of fruits per cluster and flesh thickness had negative direct effect on yield.

Singh and Cheema (2006) reported that plant height, number of branches per plant, width of fruit, number of fruits per plant and average fruit weight exhibited the maximum positive direct effect on yield. Thus, an increase in selection of these traits may lead to an overall increase in the yield. Quality traits except pericarp thickness and TSS did not play any significant direct and indirect role.

Golani et al. (2007) reported that fruit diameter exhibited the highest direct effect and could be the selection criteria for improving fruit yield plant, whereas other important characters viz., plant height, fruit length, single fruit weight, TSS and seeds per fruit that

exhibited negative direct effect are suggested to be exploited through high indirect effects.

Anjum et al. (2009) observed that days to first picking had the highest positive direct effect on fruit yield followed by harvest duration, number of fruits per plant, average fruit weight, plant height and number of flowers per cluster. Ghosh et al. (2010) observed that fruits per plant showed the highest positive direct effect on fruit yield per plant followed by individual fruits per plant. Rani et al. (2010) revealed that fruit weight had the highest positive direct effect on yield per plant.

Dar et al. (2011) observed that fruit yield per plant had highest positive direct effect towards yield per hectare followed by average fruit weight, number of locules per fruit, lycopene content per fruit. Tiwari and Uphadhyay (2011) recorded that fruit weight influenced the fruit yield per plant with high direct effect and therefore, fruit weight as an important character which may be included in selection criterion for improvement in fruit yield per plant.

Buckseth et al. (2012) reported that shelf life had maximum direct effect followed by average fruit weight and number of fruits per plant indicating that these are the real independent characters and have maximum contribution towards increase in fruit yield. Among the negative direct effect, pericarp thickness showed highest negative effect on yield per plant followed by fruit shape index, whereas lowest negative direct effect on yield per plant was observed for total soluble solids. Manna and Paul (2012) reported that number of locules per fruit, TSS, fruit length, number of fruits per plant, average fruit weight, vitamin C content and pericarp thickness had positive direct effect on fruit yield, while fruit width and total acid content had strong negative effects on the fruit yield.

Sharma and Singh (2012) revealed that average fruit weight exhibited positive direct effect on fruit yield per plant followed by number of fruits per plant, days to first fruit setting and equatorial fruit diameter. Hence these characters may be simultaneously selected to develop the high yielding with quality rich varieties.

Kumar et al. (2013) suggested that fruit weight had the highest positive direct effect on yield per plant followed by number of fruits per plant, fruit diameter and number of fruits per cluster. Direct selection based on fruit weight, number of fruits per plant, fruit diameter and number of fruits per cluster is reliable for yield improvement in tomato.

Reddy et al. (2013) revealed that plant height, number of fruits per plant, fruit length, fruit width and ascorbic acid had high positive direct effects on fruit yield per plant. Hence, direct selection for these traits is done for improving fruit yield per plant.

Khapte and Janasirani (2014) observed that fruit weight had the high positive direct effect on yield per plant followed by number of fruits per plant. Fruit diameter, fruits shape and fruit index had negative direct effect on fruit yield per plant and was regarded as the main determinants of fruit yield per plant.

Meena and Bahadur (2015) reported that fruit weight had high positive direct genotypic and phenotypic effects on fruit yield per plant followed by number of flowers per plant, fruit set percent, number of fruits per plant, total soluble solids, plant height, radial diameter of fruit, leaf curl incidence percent and days to 50 per cent flowering. The characters showed high direct effect on yield per plant indicated that direct selection for these traits might be effective and there is a possibility of improving yield per plant through.

Renuka et al. (2017) studied path coefficient analysis in cherry tomato and reported that the traits viz., number of fruits per plant, locules per fruit, pericarp thickness and number of primary branches had higher direct and positive contribution towards fruit yield.

Naveen et al. (2017) studied thirty tomato genotypes for path coefficient analysis and reported that traits viz., plant height, number of fruits per plant, fruit length, fruit width and ascorbic acid had positive direct effects on fruit yield.

Naveen et al. (2017) observed path coefficient analysis of different yield and yield contributing traits on fruit yield per plant which revealed that the number of branches per plant, days to first flowering, days to 50 per cent flowering, average fruit weight, number of fruits per plant, fruit yield per hectare, acidity and TSS: Acid ratio exhibited positive direct effects on fruit yield.

Konda et al. (2017) in path coefficient analysis studies revealed that number of branches per plant, days to first flowering, days to 50 per cent flowering, average fruit weight, number of fruits per plant and fruit yield per hectare exhibited positive direct effects on fruit yield.

Bheemureddy et al. (2018) revealed that average fruit weight exhibited high positive direct effect on fruit yield per plant followed by number of fruits per plant, days to first fruit setting and equatorial fruit diameter.

Chadha and Kumar (2018) reported that marketable fruits per plant had the maximum positive direct contribution towards marketable yield per plant followed by average fruit weight.

Bojarian et al. (2019) stated that in path analysis indicated that number of fruits per line and single fruit weight had the highest positive direct effect on yield and direct selection for these traits is possible.

Anuradha et al. (2020) evaluated eighteen tomato genotypes to study path coefficient analysis and revealed that traits like average fruit weight, number of locules, fruit length, percentage 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.

Maurya et al. (2020) carried out path coefficient analysis and indicated highest positive direct effect towards yield via days to 50 per cent flowering followed by fruit width, total soluble solids and average fruit weight. These traits may be given more emphasis for direct selection of high yielding tomato genotypes in future breeding programmes.

Srinivasulu et al. (2020) reported direct contribution towards yield came from fruit length, average fruit weight and fruit yield per plot.

Vijaylaxmi et al. (2021) studied path coefficient analysis and revealed that days to first flowering exhibited high positive direct effect on fruit yield per plant followed by average fruit weight, number of seeds per fruit, polar diameter of the fruit, number of locules per fruit while negative direct effects on yield were showed by days to 50 per cent flowering, equatorial diameter of the fruit and number of fruits per plant.

Sahoo et al. (2022) conducted a study and examined path coefficient analysis for forty-six tomato lines to determine the association between yield and morphological traits. The analysis of path coefficient showed that traits such as the number of fruits per plant, average fruit weight and number of branches per plant had a positive direct influence on yield which indicates that they have a direct influence on yield.

2.5 Stability analysis studies

The success of any crop improvement programme relies on the accurate selection of materials and their adept handling. A specified genotype does not exhibit the same

phenotypic characters including yield in all environments. The failure of genotype to give the same phenotypic performance when tested under different environments is reflection of genotype-environment interaction. $G \times E$ interactions are of major importance to the plant breeder in developing stable varieties (Eberhart and Russell, 1966). Vegetable breeders are mainly interested in increasing the level of production with minimum fluctuation in the crop performance as it influences prices of these perishable commodities in the market.

Adaptability and stability are the capacities of genotypes to respond favourably to environmental improvement and to exhibit highly predictable behaviour in response to environmental changes. Stability refers to the consistency of phenotype in varying environment. It is one of the most important properties of a genotype to be released as a variety for wide cultivation. A stable genotype is the one possessing a constant performance irrespective of any changes in environmental conditions. Stability analysis helps to select genotypes adaptable for wide and specific environments and divide large geographical areas into sub-areas. For breeders, stability of quality properties is important from the points of changing genotypes ranks throughout environments and influences selection efficiency.

Rupa et al. (2001) evaluated thirty genotypes of tomato for stability behaviour and $G \times E$ interaction and reported significant variance due to $G \times E$ interaction for the traits except number of marketable fruits per plants and marketable fruit yield per plant. Rupali and Pant T-3 were found to be the only desirable stable genotypes for marketable fruit yield.

Upadhyay et al. (2001) studied thirty tomato genotypes in four environments, to know the stability behaviour of tomato genotypes under diverse environmental conditions. Significant variance due to $G \times E$ interaction was observed for all the traits except number of marketable fruits per plant and fruit yield per plant.

Dhaduk et al. (2004) studied phenotypic stability analysis in tomato and evaluated nine varieties of tomato. The pooled analysis of variance indicated significant differences among the genotypes and $G \times E$ interactions for fruit yield, plant height, fruit girth and 10-fruits weight. It indicated that the genotypes responded differently to the changing environments with respect to above four characters. However, significant mean squares due to environments were observed for all the eight characters, indicating the effect of variable environments in expression of all the traits.

Joshi (2004) studied forty two genotypes of tomato for stability behaviour at two locations under three environmental conditions. It was observed that the non-linear component of G x E interaction were highly significant for plant height, days to 50% flowering, number of flower cluster per plant, days to 50% fruit set, days taken to first and last harvest, average fruit weight, weight of fruits per plant, number of fruits per plant and fruit yield. Three genotypes were adjudged superior and also stable for mean fruit weight. One genotype was found most stable with regard to fruit weight per plant and number of fruits per plant, the two important primary yield contributing characters.

Shobha et al. (2006) evaluated sixty genotypes of tomato to study stability of hybrids over different environments for yield. Based on the stability analysis, the genotypes are grouped as group 'A' (suitable for both normal and stress environment), group 'B' (suitable for normal environment only) and group 'C' (suitable for stress environment only).

Prasanna et al. (2007) evaluated eight varieties in four different environments to identify suitable variety for early rain season and to characterize the genotype and environment interaction. The pooled analysis of variation indicated that majority of the traits exhibited the linear predictability across the environments. The stability analysis revealed the suitability of Kashi Amrit and Kashi Anupam for different environments with high average yield.

In a study conducted by Thapliyal (2008) on thirty tomato genotypes over three environments, high significant differences were recorded among genotypes for all the thirteen characters under study. The differences among the environments were also highly significant for all the characters except number of locules per fruit where it was found to be non-significant. They also reported the presence of genotype-environment interaction for plant height, days to 50% flowering, number of flower clusters per plant, days to 50% fruit set, days to first harvest, days to last harvest, average fruit weight, fruit weight per plant, number of fruits per plant and yield (q/ha).

Jyothi et al. (2012) studied the stability of ten genotypes under three diverse environments, along with two checks of processing type. Overall performance of PTR-1, PTR-4, PTR-6 and 'Arka Ashish' was found stable for yield per plant, number of branches per plant, % fruit set, % acidity and lycopene content. Two genotypes PTR-4 and PTR-6 were stable for high yield and for good processing traits.

Ummyiah et al. (2015) evaluated sixteen varieties of tomatoes for their stability in six environments. Significant differences were observed among all the varieties for eight quantitative characters. The pooled analysis of variance for stability of varieties for the quantitative traits revealed significant differences among the genotypes and environments for all the traits studied. The interaction component genotype $\times$ environment was also significant for all the traits. The varieties stable for yield and most of the traits were Arka Meghali, Shalimar-II, Roma and Arka Vikas.

Shalini (2016) studied twenty-three genotypes of tomato for stability over three years. The genotype H-24 exhibited higher mean value for total yield per plant, number of fruits per plant and average fruit weight coupled with regression coefficient nearer to unity and non-significant Si2 di.

Sonam et al. (2016) investigated the magnitude of genotype $\times$ environment interaction and stability performance. Twenty five tomato genotypes were evaluated for yield and its components under six environments for two years. The genotype Karan was identified stable for days to 50% flowering. Lehar and Solan Lalima were most stable for days to first marketable fruit picking, Heemsohna and Leh local for total yield per plot and NS-2535 for marketable yield per plot.

Selamawit et al. (2017) evaluated six tomato varieties at six different environments to assess their quality and yield stability to make recommendations for possible release. Oval Red had significantly thicker pericarp and higher percent of total soluble solid than the rest of the varieties. Melkassa was the best yielding environment with high positive environmental index. Oval Red exhibited superior mean for fruit yield than the grand mean, non-significant regression coefficient close to unity with insignificant deviation from regression indicating its average stability *i.e.* suitable for all environments.

While evaluating the twenty-five tomato genotypes for stability over six environments, Spaldon et al. (2017) reported significant genotype $\times$ environment interaction for lycopene, beta-carotene and ascorbic acid and non-significant genotype $\times$ environment interaction for number of locules per fruit, pericarp thickness, total soluble solids and fruit pH.

Sonam et al. (2017) conducted investigation over six environments to study stability of twenty five genotypes of tomato for quality traits. Genotypes $\times$ environment interaction was significant for lycopene, beta-carotene and ascorbic acid which indicated the differential

response of genotype to various environment conditions and non significant for number of locules per fruit, pericarp thickness, total soluble solids and fruit pH. None of the genotypes was stable for all the traits and stability for one trait was independent of stability for other traits. Genotype Rupali was found stable for number of locules per plant, while genotype Karan for pericarp thickness. The genotypes Kubergeeta, Arkasaurabh and Arkameghali were identified as stable genotypes for fruit pH.

Spaldon and Hussain (2017) evaluated the twenty-three elite genotypes for yield, quality, and reaction against biotic stress. The highest number of fruits per plant was recorded in Pusa Ruby. Maximum pericarp thickness was observed in genotype Anand. Arka Vikas recorded highest fruit pH; beta-carotene and total soluble solids. Genotype Aditya gave highest lycopene content and highest ascorbic acid content was recorded in Arka Meghali. Genotype DVRT-2 showed minimum incidence of fruit borer. Genotypes Arka Vikas, Aditya and Arka Meghali were found suitable for processing.

Kumar et al. (2018) evaluated forty-three tomato genotypes (30 F1s and 13 lines) and observed that genotype $\times$ environment ($G \times E$) interaction was significant for all the characters under study. Eight crosses (H-24 $\times$ Kashi Sharad, CO-3 $\times$ Floradade, CO3 $\times$ Kashi Sharad, CO-3 $\times$ Azad T-5, Punjab Upma $\times$ Azad 18 T-5, Pant T-3 $\times$ Kashi Sharad, Kashi Amrit $\times$ Kashi Sharad and H-24 $\times$ Azad T-5) were found suitable for wide cultivation in all the four seasons.

Kumar et al. (2018) investigated on forty-three tomato genotypes (30 F1's and 13 lines) of yield and its components for four seasons from 2010 to 2012. The effects of cultivars, environment, and genotype $\times$ environment interactions were evaluated. One cross-combination (Pant T-3 $\times$ Azad T-5) was found to be responsive while eight crosses (H-24 $\times$ Kashi Sharad, CO-3 $\times$ Floradade, CO-3 $\times$ Kashi Sharad, CO-3 $\times$ Azad T-5, Punjab Upma $\times$ Azad T-5, Pant T-3 $\times$ Kashi Sharad, Kashi Amrit $\times$ Kashi Sharad and H-24 $\times$ Azad T-5) were suitable for wide cultivation in all the four seasons.

Kumar et al. (2019) evaluated eleven parents, thirty crosses and three commercial checks of tomato (*Solanum lycopersicum* L.) for stability analysis and reported significant differences among the genotypes for all the traits. Genotype $\times$ environment interaction was also found to be significant. The hybrids (EC-608415 $\times$ Arka Abha, EC-620360 $\times$ Pusa Ruby, EC-608415 $\times$ Arka Saurabh, EC-608415 $\times$ Punjab Chhuhara and EC-619982 $\times$ EC-620557) exhibited higher mean values with regression coefficients around unity.

In tomato, Bhalala and Acharya (2019) evaluated sixty-five genotypes under three artificially created environments. The $G \times E$ interactions were significant for fruit yield per plant, number of fruits per plant, fruit weight, shelf life, total soluble sugar, lycopene content and β -carotene content. The hybrids, AT 3 $\times$ TBK 00113 for fruit yield per plant and fruit weight; AT 3 $\times$ ATL 11-05 for number of fruits per plant and lycopene content; AT 3 $\times$ VTG 93 for shelf life, total soluble sugar, lycopene content; and GT 2 $\times$ ATL 11-05 for shelf life and beta-carotene content were found stable under varying environments.

Akinyode et al. (2020) evaluated the twelve genotypes of tomato which were grown in four different environments to study phenotypic stability. There was significant difference for environments, genotypes and genotype by environment interaction, an indication of variation in the performance of the genotypes across environments. The results revealed that three genotypes, NHSL23, NHSL26 and NHSL11 produced the highest yields in the four environments. Across the four environments, NHSL23 ranked highest in terms of yield and is considered as best candidate for production while the most stable genotype was NHSL21. NHSL26 can be considered for areas with moderate to low atmospheric rainfall. These genotypes can be evaluated in more environments to assess their adaptability and possible recommendation for release.

Singh et al. (2021) evaluated twenty-nine genotypes of tomato which were grown in five different environments to study phenotypic stability for fruit yield and its components. Pooled analysis of variance revealed significant differences among the genotypes for most of the characters. The variance due to $G \times E$ was significant for all the characters except numbers of primary branches per plant, fruit length; fruit weight and fruit yield per plant. The results revealed that the genotype BRH-2 followed by the genotype Arka Vikas had wider adaptability. Among the environments it was found that the pre- winter sowing, that is, sowing in September was favourable for the characters like days to 50% flowering, days to maturity, plant height, number of primary branches per plant and fruit weight. However, sowing of tomato in November favoured characters like number of fruits per plant, size of fruit and fruit yield per plant.

Bhandari et al. (2022) evaluated thirty genotypes of tomato along with check for important quality traits viz., total soluble solids (TSS), titrable acidity, ascorbic acid, carotene and lycopene content based on three locations over two years and the results indicated that the environments of Varanasi during both years had a favorable effect on all quality traits

except carotene content, as evident from environmental indices. The genotypes identified as stable are broad-adapted and can be recommended for general cultivation in different locations, while the genotypes identified as responsive can be recommended for specific environments only.

Chapter - 3

MATERIALS AND METHODS

The present research entitled “**Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)**” was carried out during the consecutive years of 2022 and 2023 to evaluate genotypes including, check variety. The contents of the materials and techniques used in the research are detailed below under the following subheadings:

3.1 Experimental sites

3.2 Experimental genetic material

3.3 Layout plan

3.4 Cultural practices

3.5 Observations recorded

3.6 Statistical analysis

3.1 Experimental sites

The present study was carried out at three diverse locations viz.,

1. Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP).
2. Experimental Research Farm, Dr YSP UHF COHF, Neri, Hamirpur (HP).
3. Experimental Research Farm, Dr YSP UHF RHR&TS, Bajaura, Kullu (HP).

3.1.1 Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP).

Experimental Farm of Department of Vegetable Science, Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, is located at an altitude of about 1270 meters above mean sea level (amsl), lying between latitude 35.5⁰ N and longitude of 77.8⁰ E. The experimental area falls in the mid hill zone of Himachal Pradesh (Zone-II). Climate of the area is mostly sub-temperate and semi-humid characterized by cold winters. Generally, May and June are the hottest months and December and January are the coldest. The annual precipitation ranges between 1000-1300 mm, most of which is received in the monsoon season (June-August). The soil of farm is sandy loam having good soil fertility and drainage capacity.

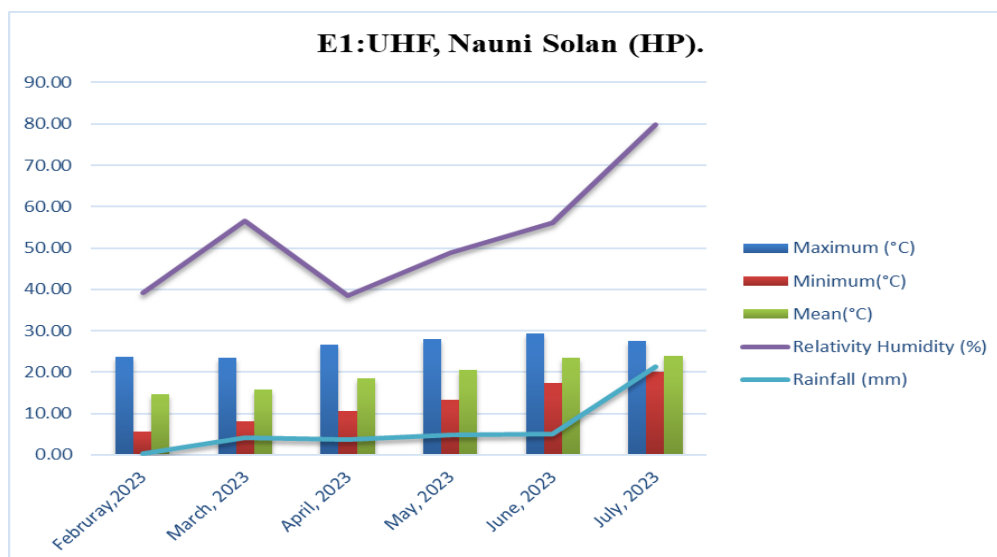


Fig. No. 3.1 Mean monthly weather conditions during the cropping season at E1 Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP).

3.1.2 Experimental Research Farm, Dr. YSP UHF COHF Neri, Hamirpur (HP).

Experimental Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur (H.P.) is located at an altitude of about 650 m above mean sea level (amsl), lying between 31°41'47.6" N latitude and 72°28'6.3" E longitude under low hill zones of Himachal Pradesh, India. It is located in the Hamirpur district of the state low-hill, sub-humid zone (Zone-I) and has hot summers and mild winters with modest monsoon rainfall (975 mm). The soil of farm is sandy loam having good soil fertility and drainage capacity.

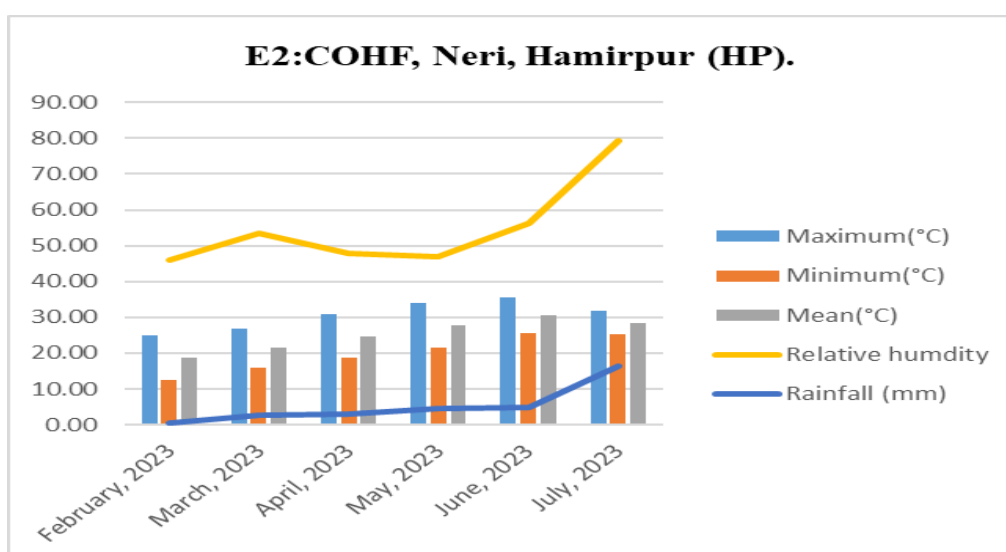


Fig. No. 3.2 Mean monthly weather conditions during the cropping season at E2: Experimental Research Farm, Dr. YSP UHF COHF, Neri, Hamirpur (HP).

LOCATION MAP

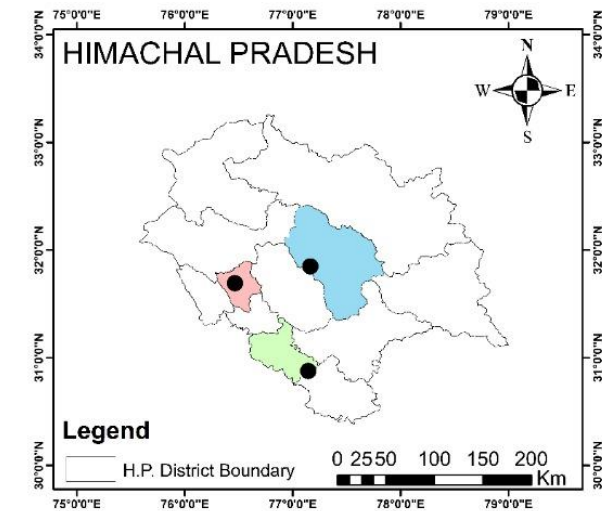
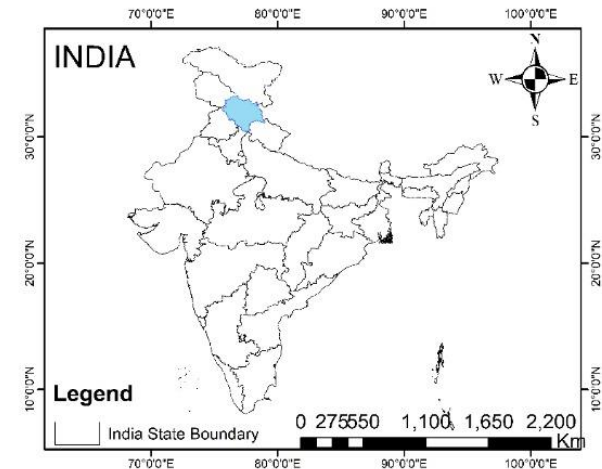
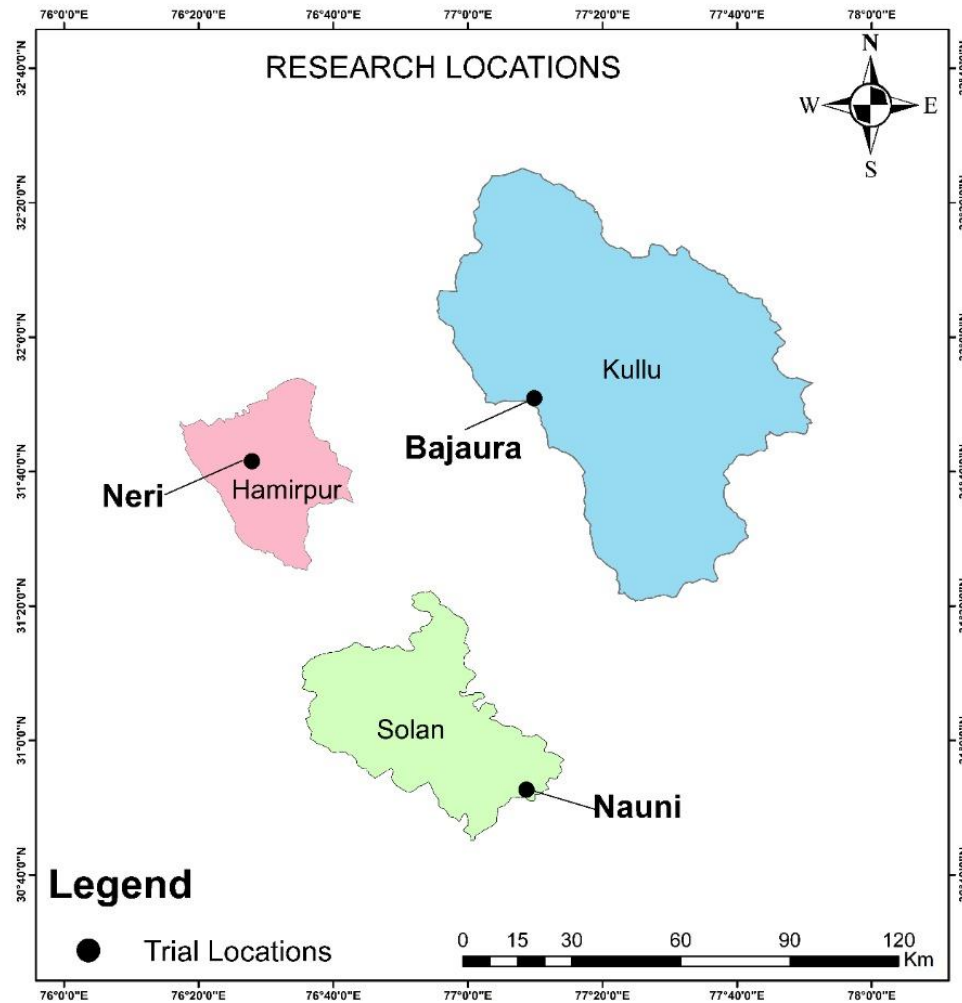


Plate 3.1 Research trials conducted at different locations of Himachal Pradesh.

3.1.3 Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP).

The Experimental Farm of Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP) is located at 31° 8' N latitude and 77° 4' E longitude at a height of 1090 m above mean sea level (amsl) is located in the Kullu district of the state mid-hill temperate, sub-humid zone (Zone-II) and has moderate summers and cold winters with modest monsoon rainfall (975 mm). The soil of farm is sandy loam with an acidic to neutral response and high-water table.

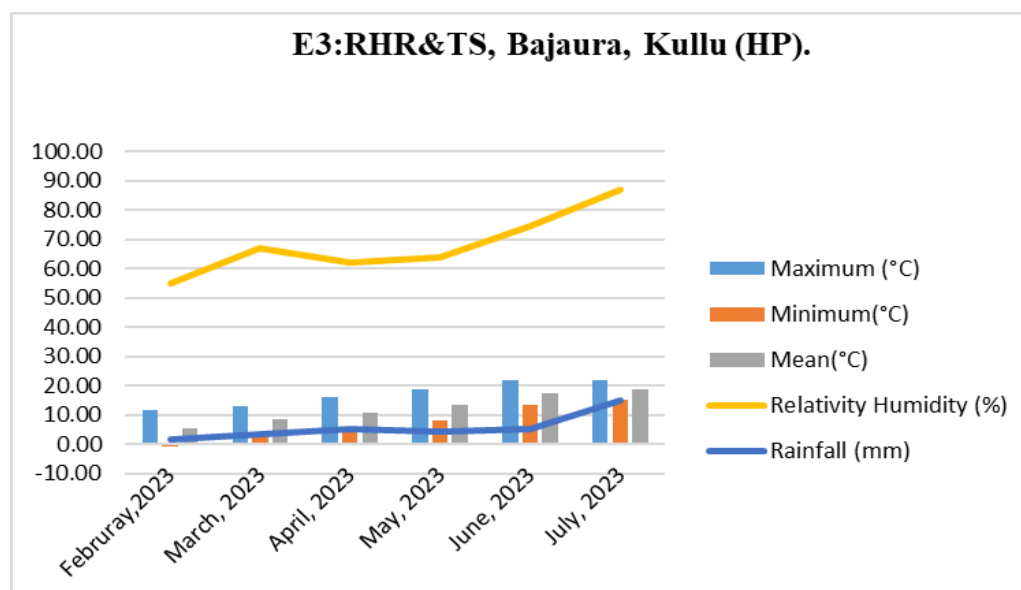


Fig. No. 3.3 Mean monthly weather conditions during the cropping season at E3: Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP).

3.2 EXPERIMENTAL GENETIC MATERIAL

Two separate experiments were conducted during the course of investigation. The materials and methods adopted during the present studies have been described experiment wise as follows:

3.2.1 Experiment 1: Variability, heritability, correlation and path coefficient analysis

In summer 2022, twenty five diverse genotypes of tomato have been presented in Table 3.1 were evaluated to estimate the extent of variability, heritability and genetic advance, correlation, path coefficient analysis for horticultural traits and on the basis of their mean performance (Appendix-1) elite genotypes were selected for stability analysis.

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

Sr. No.	Genotypes	Source
1.	EC-654289	ICAR-NBPGR, New Delhi
2.	EC-632936	ICAR-NBPGR, New Delhi
3.	EC-635529	ICAR-NBPGR, New Delhi
4.	EC-687604	ICAR-NBPGR, New Delhi
5.	EC-631415	ICAR-NBPGR, New Delhi
6.	EC-631438	ICAR-NBPGR, New Delhi
7.	EC-698849	ICAR-NBPGR, New Delhi
8.	EC-615039	ICAR-NBPGR, New Delhi
9.	EC-687423	ICAR-NBPGR, New Delhi
10.	EC-631359	ICAR-NBPGR, New Delhi
11.	EC-692350	ICAR-NBPGR, New Delhi
12.	EC-631399	ICAR-NBPGR, New Delhi
13.	EC-631427	ICAR-NBPGR, New Delhi
14.	EC-631411	ICAR-NBPGR, New Delhi
15.	EC-631351	ICAR-NBPGR, New Delhi
16.	EC-635526	ICAR-NBPGR, New Delhi
17.	EC-692336	ICAR-NBPGR, New Delhi
18.	EC-687422	ICAR-NBPGR, New Delhi
19.	EC-654286	ICAR-NBPGR, New Delhi
20.	EC-631357	ICAR-NBPGR, New Delhi
21.	COHF-T-1	Department of Vegetable Science, COH&F, Neri, Hamirpur
22.	COHF-T-2	Department of Vegetable Science, COH&F, Neri, Hamirpur
23.	COHF-T-3	Department of Vegetable Science, COH&F, Neri, Hamirpur
24.	COHF-T-4	Department of Vegetable Science, COH&F, Neri, Hamirpur
25.	Solan Lalima (Check)	Dr. YSPUHF, Nauni

3.2.2 Experiment 2: Genotype x Environment interaction for yield and quality traits

In summer 2023, ten diverse genotypes (including check) of tomato have been evaluated for stability analysis at three different locations viz.

1. Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP).
2. Experimental Research Farm, Dr. YSP UHF COHF, Neri, Hamirpur (HP).
3. Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP).

No. of genotypes	:	10 (including check)
Check	:	01
Locations	:	03
Date of Sowing	:	03
Replications	:	03



Plate 3.2 General view of crop at Experimental Research Farm, Department of Vegetable Science, UHF, Nauli Solan (HP)



Plate 3.3 General view of crop at Experimental Research Farm, Dr. YSP UHF COHF Neri, Hamirpur (HP)



Plate 3.4 General view of crop at Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP)

3.3 Layout plan

The experimental material was sown in the nursery bed of size 3 m × 1 m × 15 cm over the location as per details given in table 2. The seedlings were ready for transplanting in about four weeks after seed sowing in the respective environment. The seedlings of these ten genotypes (including check) were laid out in Randomized Complete Block Design with three replications at each location by transplanting at different dates as mentioned in table 3.2. Each genotype was planted in plots measuring 2.7×2.1 m² consisting of 21 plants in each replication with inter and intra row spacing of 90 × 30 cm each, respectively.

Table 3.2. Date of nursery sowing and transplanting at various locations.

Sr. No.	Locations/Environments	Date of nursery sowing	Date of Transplanting
1.	Vegetable Research Farm, UHF, Nauni, Solan (HP).	26 Feb 2023	31 March 2023
2.	Vegetable Research Farm, Dr. YSP UHF COHF Neri, Hamirpur (HP).	16 Feb 2023	20 March 2023
3.	Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP).	23 Feb 2023	27 March 2023

3.4 Cultural practices

A three-disc tractor was used to plough the field, followed by a tractor-driven rotavator. Nutrients were important for economic yields of crop. The appropriate amount of well-rotten farmyard manure @ 25 tonnes per hectare was mixed into the soil during field preparation. The fertilizers were administered at 120:80:50 kg N, P₂O₅ and K₂O per hectare, with half of the required N, full P₂O₅ and K₂O applied at transplanting time and the remaining N was given as top dressing after 30-35 days of transplanting. Light irrigation was provided at the time of transplanting. Subsequent irrigations were provided as and when required depending on the weather conditions. Staking operation was started after 45 days of transplanting. Regular cultural practices and plant protection procedures were followed.

3.5 ` OBSERVATIONS RECORDED

The observations were recorded on five randomly taken plants from each entry in each replication and their average was worked out to record the data.

The observations were recorded on following characters:

3.5.1 Days 50% flowering

It was observed as the total number of days counted from the date of transplanting to the opening of at least one flower on 50 % of the plant population of each genotype.

3.5.2 Days to first fruit picking (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.

3.5.3 Plant height (cm)

Plant height was measured in cm from the soil surface to the top of the central apical shoot at the time of final harvest on chosen plants and the mean was calculated to acquire the average plant height in cm.

3.5.4 Number of fruit clusters per plant

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

3.5.5 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.

3.5.6 Number of fruits per plant

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

3.5.7 Average fruit weight (g)

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

3.5.8 Fruit length (mm)

The average length of fruit was calculated from the randomly selected ten fruits of each



Preparation of nursery bed and line sowing of seeds.



Emergence of seedlings



Layout of field



Seedlings transplanted to the main field



Flowering



Fruiting

genotype with vernier caliper and mean value were averaged and recorded in millimeters.

3.5.9 Fruit width (mm)

The average width of fruit was calculated from the randomly selected ten fruits of each genotype with vernier caliper and value were averaged and recorded in millimeters.

3.5.10 Fruit shape index

Polar and equatorial diameters of five randomly picked fruits were measured with digital vernier calliper. Ratio of polar diameter to equatorial diameter was worked out to calculate fruit shape index. Fruits having index values 1.0 or more were described as oval, between 0.99 to 0.86 as spherical, between 0.85 to 0.71 as flat round and less than 0.70 as flat shaped as per the method suggested by Roy and Choudhary (1972).

3.5.11 Pericarp thickness (mm)

Pericarp thickness of same fruits used for counting number of locules/fruit was measured to generate the data in each entry. Measurement was done with digital vernier calliper in millimeters and mean value was worked out.

3.5.12 Fruit firmness (g/0.503cm³)

Whole fruit firmness of five randomly taken fruits at second harvest in each entry was reordored with the help of penetrometer and mean value was calculated.

3.5.13 Number of locules per fruit

Five fruits from second harvest in each entry were transversely cut with sharp knife and number of locules per fruit was recorded to work out the mean value.

3.5.14 Total soluble solids (°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 were noted. A mean of five readings was taken in every replication in each entry.

3.5.15 Titrable acidity (%)

Acidity was determined following the procedure of Ranganna (1986). A 30g of fresh fruit from each genotype was crushed thoroughly in an electrically operated mixer. The pulp

27 obtained was filtered and 10 ml of the sample was taken from the filtrate. The sample was diluted to a volume of 100 ml with freshly boiled distilled water. An aliquot of 30 ml of the diluted sample was titrated against 0.025 N NaOH using 1-2 drops of 1% phenolphthalein solution as an indicator. The value of titrate was recorded. The titration was repeated three times for each genotype. Average volume of titrate used was worked out. The acidity as per cent citric acid was calculated as:

$$\text{Titratable acidity (\%)} = \frac{\text{Titre reading} \times \text{normality of NaOH} \times \text{volume made} \times \text{equivalent weight} \times 100}{\text{Volume of sample taken} \times \text{weight of sample} \times 1000}$$

3.5.16 TSS: acid ratio

The TSS-acid ratio was calculated by the following formula as given by Ranganna (1986).

$$\text{TSS- acid ratio} = \frac{\text{Total soluble solids (}^{\circ}\text{B)}}{\text{Titratable acidity (\%)}}$$

3.5.17 Ascorbic acid content (mg/100g): Ascorbic acid content in tomato juice was calculated according to the 2,6-Dichlorophenol-Indophenol Visual Titration Method, proposed by Ranganna (1986).

a. Reagents required: 3 per cent metaphosphoric acid obtained by dissolving 30g of HPO_3 in distilled water and making volume upto 1000ml.

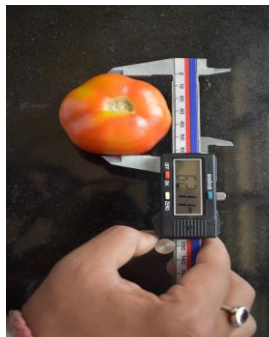
b. Ascorbic acid standard: 100 mg of L-ascorbic acid were dissolved in 3 per cent HPO_3 and volume made up to 100 ml. 10 ml from this solution were further diluted to 100 ml with 3 per cent HPO_3 (1 ml= 0.1 mg of ascorbic acid).

c. Dye solution: 50 mg of sodium salt of 2, 6-dichlorophenol-indophenol were dissolved in 150 ml of hot distilled water containing 42 mg of sodium bicarbonate. The solution cooled and diluted with distilled water to 200 ml and filtered. This dye solution was stored in refrigerator and standardized every day.

d. Standardization of dye: 5 ml of 3 per cent HPO_3 were added to 5 ml of standard ascorbic acid and titrated with dye solution to a pink colour which persisted for 15 seconds. The dye factor i.e., mg of ascorbic acid per ml of the dye was determined using the formula:



Average fruit weight



Fruit length



Fruit width



Pericarp thickness



Locules per fruit



Fruit firmness

Plate 3.6 Recording of various quantitative traits in tomato

$$\text{Dye factor} = \frac{0.5}{\text{Titer value}}$$

e. Procedure for preparation of sample: 10 g sample of red fruits of each genotype was weighed and crushed in an electric mixer to obtain the pure juice, 5 ml of which was dissolved in 3 per cent HPO_3 to make up the volume to 50 ml. Then it was filtered through the filter paper.

f. Determination of ascorbic acid: An aliquot of 5 ml of the HPO_3 extract of the sample was titrated with the standard dye to pink end point. The titration was repeated thrice and average volume of dye used was calculated.

g. Calculations: Ascorbic acid content of the sample was calculated by using the following formulae:

$$\text{Ascorbic acid (mg/100 ml/ g)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up}}{\text{Aliquot of Extract} \times \text{Weight of sample}} \times 100$$

Where,

Volume made up = 50 ml

Aliquot of extract = 5 ml

Weight of sample = 10 g

3.5.18 Lycopene content (mg/100g)

Lycopene content (mg/100g) (Sadasivam and Manickam, 1992): The lycopene content of fruit was measured by using a spectrophotometer and the procedure involved is as under:

Reagents:

1. Acetone (AR grade)
2. Petroleum ether bp 40-60° C (AR)
3. Anhydrous sodium sulphate
4. 5% sodium sulphate

Procedure: Tomato fruits (3-4) were taken and pulped well to a smooth consistency in a waring blender. 5-10 g of this pulp was extracted repeatedly with acetone using pestle mortar until the residue was colourless. The acetone extract was pooled and transferred to separating funnel containing 20 ml petroleum ether and mixed gently. To this, 20 ml of 5%

sodium sulphate solution was added and the separating funnel was shaken gently. As the volume of petroleum ether reduces during this process because of its evaporation, 20 ml more of petroleum ether was added to the separating funnel for clear separation of two layers. Most of the colour was noticed in the upper petroleum ether layers.

The two phases were separated and the lower aqueous phase was re-extracted with additional 20 ml petroleum ether until the aqueous phase became colourless. The petroleum ether extract was pooled and washed once with a little distilled water. The washed petroleum ether extract containing carotenoids was poured into a brown bottle containing about 10 g of anhydrous sodium sulphate and was kept aside for 30 minutes or longer. The petroleum ether extract was decanted into a 100 ml volumetric flask through a funnel containing cotton wool. Then, sodium sulphate was washed with petroleum ether until it became colourless and the washings were then transferred to the volumetric flask. Finally, the volume was made up to 100 ml and the absorbance was measured in a spectrophotometer at 503 nm using petroleum ether as blank.

Calculation: Absorbance (1 unit) = 3.1206 g lycopene/ml

$$\text{Lycopene in 100g sample (mg)} = \frac{31.206 \times \text{absorbance}}{\text{weight of sample (g)}}$$

3.5.19 Number of seeds per fruit

The number of seeds from five fruits collected on five randomly selected plants were counted and average was worked out.

3.5.20 Thousand seed weight (g)

Five samples of thousand seeds from each treatment were taken at random and weighed and the mean weight of thousand seeds was expressed in grams.

3.5.21 Harvest duration (days)

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

3.5.22 Fruit yield (kg/plant)

The pickings were made at half ripe stage or breaker stage for recording fruit yield per plant (Thompson and Kelly, 1985). Fruit yield was recorded at every picking in grams and added up for all the pickings to arrive at the total yield per plant.

3.5.23 Fruit yield per hectare (q/ha)

The total yield per hectare was obtained by adding the yield of each harvest in the plot and further multiplied to get fruit yield per hectare.

3.5.24 Fruit colour

Colour of the fruits at fresh marketable stage was compared with the Royal Horticultural Society (RHS) Colour charts and classified into different colour groups.

3.6 Statistical analysis

Analysis of variance was done as suggested by Gomez and Gomez (1984).

3.6.1. ANOVA for RCBD

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F _{cal}
Genotypes	(g-1)	S _g	M _g = S _g / (g-1)	M _g / M _e
Replications	(r-1)	S _r	M _r = S _r /(r-1)	M _r /M _e
Error	(r-1)(g-1)	S _e	M _e = S _e /(r-1)(g-1)	
Total	(rg-1)	S _T		

Where,

r	=	Number of replications
g	=	Number of genotypes
S _r	=	Sum of squares due to replications
S _g	=	Sum of squares due to genotypes
S _e	=	Sum of squares due to error
S _T	=	Total sum of squares
M _r	=	Mean sum of squares due to replications
M _g	=	Mean sum of squares due to genotypes
M _e	=	Mean sum of squares due to error

The replication and entries mean sum of squares was tested against error mean squares by 'F' test at (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom for RCBD at 5% level of significance.

The calculated F-values were compared with tabulated F- value. When F- test found significant, critical differences were calculated to find out the superiority of one genotype over the others.

Critical difference (CD) was calculated as follows

$$CD_{0.05} = S.E. (d) \times t_{(0.05)} (r-1) (g-1) df$$

$$SE (d) \pm = \sqrt{2 Me/r}$$

$$SE (m) \pm = \sqrt{Me/r}$$

Where,

$$SE (m) \pm = \text{Standard error of mean}$$

$$SE (d) \pm = \text{Standard error of difference}$$

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

3.6.2. Parameters of variability

Parameters of variability were estimated as per formula given by Burton and Devane (1953).

3.6.2.1. Phenotypic coefficient of variation (PCV)

$$PCV (\%) = \frac{\sqrt{\text{Phenotypic variance (Vp)}}}{\text{General mean of population (GM)}} \times 100$$

3.6.2.2. Genotypic coefficient of variation (GCV)

$$GCV (\%) = \frac{\sqrt{\text{Genotypic variance (Vg)}}}{\text{General mean of population (GM)}} \times 100$$

Where:

$$V_e = M_e$$

$$V_g = \text{Genotypic variance } (M_g - M_e)/r$$

$$V_p = \text{Phenotypic variance } (V_g + V_e)$$

3.6.2.3. Heritability

Heritability in broad sense was calculated as per formula given by Burton and Devane (1953) and Allard (1960).

$$H (\%) = \frac{V_g}{v_p} \times 100$$

Where,

H = Heritability (%)

V_g = Genotypic variance [$V_g = (M_g - M_e) / r$]

V_p = Phenotypic variance ($V_g + V_e$)

3.6.2.4. Genetic advance

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

$$GA = H \times \sigma_p \times K$$

Where,

H = Heritability (%)

σ_p = Phenotypic standard deviation

K = Selection differential at 5% selection index (K = 2.06)

3.6.2.5. Genetic gain

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

$$GG = \frac{GA}{GM} \times 100$$

Where,

GG = Genetic gain

GA = Genetic advance

GM = Population mean

For categorization of magnitude of different parameters, following limits were used (Warshamana, 2005)

PCV and GCV	> 30%	-	High
	15-30%	-	Moderate
	<15%	-	Low

Heritability	>80%	-	High
	50-80%	-	Moderate
	< 50%	-	Low
Genetic gain	>50%	-	High
	25-50	-	Moderate
	<25%	-	Low

3.7. CORRELATION ANALYSIS

The correlations between all characters under study, at genotypic, phenotypic and environmental level were estimated as per the method described by Al-Jibouri et al. (1958).

3.7.1. ANOVA for Correlation

Source of variation	Degree of freedom	Mean sum of square		Mean sum of square	Variation ratio (F- value)
		X	Y		
Replication (r)	r-1				
Genotypes (t)	g-1	$M_g X$	$M_g Y$	$M_g XY = MP_1$	MP_1 / MP_2
Error (r)	(r-1)(g-1)	$M_e X$	$M_e Y$	$M_e XY = MP_2$	

Genotypic, Phenotypic and environmental co-variance between X and Y characters worked out as under:

$$\begin{aligned}
 \text{Environmental covariance (V}_e \text{ XY)} &= MP_2 \\
 \text{Genotypic covariance (V}_g \text{ XY)} &= (MP_1 - MP_2)/r \\
 \text{Phenotypic covariance (V}_p \text{ XY)} &= V_g \text{ XY} + V_e \text{ XY}
 \end{aligned}$$

Where,

$$\begin{aligned}
 V_e \text{ XY} &= \text{Environmental covariance between X and Y} \\
 V_g \text{ XY} &= \text{Genotypic covariance between X and Y} \\
 V_p \text{ XY} &= \text{Phenotypic covariance between X and Y}
 \end{aligned}$$

Coefficients of correlation:

3.7.2. Phenotypic correlation between characters X and Y:

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

3.7.3. Genotypic correlation between characters X and Y:

$$r_g = \frac{V_{gXY}}{\sqrt{V_{gX} \times V_{gY}}}$$

3.7.4. Environmental correlation between characters X and Y:

$$r_e = \frac{V_{eXY}}{\sqrt{V_{eX} \times V_{eY}}}$$

Where,

$V_p XY$, $V_g XY$, $V_e XY$ denotes phenotypic, genotypic and environmental covariances between characters X and Y, respectively.

$V_p X$, $V_g X$, $V_e X$ denotes phenotypic, genotypic and environmental variances between characters X, whereas, $V_p Y$, $V_g Y$, $V_e Y$ denotes phenotypic, genotypic and environmental variances between characters Y.

3.8. PATH COEFFICIENT ANALYSIS

The following formula was used for calculating path coefficient analysis suggested by Dewy and Lu (1959). The path coefficient was obtained by the simultaneous selection of following equations, which express the basic relationship between genotypic correlation (r) and path coefficient (P)

$$\begin{aligned} r_{14} &= P_{14} + r_{12} P_{24} + r_{13} P_{34} \\ r_{24} &= r_{21} P_{14} + P_{24} + r_{23} P_{34} \\ r_{34} &= r_{31} P_{14} + P_{32} + r_{24} P_{34} \end{aligned}$$

where r_{14} , r_{24} and r_{34} are genotypic correlation of components characters with yield (dependent variable) and r_{13} , r_{23} and r_{34} are genotypic correlations among the component characters (independent variable) and $r_{12} P_{24}$, $r_{13} P_{34}$, $r_{21} P_{14}$, $r_{23} P_{34}$, $r_{31} P_{14}$ and $r_{24} P_{34}$ indirect effects.

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

$$\begin{aligned} P_{14} &= C_{11} r_{14} + C_{12} r_{24} + C_{13} r_{34} \\ P_{24} &= C_{21} r_{14} + C_{22} r_{24} + C_{23} r_{34} \\ P_{34} &= C_{31} r_{14} + C_{32} r_{24} + C_{33} r_{34} \end{aligned}$$

Where C_{11} , C_{12} , C_{23} and C_{33} are constants and P_{14} , P_{24} and P_{34} are the estimates of direct effects.

3.8.1. Residual effect:

It measures the role of other possible independent variables which were not included in the study on dependent variable. The residual effect was estimated with the help of direct effect and simple correction coefficient as given below:

$$I = P^2_{X4} + P^2_{14} + P^2_{24} + P^2_{34} + 2P_{14r_{12}}P_{24} + 2P_{14r_{13}}P_{34} + 2P_{24r_{22}}P_{34}$$

3.9. Statistical analysis

3.9.1 Analysis of variance

Source	Degree of Freedom	Mean Squares	F- Value	Expected Mean Squares
Replications	$r-1$	M_r	M_r/M_e	$\sigma^2_e + g \sigma^2_r$
Treatments	$g-1$	M_g	M_g/M_e	$\sigma^2_e + r \sigma^2_g$
Error	$(r-1)(g-1)$	M_e	---	σ^2_e

Where,

- r = Number of replications
- g = Number of genotypes
- σ^2_r = Variance due to replications (M_r)
- σ^2_g = Variance due to genotypes (M_g)
- σ^2_e = Error variance (M_e)

The standard error of mean SE (m), standard error of difference SE (d) and critical difference (CD) for comparing the means of any two genotypes were calculated as below:

$$SE(m) = \pm \sqrt{\frac{M_e}{r}}$$

$$SE(m) = \pm \sqrt{\frac{2M_e}{r}}$$

$$\text{Critical difference (CD)} = SE(d) \times t(5\%) \text{ value at error degree of freedom}$$

At a 5% level of significance, the estimated F values were compared to the tabulated F values. It was considered significant if the computed F value was greater than the tabulated F value. All of the features that revealed significant variations across genotypes were subsequently examined for the various parameters. The coefficient of variation (CV) was computed using the formula below:

$$CV (\%) = \sqrt{\frac{Me}{x}} \times 100$$

3.9.2 Stability analysis

The analysis for stability performance of genotypes grown under different environments was done as per the model suggested by Eberhart and Russell (1966). The stability analysis was done using DOSBox 0.74-3 software STABMUL software by TNAU and OPSTAT by HAU Haryana.

$$Y_{ij} = \mu_i + b_{ij} I_j + \delta_{ij}$$

Where,

Y_{ij} = Mean performance of the i^{th} genotype in the j^{th} environment

μ_i = Mean yield of i^{th} genotype over all the environments

b_{ij} = Regression coefficient that measures the response of the i^{th} genotype to varying environments

I_j = Environmental index, expressed as deviation of mean of all the varieties at a given location from the overall mean *i.e.*, mean of all the genotypes at the j^{th} environment minus the grand mean

δ_{ij} = Deviation from regression the i^{th} genotype in the j^{th} environment.

I) Stability parameters

The three parameters of stability for sixteen genotypes at seven environments were computed as follows:

a) Mean performance (X_i) = $\Sigma Y_{ij}/n$

Where,

$\Sigma Y_{ij}/n$ = Mean of i^{th} genotype over n environments

b) Regression coefficient (b_i) = $\Sigma Y_{ij}I_j / \Sigma I_j^2$

Where,

$\Sigma Y_{ij}I_j$ = Sum of products of i^{th} genotype in j^{th} environment and j^{th} environmental index

ΣI_j^2 = Sum of squares due to environmental index

c) Deviations from regression (S^2_{di}) = $\{\Sigma \delta^2_{ij}/(n-2)\} - S^2_e/r_j$

(S^2_{di} is the non-linear component of genotype $\times$ environment interaction of i^{th} genotype)

Where,

$$\Sigma_j \delta^2_{ij} = (\Sigma_j Y^2_{ij} - Y^2_i/n) - [(\Sigma_j Y_{ij}I_j)^2 / \Sigma_j I_j^2]$$

S^2_e = Estimate of the pooled error of the variance of a genotype mean of the I^{th} environment.

r = Number of replications

ii) Computation of environmental index (I_j)

$$I_j = \Sigma Y_{ij}/g - \Sigma \Sigma Y_{ij}/gn$$

$$F = \frac{\text{Total of all varieties at } j^{\text{th}} \text{ location}}{\text{Number of varieties}} - \frac{\text{Grand total}}{\text{Total no. of observations}}$$

Analysis of variance of multi-environment data using Eberhart and Russell (1966) model

Source	Df	SS	MS
Total	ng-1	$\Sigma_i \Sigma_j Y^2_{ij} - C.F.$	-
Genotypes(G)	g-1	$1/n \Sigma_i Y^2_i - C.F.$	MS_1
Environments (E)	(n-1)	$1/g \Sigma_j Y^2_{.j} - C.F.$	-
G $\times$ E	(g-1) (n-1)	$\Sigma_i \Sigma_j Y^2_{ij} - Y^2_i/n - Y^2_{.j}/g + C.F.$	-
E + G $\times$ E	g (n-1)	$\Sigma_i \Sigma_j Y^2_{ij} - \Sigma Y^2_i/n$	-
Environment (linear)	1	$1/g (\Sigma_j Y_{.j}I_j)^2 / \Sigma_j I_j^2$	σ^2_e
G $\times$ E (linear)	(g-1)	$\Sigma_i [(\Sigma_j Y_{ij}I_j)^2 / \Sigma_j I_j^2] - \text{Env. (linear)SS}$	MS_2
Pooled deviations	g(n-2)	$\Sigma_i \Sigma_j \delta^2_{ij}$	MS_3
Pooled deviations due to i^{th} genotype	n-2	$\Sigma_j \delta^2_{ij}$	-
Pooled error	n(g-1) (r-1)	Me	S^2_e or MS_4

$$* C.F. = \sum_i \sum_j Y_{ij}^2 - \sum Y_{i.}^2 / n$$

Where,

r, n and g indicate the number of replications, environments and genotypes, respectively and S^2_e is the mean square due to pooled error which were calculated as:

$$S^2_e = \sum_j \{s_j^2 / (r-1) (g-1) n\} / r$$

Where,

s_j^2 = error sum of square at the j^{th} location.

iii) Test of significance

- a) The significance of pooled deviations was tested against the pooled error mean sum of squares as MS_3/MS_4 .

$$F = \frac{\text{MS due to pooled genotype}}{\text{MS due to pooled error}}$$

- b) The significance of the difference among genotypic means was tested using F test.

$$H_0: \mu_1 = \mu_2 = \dots = \mu_g$$

$$F = \frac{\text{MS due to pooled genotype}}{\text{MS due to pooled error}} = MS_1/MS_4$$

- c) The significance of genotype $\times$ environment interaction was tested as:

$$F = \frac{\text{MS due to G} \times \text{E interaction}}{\text{MS due to pooled error}}$$

- d) To test that there are no differences among genotypes for their regression on the environmental index:

$$H_0: b_1 = b_2 = \dots = b_g$$

$$F = \frac{\text{MS due to G} \times \text{E (linear)}}{\text{MS due to pooled error}} = MS_2/MS_3$$

- e) To test that any regression (bi) does not differ from unity, t test was used as follow:

$$t = \frac{1-b_i}{SE(b_i)} \quad \text{at } g(n-2) \text{ df at 5\% level of significance}$$

Where,

$$SE(b_i) = \pm \frac{\sqrt{MS \text{ due to pooled deviations}}}{\sum I_2 j / j}$$

f) The deviations from regression (S^2_{di}) from each genotype were tested using F test.

$$F = (\sum_j \delta^2_{ij} / n - 2) / \text{pooled error MS}$$

iv) Standard errors and means

a) Mean of regression coefficient (b_i) = $\sum b_i / g$

b) Grand Mean (X) = $\frac{\text{Grand total}}{\text{No. of observations}}$

c) SE (Mean) = $\frac{\sqrt{MS \text{ due to pooled deviations} / (n-1)}}{n}$

d) SE (difference) = $\frac{\sqrt{2 \times MS \text{ due to pooled deviations} / (n-1)}}{n}$

e) CD (5%) = SE(d) $\times$ t (5%) at pooled error df

Stable genotype:

A genotype with high mean value, unit regression coefficient and deviation not significantly differing from zero ($S^2_{di} = 0$) was taken as stable genotype.

3.9.3 Eberhart and Russell's model

The Eberhart and Russell's (1966) model is based on different stability parameters i.e., mean, regression coefficient (b_i) and deviation from regression (S^2_{di}) for estimating genotypic worth for consistent performance of yield and other traits. The objective of the present study was to identify genotypes with high mean performance, unity regression coefficient ($b_i=1.00$) and minimum deviation (non-significant) from regression ($S^2_{di}=0$) depicting consistent performance for the commercialization of the genotype (s). When the regression coefficient is unity (b_i), it indicates average stability to change in environments. However, when it is associated with high mean performance and minimum or non-significant deviation from regression, genotypes have general adaptability to all environments but if it is associated with low mean, genotypes are poorly adapted to all environments. The genotypes with higher b_i value ($b_i>1$) indicated below average stability and increasing sensibility to

environment changes. Such genotypes would perform better in high yielding or favourable environments but its performance will be lower in stress environments as compared to its genetic potential. Reverse is true when b_i value is less than unity ($b_i < 1$). It means above average stability and hence these genotypes perform better in unfavourable or stress environments.

3.9.4 GGE biplot analysis

The GGE biplots were constructed using the basic model

$$Y_{ij} - \mu - E_j = G_i + GE_{ij} \quad (1)$$

A two-way yield dataset comprising the genotypes and environments was subjected to singular value decomposition (SVD) to generate principal components (PC) along with the eigen vector values of genotypes and environments. Using the singular values of PC and the eigen vector values of genotypes and environments, Eq. (2) could be denoted as follows:

$$Y_{ij} - \mu - E_j = \lambda_1 \xi_{i1} \eta_{1j} + \lambda_2 \xi_{i2} \eta_{2j} + e_{ij} \quad (2)$$

where Y_{ij} is the response variable of i^{th} genotype at j^{th} location; μ is the overall mean; λ_1 and λ_2 are the singular values of PC1 and PC2, respectively; ξ_{i1} and ξ_{i2} are the eigen vectors of i^{th} genotype for PC1 and PC2, respectively; η_{1j} and η_{2j} are the eigen vectors of j^{th} environment for PC1 and PC2, respectively; and e_{ij} is the overall residual associated with genotype i and environment j .

The partitioning of singular values into the corresponding genotype and environment eigen vectors can be generalized as follows

$$g_{il} = \lambda_l f \xi_{il} \text{ and } e_{lj} = \lambda_l (1 - f) \eta_{lj} \quad (3 \text{ and } 4)$$

where l can be the principal component number 1 or 2 and f is the partition factor ($0 < f < 1$).

To generate the GGE biplot, the principal component scores of i^{th} genotypes and j^{th} environment are used as follows:

$$Y_{ij} - \mu - E_j = g_{i1} e_{1j} + g_{i2} e_{2j} + e_{ij} \quad (5)$$

Where, Y_{ij} is the response variable of i^{th} genotype at j^{th} location, μ is the overall mean, g_{i1} and g_{i2} are the PC scores of genotypes i ; e_{1j} and e_{2j} are the PC scores of

environment j . Standard deviation (SD) scaling was used to generate the initial standardized two-way data. Data centring used was Genotype + GE and Singular Value Decomposition (SVD) was dual metric preservation (both genotypes and environments). The biplot analyses were performed using GGE Biplot software R-Package “GGE” version 1.4 (Yan and Tinkers, 2006).

Chapter - 4

RESULTS AND DISCUSSION

The genetic improvement for yield and other traits in any crop can be brought about in two ways; first by manipulating the genetic makeup of the plant through several desirable genes and secondly by getting rid of the undesirable genes which restrain certain pathways leading to higher productivity. The first step in this direction is the basic understanding of genetic makeup of attributes, variability available and genetic association among various traits.

EXPERIMENT-1

In experiment-1, the present investigation aimed to assess the performance, genetic variability, correlation coefficients and path coefficients in twenty-five diverse genotypes of tomato for fruit yield and its component characters was carried out. The experimental results obtained are presented and discussed under the following sub heads:

4.1 ANALYSIS OF VARIANCE

4.2 GENERAL PERFORMANCE OF THE GENOTYPES

4.3 GENETIC VARIABILITY

4.3.1 Phenotypic coefficient of variation

4.3.2 Genotypic coefficient of variation

4.3.3 Heritability

4.3.4 Genetic advance and genetic gain

4.4 CORRELATION COEFFICIENT ANALYSIS

4.5 PATH COEFFICIENT ANALYSIS

4.1 ANALYSIS OF VARIANCE

The analysis of variance (ANOVA) revealed that mean sum of squares due to genotypes were significant (Appendix-I) for all the horticultural characters studied viz., days to 50 % flowering (48.29), days to first picking (149.71), plant height (1297.51), number of fruit clusters per plant (24.92), number of fruits per cluster (4.73), number of fruits per plant (513.86), average fruit weight (581.49), fruit length (207.36), fruit width (303.74), fruit shape index (0.03), pericarp thickness (2.91), fruit firmness (107224.54), number of locules (1.86), TSS (2.91), titratable acidity (0.02), TSS : Acid ratio (83.02), ascorbic acid (72.89), lycopene

content (4.74), harvest duration (146.25), number of seeds per fruit (2618.43), thousand seed weight (3.18) yield per plant (1.55) and yield per hectare (77556.85) thereby indicating the presence of sufficient genetic variability among the genotypes for these characters.

4.2 GENERAL PERFORMANCE OF THE GENOTYPES

In order to illustrate variability studies in twenty-five tomato genotypes, the mean performance of genotypes along with standard error of mean, coefficient of variation and critical difference were recorded for the traits viz., days to 50 % flowering, days to first picking, plant height (cm), number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight (g), fruit length (mm), fruit width (mm), fruit shape index, pericarp thickness (mm), fruit firmness (g/cm³), number of locules, TSS (°B), titratable acidity (%), TSS: Acid ratio, ascorbic acid (mg/100g), lycopene content (mg/100g), harvest duration, number of seeds per fruit, thousand seed weight, yield per plant (kg) and yield per hectare (q). The results pertaining for all the characters are described below and given in tables 4.1 to 4.7.

4.2.1 Days to 50 % flowering

Days to 50% flowering also indicates earliness which is a most desirable trait in tomato to fetch high market prices. Significant variation was observed for this trait. The value ranged from 26.67 to 40.00 days with an overall mean of 33.81 days (Table 4.1). The minimum number of days to 50% flowering was recorded in COHF-T-1 (26.67 days) which was statistically at par with COHF-T-3 (27.67 days). The maximum number of days to 50% flowering was recorded in EC-698849 (40.00 days) which was statistically at par with EC-631438 (39.33 days) and EC-615039 (38.67 days). Seven genotypes viz., COHF-T-1 (26.67 days), COHF-T-3 (27.67 days), COHF-T-2 (28.33 days), COHF-T-4 (29.00 days), EC-635526 (30.00), EC-654286 (30.33) and EC-654289 (30.67) were significantly earlier in days to 50 % flowering than standard check Solan Lalima (33.33 days). Considerable amount of variation with respect to this character was also reported by Raj et al. (2018), Limbani and Makati (2020) and Waiba et al. (2021).

4.2.2 Days to first picking

Earliness is important to fetch premium prices in a market. Therefore, days to first picking is a primary indicator to predict earliness in a crop like tomato. The value ranged from 57.33 to 78.67 days with an overall mean of 69.60 days (Table 4.1). The minimum number of days to first picking were recorded in COHF-T-3 (57.33 days) which was statistically at par with

COHF-T-1 (59.00 days). The maximum days to first picking were recorded in EC-631438 (78.67 days) which was statistically at par with genotypes EC-615039 (78.00 days) followed by EC-698849 (77.67 days), EC-631357 (77.00 days) and EC-687422 (76.67 days). COHF-T-3 (57.33 days), COHF-T-1 (59.00 days), COHF-T-2 (59.67 days), EC-635526 (61.00 days), COHF-T-4 (61.67 days), EC-654289 (62.33), EC-687604 (62.67 days) and EC-654682 (64.00 days) and were significantly earlier for days to first picking than check Solan Lalima (67.00 days). Tremendous variability with respect to days to first picking was also reported by Sharma and Thakur (2008) from 61 to 82.33 days, Rai et al. (2016), Raj et al. (2018), Waiba et al. (2021) and Mamta et al. (2022).

Table 4.1 Mean performance of tomato genotypes for days to 50% flowering, days to first picking and plant height (cm)

S. No.	Genotypes	Days to 50% flowering	Days to first picking	Plant height (cm)
1	EC-654289	30.67	62.33	117.00
2	EC-632936	36.00	75.67	85.72
3	EC-635529	35.67	72.00	86.49
4	EC-687604	30.00	62.67	113.93
5	EC-631415	38.00	75.00	104.39
6	EC-631438	39.33	78.67	66.16
7	EC-698849	40.00	77.67	64.93
8	EC-615039	38.67	78.00	71.36
9	EC-687423	32.00	66.67	123.59
10	EC-631359	39.00	75.67	78.91
11	EC-692350	35.67	75.00	97.46
12	EC-631399	35.00	71.00	85.62
13	EC-631427	34.00	67.67	77.00
14	EC-631411	34.33	70.33	95.71
15	EC-631351	34.67	74.67	113.44
16	EC-635526	30.00	61.00	118.58
17	EC-692336	33.00	73.67	92.66
18	EC-687422	36.00	76.67	118.52
19	EC-654286	30.33	64.00	119.32
20	EC-631357	38.00	77.00	68.47
21	COHF-T-1	26.67	59.00	127.37
22	COHF-T-2	28.33	59.67	122.25
23	COHF-T-3	27.67	57.33	123.49
24	COHF-T-4	29.00	61.67	114.91
25	Solan Lalima	33.33	67.00	117.33
	Mean	33.81	69.60	100.18
	Range	26.67-40.00	57.33-78.67	64.93-127.37
	SE (m)±	0.61	0.76	1.73
	CD (0.05)	1.73	2.18	4.95

4.2.3. Plant height (cm)

Plant height is important trait for longer harvest duration. Significant differences were observed among all the genotypes for plant height ranging from 64.93 cm to 127.37 cm (Table 4.1). Maximum plant height was observed in COHF-T-1 (127.37cm) which was statistically at par with COHF-T-3 (123.49cm) whereas minimum plant height was recorded in EC-698849 (64.93cm) which was statistically at par with EC-631438 (66.16 cm) and EC-631357 (68.47cm). Four genotypes viz., COHF-T-2 (122.37cm), COHF-T-3 (123.49 cm), EC-687423 (123.59 cm) and COHF-T-1 (127.37 cm) were found to be significantly superior than Solan Lalima (117.33 cm). Considerable amount of variation with respect to this character was also reported by Khapte and Jhansirani (2014), Singh et al. (2015), Raj et al. (2018) and Ritonga et al. (2018).

4.2.4. Number of fruit clusters per plant

Number of fruit clusters per plant is an essential yield contributing character that affects the final yield of the genotypes. Statistical analysis showed divergence among the genotypes for number of fruit clusters per plant (Appendix II). Overall mean for the character was 7.72 (Table 4.2). Maximum number of fruit clusters per plant was recorded in COHF-T-1 (13.08) which was statistically at par with EC-687423 (12.87) and COHF-T-3 (12.95) however, minimum number of fruit clusters per plant was found in EC-698849 (4.43) which was statistically at par with EC-631357 (4.68). Eight genotypes namely EC-654289 (9.01), EC-654286 (9.62), EC-687422 (9.74), EC- 635526 (10.40), COHF-T-2 (12.21), E-687423 (12.87), COHF-T-3 (12.95) and COHF-T-1 (13.08) under study produced significantly a greater number of fruit clusters per plant than standard check, Solan Lalima (8.17). Sufficient range of variability for the number of fruit clusters per plant was also recorded by Meitei et al. (2014) and Prajapati et al. (2015).

4.2.5. Number of fruits per cluster

The results observed for number of fruits per cluster show large variability between all the genotypes (Table 4.2). The attribute mean performance value was 4.79 and range varied from 2.87 to 6.99. Maximum number of fruits per cluster was recorded in COHF-T-1 (6.99) which was statistically at par with EC-654289 (6.73) ad EC-687423(6.84). Whereas, minimum number of fruits per cluster was found in EC-632438 (2.87) which was statistically equivalent with EC-698849 (3.04). Eleven genotypes viz., EC-654286 (5.27), EC-631411 (5.31), EC-631351 (5.44), EC-687604 (5.44), EC-635526 (5.67), EC-687422 (5.78), EC-

692350 (5.91), COHF-T-3 (6.27), EC-654289 (6.73), EC-687423 (6.84) and COHF-T-1 (6.99) were found to be significantly superior than Solan Lalima (4.85). These results are in line with Shankar et al. (2013), Madhukar et al. (2015), Prajapati et al. (2015), Rai et al. (2016) Kavyashree et al. (2017) and Bhandari et al. (2017).

4.2.6. Number of fruits per plant

Number of fruits per plant is the most important component trait which is directly related to increased fruit yield per plant. The observations for this character have been presented in Table 4.2, which showed significant variation among the genotypes ranging

Table 4.2 Mean performance of tomato genotypes for number of fruit clusters per plant, number of fruits per cluster and number of fruits per plant

S. No.	Genotypes	Number of fruit clusters per plant	Number of fruits per cluster	Number of fruits per plant
1	EC-654289	9.01	6.73	30.11
2	EC-632936	5.49	4.24	19.81
3	EC-635529	5.31	3.33	14.74
4	EC-687604	7.51	5.44	28.97
5	EC-631415	6.67	4.52	23.28
6	EC-631438	4.61	2.87	10.24
7	EC-698849	4.43	3.04	10.55
8	EC-615039	4.94	3.50	12.96
9	EC-687423	12.87	6.84	30.01
10	EC-631359	5.20	3.75	15.47
11	EC-692350	7.04	5.91	23.01
12	EC-631399	5.48	3.47	16.76
13	EC-631427	5.25	3.81	16.91
14	EC-631411	6.51	5.31	27.51
15	EC-631351	8.13	5.44	25.64
16	EC-635526	10.40	5.67	38.51
17	EC-692336	6.05	4.08	22.97
18	EC-687422	9.74	5.78	30.28
19	EC-654286	9.62	5.27	37.10
20	EC-631357	4.68	3.68	14.17
21	COHF-T-1	13.08	6.99	35.18
22	COHF-T-2	12.21	4.95	31.20
23	COHF-T-3	12.95	6.27	33.64
24	COHF-T-4	7.56	4.12	29.02
25	Solan Lalima	8.17	4.85	28.04
	Mean	7.72	4.79	24.24
	Range	4.43-13.08	2.87-6.99	10.24-38.51
	SE (m)±	0.111	0.09	0.43
	CD (0.05)	0.32	0.25	1.21

from 10.24-38.51 fruits per plant with the overall population mean of 24.24 fruits per plant. Maximum number of fruits per plant was recorded in genotype EC-635526 (38.51) while minimum number of fruits per plant was recorded in genotype EC-631438 (10.24) which was statistically similar with EC-698849 (10.55). Ten genotypes *i.e.*, EC-687604 (28.97), COHF-T-4 (29.02), EC-687423 (30.01), EC-654289 (30.11), EC-687422 (30.28), COHF-T-2 (31.20), COHF-T-3 (33.64), COHF-T-1 (35.18), EC-635526 (37.10) and EC-635526 (38.51) were found to be significantly superior than check variety Solan Lalima (28.04). The results with respect to number of fruits per plant are in line with earlier reports Madhurina and Amitava (2012), Singh et al. (2015), Mishra and Pandey (2018), Panchbhैया et al., (2018), Anuradha et al. (2020), Limbani and Makati (2020), Rawat et al. (2020) and Pooja et al. (2022).

4.2.7 Average fruit weight (g)

Average fruit weight is an important character because it is associated with fruit yield. Average fruit weight for the 25 genotypes under study varied from 43.25-74.02 g with the overall mean of 57.01g as presented in Table 4.3. Genotype EC-687423 weighed highest (74.02 g) among all the genotypes which was found statistically at par with COHF-T-4 (73.05 g). Whereas, genotype EC-631399 weighed lowest (43.25 g) which was found statistically at par with EC-687422 with an average fruit weight 43.70 g, EC-631351 with an average fruit weight 44.20 g and with EC-687422 with an average fruit weight 43.70 g, EC-632936 with an average fruit weight 44.38 g. However, the genotypes *viz.*, EC-692336 (68.73 g), EC-654289 (70.12 g), COHF-T-4 (73.05 g) and EC-687423 (74.02 g) were statistically found superior in terms of average fruit weight as compared to the check, Solan Lalima (67.12 g). Results of the present study were in accordance with the findings of Meitei et al. (2014), Prajapati et al. (2015), Singh et al. (2015), Rai et al. (2016), Raj et al. (2018), Anuradha et al. (2020) and Rawat et al. (2020),

4.2.8 Fruit length

Fruit length is directly proportional to yield. The perusal of data pertaining to fruit length is presented in Table 4.3. A wide range of variation was found among the genotypes for fruit length (Appendix II), ranges from 32.35 mm to 57.11 mm with the mean fruit length of 42.76 mm. Maximum fruit length was recorded in EC-687423 (57.11 mm) which was found to be statistically at par with COHF-T-4 (55.40 mm) and COHF-T-1 (55.65mm) while minimum fruit length was recorded in EC-635529 (32.35mm) which was statistically at par with EC-698849 (33.13 mm), EC-631359 (33.76mm) and EC-631357 (32.52mm). Six genotypes

viz., COHF-T-3 (51.26 mm), EC-687422 (51.81 mm), EC-635526 (52.75 mm), COHF-T-4 (55.40 mm), COHF-T-2 (56.50 mm) and EC-687423 (57.11 mm) were found to show larger fruit length as compared to the check variety, Solan Lalima (48.98 mm). Tremendous variability with respect to fruit length was also reported by Prajapati et al. (2015), Ullah (2015) and Ritonga et al. (2018).

Table 4.3 Mean performance of tomato genotypes for average fruit weight (g), fruit length (cm), fruit width (cm) and fruit shape index

S. No.	Genotypes	Average fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Fruit shape index
1	EC-654289	70.12	46.56	51.74	0.90
2	EC-632936	44.38	34.49	35.79	0.96
3	EC-635529	47.69	32.35	30.45	1.06
4	EC-687604	68.79	49.70	58.26	0.85
5	EC-631415	45.81	38.54	36.87	1.05
6	EC-631438	49.58	37.54	38.04	0.99
7	EC-698849	52.76	33.13	30.87	1.07
8	EC-615039	62.81	38.68	30.63	1.27
9	EC-687423	74.02	57.11	50.01	1.14
10	EC-631359	49.38	33.76	35.35	0.95
11	EC-692350	47.65	40.94	44.64	0.92
12	EC-631399	43.25	34.40	32.66	1.05
13	EC-631427	65.28	38.23	40.19	0.95
14	EC-631411	46.32	37.20	39.74	0.93
15	EC-631351	44.20	42.11	39.40	1.07
16	EC-635526	53.51	52.75	57.11	0.92
17	EC-692336	68.73	35.58	31.24	1.14
18	EC-687422	43.70	51.81	49.81	1.04
19	EC-654286	56.28	47.76	56.03	0.85
20	EC-631357	61.76	32.52	33.77	0.96
21	COHF-T-1	61.36	55.65	51.55	1.09
22	COHF-T-2	65.74	56.50	58.46	0.97
23	COHF-T-3	61.85	51.26	53.45	0.96
24	COHF-T-4	73.05	55.40	55.58	1.00
25	Solan Lalima	67.12	48.98	51.09	0.96
	Mean	57.01	42.76	43.67	0.99
	Range	43.25-74.02	32.35-57.11	30.45-58.46	0.82-1.27
	SE (m)±	0.73	0.67	0.60	0.02
	CD (0.05)	2.08	1.91	1.72	0.06

4.2.9 Fruit width

In tomato, fruit width is a key determinant of the overall size of the fruit. Fruits having larger width are bigger in size which eventually affects the yield. Fruit width ranged

from 30.45 to 58.46 mm with an overall mean 43.67 mm (Table 4.3). The maximum fruit width was recorded in genotype COHF-T-2 (58.46 mm) which was statistically at par with EC-687604 (58.26 mm) while, minimum fruit width was observed in EC-635529 (30.45 mm) which was statistically at par with EC-615039 (30.63 mm), EC-698849 (30.87 mm) and EC-692336 (31.24 mm). Six genotypes viz., COHF-T-3 (53.45 mm), COHF-T-4 (55.58 mm), EC-654286 (56.03 mm), EC-635526 (57.11 mm), EC-687604 (58.26 mm) and COHF-T-2 (58.46 mm) were found significantly superior than check Solan Lalima (51.09 mm) in terms of fruit width. Wide range of variability for fruit width was also recorded by Meitei et al. (2014), Prajapati et al. (2015) and Ullah et al. (2015).

4.2.10 Fruit shape index

The fruit shape index is defined as the ratio of the polar diameter to the equatorial diameter of the fruit. Generally, round-shaped fruits are preferred for table purposes, while oval-shaped fruits are preferred for processing. A wide range of variation was found among the genotypes for fruit shape index (Appendix II), ranges from 0.82 to 1.27 with the mean fruit shape index of 0.99. The data presented in table 4.3 reflected significant differences among genotypes for fruit shape index. Maximum fruit shape index was observed in EC-615039 (1.27) whereas, minimum fruit shape index was observed in COHF-T-1 (0.82 mm). The results with respect to fruit shape index are in line with earlier reports of Solieman et al. (2013), Khapte et al. (2019) and Kathimba et al. (2022) and Sathiyavarsha et al. (2023).

4.2.11 Pericarp thickness (mm)

Fruits having high pericarp thickness can withstand shipping and remain firm for more number of days as compared to thin fleshed fruits. Pericarp thickness ranged from 3.08 mm to 6.79 mm with the population mean of 4.71 mm (Table 4.4) indicating the presence of genetic variability among the genotypes for pericarp thickness. Maximum pericarp thickness was recorded in COHF-T-4 (6.79 mm) which was statistically at par with EC-654286 (6.59 mm) while minimum pericarp thickness was recorded in EC-635529 (3.08 mm). Statistical analysis of data indicated that seven genotypes viz. EC-687423 (5.24 mm), EC-654289 (5.30 mm), EC-687604 (5.70 mm), COHF-T-3 (5.91 mm), EC-635526 (6.03 mm), EC-654286 (6.59 mm) and COHF-T-4 (6.79 mm) recorded significantly higher pericarp thickness than standard check Solan Lalima (4.89 mm). Similar findings were also recorded by Dar et al. (2011), Sajjan et al. (2016), Sharma and Thakur (2008), Khapte and Jhansirani, (2014), Singh et al. (2015) and Raj et al., (2018).

4.2.12 Fruit firmness (g/cm³)

Fruit firmness becomes especially important when resistance during bulk transportation is an issue, independently of the tomato end use. A wide range of variation was found among the genotypes for fruit firmness (Appendix II), ranges from 603.74 to 1274.60 with the mean fruit firmness of 837.75. The data presented in table 4.4 reflected significant differences among genotypes for fruit firmness. Maximum fruit firmness was observed in COHF-T-4 (1274.60 g/cm³) whereas, genotype EC-635529 (603.74 g/cm³) weighed lowest fruit firmness. However, the genotypes viz., EC-654289 (900.04 g/cm³), EC-687604 (1104.49

Table 4.4 Mean performance of tomato genotypes for pericarp thickness (mm), fruit firmness (g/cm³) and number of locules

S. No.	Genotypes	Pericarp Thickness (mm)	Fruit firmness (g/cm ³)	Number of locules
1	EC-654289	5.30	900.04	4.26
2	EC-632936	4.92	803.39	3.30
3	EC-635529	3.08	603.74	4.82
4	EC-687604	5.70	1104.49	4.60
5	EC-631415	3.66	703.37	4.32
6	EC-631438	3.78	720.73	4.12
7	EC-698849	4.53	752.01	3.62
8	EC-615039	4.25	741.22	4.08
9	EC-687423	5.24	862.26	2.53
10	EC-631359	4.76	788.48	3.27
11	EC-692350	3.60	683.27	4.57
12	EC-631399	3.92	722.90	4.20
13	EC-631427	4.52	761.44	3.34
14	EC-631411	5.08	812.82	3.01
15	EC-631351	3.54	649.67	4.46
16	EC-635526	6.03	1158.88	2.64
17	EC-692336	3.63	692.42	4.22
18	EC-687422	4.33	739.90	4.09
19	EC-654286	6.59	1203.91	2.54
20	EC-631357	4.78	773.26	4.14
21	COHF-T-1	4.51	758.44	4.10
22	COHF-T-2	4.42	748.40	3.81
23	COHF-T-3	5.91	1126.92	2.60
24	COHF-T-4	6.79	1274.60	2.34
25	Solan Lalima	4.89	857.25	2.99
	Mean	4.71	837.75	3.34
	Range	3.08-6.79	603.74-1274.60	2.34-4.82
	SE (m)±	0.07	11.30	0.09
	CD (0.05)	0.20	32.22	0.25

g/cm³), COHF-T-3 (1126.92 g/cm³), EC-635526 (1158.88 g/cm³), EC-654286 (1203.91 g/cm³) and COHF-T-4 (1274.60 g/cm³) were found statistically superior in terms of fruit firmness as compared to the check, Solan Lalima (857.25 g/cm³). Results of the present study were in accordance with the findings of Kharshandi (2015).

4.2.13 Number of locules per fruit

Locules are the chambers inside the fruit that contain the seeds. Number of locules per fruit in tomato depicts the juice content and shelf life of the genotypes. If there are more number of locules then fruit will have more juice content. It had a mean performance of 3.34 with a range of 2.34 to 4.82. Minimum number of locules were recorded in COHF-T-4 (2.34) which was statistically at par with EC-687423 (2.53) and EC-654286 (2.54). Maximum number of locules per fruit were observed in EC-635529 (4.82) which was statistically at par with EC-687606 (4.60) and EC-692350 (4.57). Eighteen genotypes were found significantly superior for number of locules per fruit as compared to standard check, Solan Lalima (2.99). Significant variation for number of locules per fruit was also recorded by Golani et al. (2007), Prashanth et al. (2007), Prajapati et al. (2015), Rai et al. (2016), Sajjan et al. (2016), Singh and Singh (2018) and Pooja et al. (2022).

4.2.14 Total soluble solids (°B)

TSS is the measure of total amount of solids dissolved within a substance. TSS content is an important quality trait for processing. TSS ranged from 2.34 to 5.13 °B with the mean value of 3.53 °B (Table 4.5). It was recorded lowest for EC-632936 (2.34 °B) which was statistically at par with EC-631359 (2.61°B), EC-698849 (2.62°B), EC-631438 (2.71°B) and EC-615039 (2.72 °B). While, highest value was recorded for EC-687422 (5.13°B), which was statistically at par with COHF-T-2 (5.07°B), EC-6631411 (4.88°B) and EC-687423 (4.81°B). Six genotypes *i.e.*, EC-631427 (4.13°B), EC-635529 (4.56°B), EC-687423 (4.81 °B), EC-631411 (4.88 °B), COHF-T-2 (5.07°B) and EC-687422 (5.13 °B) were found to be significantly superior in terms of TSS than the check, Solan Lalima (3.59 °B). Similar results were also reported by Shankar et al. (2013), Sharma and Sharma (2013), Khapte and Jhansirani (2014), Meena et al. (2015), Singh et al. (2015), Kumar et al. (2016) and Rai et al. (2016).

4.2.15 Titratable acidity (%)

Titrateable acidity determines the total acid content present in a fruit. Typically, unripe fruits have high titrateable acidity which gives them a sourer taste. It ranged from 0.23

to 0.51% being maximum in EC-632936 (0.51 %) which were statistically at par with EC-631359 (0.50 %) and EC-698849 (0.48 %). The population mean for this trait was 0.36 % EC-687422 (0.23 %) and recorded lowest titratable acidity which was statistically at par with COHF-T-2 (0.25 %) and EC-687423 (0.26 %). Thirteen genotypes were recorded significantly superior in terms of titratable acidity than the standard check, Solan Lalima (0.32 %). Significant variation for titratable acidity was also observed by Prashanth et al. (2007), Kumar et al. (2016) and Panchbhaiya et al. (2018).

Table 4.5 Mean performance of tomato genotypes for TSS (°Brix), titratable acidity (%) and TSS: Acid ratio

S. No.	Genotypes	TSS (°Brix)	Titratable acidity (%)	TSS: Acid ratio
1	EC-654289	3.17	0.37	8.48
2	EC-632936	2.34	0.51	4.59
3	EC-635529	4.56	0.27	16.88
4	EC-687604	3.10	0.37	8.39
5	EC-631415	3.06	0.39	7.84
6	EC-631438	2.71	0.46	5.89
7	EC-698849	2.62	0.48	5.43
8	EC-615039	2.72	0.45	6.04
9	EC-687423	4.81	0.26	18.51
10	EC-631359	2.61	0.50	5.22
11	EC-692350	3.01	0.43	6.99
12	EC-631399	3.85	0.30	12.84
13	EC-631427	4.13	0.28	14.91
14	EC-631411	4.88	0.27	18.07
15	EC-631351	3.44	0.33	10.44
16	EC-635526	3.90	0.29	13.47
17	EC-692336	3.00	0.43	6.98
18	EC-687422	5.13	0.23	20.53
19	EC-654286	3.02	0.42	7.14
20	EC-631357	3.36	0.35	9.69
21	COHF-T-1	3.38	0.34	9.94
22	COHF-T-2	5.07	0.25	20.30
23	COHF-T-3	3.60	0.31	11.59
24	COHF-T-4	3.07	0.38	8.08
25	Solan Lalima	3.59	0.32	11.21
	Mean	3.53	0.36	10.78
	Range	2.34-5.13	0.23-0.51	4.59-20.53
	SE (m)±	0.13	0.07	0.46
	CD (0.05)	0.36	0.03	1.32

4.2.16 TSS: Acid ratio (%)

Perusal of the data recorded in Table 4.5 revealed wide range of variability for TSS: Acid ratio which ranged from 4.59-20.53 with the grand mean of 10.78. Maximum value for TSS: Acid ratio was observed in EC-687422 (20.53%) which was statistically at par with COHF-T-2 (20.30%). While, minimum value for TSS: Acid ratio was recorded for EC-632936 (4.59%) which was statistically at par with EC-631359 (5.22%), EC-698849 (5.43%) and EC-631438 (20.53%). However, the genotypes viz., EC-631399 (12.84 %), EC-635526 (13.47 %), EC-631427 (14.91 %), EC-635529 (16.88 %), EC-631411 (18.07 %), EC-687423 (18.51 %), COHF-T-2 (20.30 %) and EC-687422 (20.53 %) were statistically found superior in terms of TSS: Acid ratio as compared to the check, Solan Lalima (11.21%). Results of the present study were in accordance with the findings of Sajjan et al. (2016), Singh and Singh (2018) and Sathiyavarsha et al. (2023).

4.2.17 Ascorbic acid (mg/100g)

Ascorbic acid is a precursor of vitamin C and is one of the most important quality parameters in tomato. Ascorbic acid is an important trait, which contributes to the nutritional value of tomato. Ascorbic acid ranged from 16.91 to 31.65 mg/100g with an overall mean of 24.71 mg/100g. Maximum value for ascorbic acid was observed in EC-692336 (31.65 mg/100g) which was statistically at par with EC-698849 (30.77 mg/100g), EC-631359 (30.60 mg/100g), EC-687422 (30.22 mg/100g) and EC-635526 (29.89 mg/100g). While, minimum value for ascorbic acid was recorded for COHF-T-1 (16.91 mg/100g) which was statistically at par with EC-635529 (17.12 mg/100g), COHF-T-2 (17.45 mg/100g), EC-631411 (17.66 mg/100g) and EC-631415 (18.58 mg/100g). Six genotypes viz. EC-631351 (28.83 mg/100g), EC-635526 (29.89 mg/100g), EC-687422 (30.22 mg/100g), EC-631359 (30.60 mg/100g), EC-698849 (30.77 mg/100g) and EC-692336 (31.65 mg/100g) were recorded significantly superior for ascorbic acid content than the standard check Solan Lalima (26.48 mg/100g). The results of present study for ascorbic acid were in accordance with findings of Meena et al. (2015), Kumar et al. (2016) and Raj et al. (2018).

4.2.18 Lycopene content (mg/100g)

Lycopene is a carotenoid pigment, primarily responsible for the deep-red colour of ripe tomato fruits. Lycopene content for the twenty five genotypes under study varied from 3.50-7.56 mg/100g with the overall mean of 5.24 mg/100g as presented in Table 4.6.

Genotype EC-635526 highest lycopene content (7.56 mg/100g) among all the genotypes which was found statistically at par with EC-687422 (7.48 mg/100g) and COHF-T-2 (7.43 mg/100g) whereas, genotype EC-698849 weighed lowest (3.50 mg/100g) which was found statistically at par with EC-631359 (3.56 mg/100g), EC-632936 (3.61 mg/100g) and EC-615039 (3.62 mg/100g). However, the genotypes viz., COHF-T-1 (6.25 mg/100g), EC-631427 (6.89 mg/100g), EC-631411 (6.95 mg/100g), COHF-T-2 (7.43 mg/100g), EC-687422 (7.48 mg/100g) and EC-635526 (7.56 mg/100g) were statistically found superior in terms of lycopene content as compared to the check, Solan Lalima (5.77). Results of the present study were in accordance with the findings of Khan and Jindal (2016), Khapte et al. (2019).

4.2.19. Number of seeds per fruit

Number of seeds per fruit is an important character because seed is a propagating material and is also responsible for early-stage growth and development of the plant. As presented in the Table 4.6, significant variation was found for the number of seeds per fruit in the population under study ranging from 63.09-153.08 seeds per fruit with the population mean of 102.26 seeds per fruit. EC-635526 was found to produce highest number of seeds (153.08 seeds per fruit) which was statistically at par with COHF-T-3 (148.63 seeds per fruit), COHF-T-1 (148.61 seeds per fruit), COHF-T-2 (146.55 seeds per fruit) and EC-687432 (139.44 seeds per fruit) whereas, EC-635529 (63.09 seeds per fruit) which was statistically at par with EC-698849 (66.28 seeds per fruit), EC-692336 (71.55 seeds per fruit), EC-631438 (76.46 seeds per fruit), EC-632936 (78.37 seeds per fruit) and EC-631359 (78.69 seeds per fruit). Statistical analysis of data indicated that six genotypes viz. EC-687604 (135.02 seeds per fruit), EC-687423 (139.44 seeds per fruit), COHF-T-2 (146.55 seeds per fruit), COHF-T-1 (148.61 seeds per fruit), COHF-T-3 (148.63 seeds per fruit) and EC-635526 (153.08 seeds per fruit) recorded significantly higher number of seeds per fruit than standard check Solan Lalima (110.11 seeds per fruit). Confirming the results of present findings; Prashanth (2007), Prajapati et al. (2015), Kumar et al. (2016), Bhandari et al. (2017) and Singh et al. (2021).

4.2.20 Thousand seed weight (g)

Thousand seed weight is a very important measure of seed quality, which affects germination, seed potential, seedling growth and plant performance. The observations pertaining to thousand seed weight for various genotypes under study has been presented in the Table 4.6; where it is clearly reported that the thousand seed weight for present study ranged from 1.88 to 4.83 g with the overall mean of 3.36 g. The genotype COHF-T-3 had the

maximum thousand seed weight (4.83 g) which was statistically at par with the EC-635526 (4.78 g). However, EC-631357 had the minimum thousand seed weight (1.88 g) which was statistically at par with the thousand seed weight of EC-635529 (1.92 g) and EC-698849 (1.98 g). However, COHF-T-4 (4.01 g), EC-687422 (4.10 g), EC-654289 (4.11 g), EC-654286 (4.17 g), EC-687423 (4.25 g), EC-687604 (4.27 g), COHF-T-1 (4.53 g), COHF-T-2 (4.68 g), EC-635526 (4.78 g) and COHF-T-3 (4.83 g) were reported significantly superior in terms of thousand seed weight than the check Solan Lalima (3.87 g). Wide range of variations for this character were also reported by Srinivasulu et al. (2020) and Rahimi et al. (2022).

Table 4.6 Mean performance of tomato genotypes for ascorbic acid (mg/100g), lycopene content (mg/100g), number of seeds per fruit and thousand seed weight

S. No.	Genotypes	Ascorbic acid (mg/100g)	Lycopene content (mg/100g)	Number of seeds per fruit	Thousand seed weight
1	EC-654289	22.50	5.48	113.37	4.11
2	EC-632936	27.80	3.61	78.37	2.53
3	EC-635529	17.12	5.42	63.09	1.92
4	EC-687604	26.37	4.89	135.02	4.27
5	EC-631415	18.58	4.70	82.52	2.88
6	EC-631438	27.75	4.52	76.46	2.21
7	EC-698849	30.77	3.50	66.28	1.98
8	EC-615039	21.26	3.62	83.02	2.05
9	EC-687423	20.54	5.18	139.44	4.25
10	EC-631359	30.60	3.56	78.69	2.39
11	EC-692350	25.37	4.19	84.27	2.80
12	EC-631399	25.16	5.06	81.84	3.00
13	EC-631427	19.23	6.89	86.34	3.00
14	EC-631411	17.66	6.95	98.38	3.87
15	EC-631351	28.83	4.84	92.91	3.70
16	EC-635526	29.89	7.56	153.08	4.78
17	EC-692336	31.65	4.93	71.55	2.21
18	EC-687422	30.22	7.48	116.50	4.10
19	EC-654286	24.71	5.04	123.21	4.17
20	EC-631357	25.07	4.79	77.94	1.88
21	COHF-T-1	16.91	6.25	148.61	4.53
22	COHF-T-2	17.45	7.43	146.55	4.68
23	COHF-T-3	27.54	4.49	148.63	4.83
24	COHF-T-4	28.20	4.89	100.27	4.01
25	Solan Lalima	26.48	5.77	110.11	3.87
	Mean	24.71	5.24	102.26	3.36
	Range	16.91-31.65	3.50-7.56	63.09-153.08	1.88-4.83
	SE (m)±	0.78	0.07	5.68	0.05
	CD (0.05)	2.24	0.21	16.20	0.14

4.2.21 Harvest duration (days)

Longer harvest duration ensures the continuous supply of produce and good price of tomato for over a longer period. It also keeps a balance between the demand and supply, thereby in avoiding glut in the market and fall in prices. It had a mean performance of 30.64 days with a range of 20.33 to 40.33 days. Maximum harvest duration was reported in COHF-T-3 (40.33 days) which was statistically at par with COHF-T-1 (40.00 days). Minimum harvest duration was observed for EC-698849 (20.33 days) which was statistically at par with EC-631438 (20.67 days), EC-635529 (21.33 days) EC-631359 (21.33 days) and EC-615039 (21.67 days). Statistical analysis of data indicated that seven genotypes viz. EC-631351 (36.67 days), EC-687423 (37.00 days), EC-692350 (37.67 days), EC-654286 (37.67 days), COHF-T-2 (38.67 days), COHF-T-1 (40.00 days) and COHF-T-3 (40.33 days) recorded significantly longer harvesting period than the check Solan Lalima (35.00 days). Similar findings were also recorded by Sharma and Sharma (2013) and Rai et al. (2016).

4.2.22 Yield per plant (kg)

The goal of any breeding programme is target to achieve maximization of marketable yield. This is also the key factor in adoption or rejection of a variety or hybrid by the farmer. High fruit yield per plant along with high fruit quality is considered as a most important trait in tomato thus; deserve highest attention from improvement point of view. The observations pertaining to fruit yield per plant have been recorded in Table 4.7, which showed a wide range of variability. The fruit yield per plant for all the genotypes varied from 0.48-2.19 kg fruits per plant with the overall grand mean of 1.38 kg fruits per plant. The maximum yield was obtained from the genotype EC-687423 (2.19 kg fruits per plant) which was statistically at par with COHF-T-1 (2.13 kg fruits per plant) and COHF-T-4 (2.09 kg fruits per plant) whereas, minimum yield was obtained from EC-631438 (0.48 kg fruits per plant) which was statistically at par with EC-698849 (0.55 kg fruits per plant) and EC-635529 (0.63 kg fruits per plant). Eight genotypes viz., EC-687604 (1.96 kg fruits per plant) followed by COHF-T-2 (2.02 kg fruits per plant), EC-635526 (2.03 kg fruits per plant), COHF-T-3 (2.05 kg fruits per plant), EC-654286 (2.06 kg fruits per plant), EC-654289 (2.07 kg fruits per plant), COHF-T-4 (2.09 kg fruits per plant) and COHF-T-1 (2.13 kg fruits per plant) were found significantly superior for fruit yield per plant than the check Solan Lalima (1.85 kg fruits per plant). Similar results were also recorded by Kumar and Thakur (2007) and Spaldon and Hussain (2017).

Table 4.7 Mean performance of tomato genotypes for harvest duration (days), yield per plant (kg) and yield per hectare (q/ha)

S. No.	Genotypes	Harvest duration (days)	Yield per plant (kg)	Yield per hectare (q/ha)
1	EC-654289	33.67	2.07	414.63
2	EC-632936	28.00	0.85	251.85
3	EC-635529	21.33	0.67	199.50
4	EC-687604	29.67	1.96	381.55
5	EC-631415	33.00	1.04	307.60
6	EC-631438	20.67	0.48	142.04
7	EC-698849	20.33	0.53	156.05
8	EC-615039	21.67	0.78	231.51
9	EC-687423	37.00	2.19	448.51
10	EC-631359	21.33	0.73	216.58
11	EC-692350	37.67	1.09	323.92
12	EC-631399	25.33	0.69	204.41
13	EC-631427	26.33	1.07	318.20
14	EC-631411	32.67	1.24	368.77
15	EC-631351	36.67	1.10	326.77
16	EC-635526	35.33	2.03	402.41
17	EC-692336	22.67	1.55	458.28
18	EC-687422	33.33	1.29	383.20
19	EC-654286	37.67	2.06	409.78
20	EC-631357	23.00	0.85	251.36
21	COHF-T-1	40.00	2.13	430.43
22	COHF-T-2	38.67	2.02	398.88
23	COHF-T-3	40.33	2.05	407.72
24	COHF-T-4	34.67	2.09	419.51
25	Solan Lalima	35.00	1.85	348.52
	Mean	30.64	1.38	328.08
	Range	20.33-40.33	0.48-2.19	142.04-458.28
	SE (m)±	0.55	0.08	23.60
	CD (0.05)	1.58	0.23	67.31

4.2.23 Yield per hectare (q/ha)

Highly significant variations were observed for yield per hectare among the genotypes and it ranged from 142.04 to 458.28 (q/ha) with an overall mean of 328.08 (q/ha) (Table 4.7). Minimum yield per hectare was recorded for EC-631438 (142.04 q/ha) whereas EC-687423 (458.28 q/ha) showed maximum yield per hectare which was statistically at par with which was statistically at par with COHF-T-1 (430.43 q/ha) and COHF-T-4 (419.51 q/ha), EC-654289 (414.63q/ha), EC-654286 (409.78q/ha), COHF-T-3 (407.72 q/ha), EC-635526

(402.41 q/ha) and COHF-T-2 (398.88 q/ha). Eight genotypes viz., EC-687604 (381.55 q/ha) followed by COHF-T-2 (398.88 q/ha), EC-635526 (402.41 q/ha), COHF-T-3 (407.72 q/ha), EC-654286 (409.78q/ha), EC-654289 (414.63q/ha), COHF-T-4 (419.51 q/ha), COHF-T-1 (430.43 q/ha) and EC-687423 (458.28 q/ha) were found significantly superior for fruit yield per plant than the check Solan Lalima (348.52 q/ha). Sufficient range of variability for yield per hectare was reported by Rahimi et al. (2022).

4.2.24 Colour of the fruits

The colour pattern of the fruit has been presented in the Table 4.8 At ripe stage all the twenty-five genotypes were in red grouped and orange. However, different shades of red colour were found within the red group. Ample amount of variation for the fruit colour were also reported by Thakur et al. (2022).

Table 4.8 Fruit colour of tomato genotypes at marketable stage.

S. No.	Genotypes	Fruit color
1	EC-654289	RED GROUP (43 B)
2	EC-632936	RED GROUP (45C)
3	EC-635529	RED GROUP (42A)
4	EC-687604	RED GROUP (43A)
5	EC-631415	RED GROUP (44A)
6	EC-631438	RED GROUP (44 B)
7	EC-698849	RED GROUP (42 B)
8	EC-615039	RED GROUP (45C)
9	EC-687423	RED GROUP (42 B)
10	EC-631359	ORANGE-RED GROUP (34A)
11	EC-692350	RED GROUP (44A)
12	EC-631399	RED GROUP (42C)
13	EC-631427	ORANGE-RED GROUP (33A)
14	EC-631411	RED GROUP (43A)
15	EC-631351	RED GROUP (45C)
16	EC-635526	RED GROUP (43A)
17	EC-692336	ORANGE-RED GROUP (33 B)
18	EC-687422	RED GROUP (43A)
19	EC-654286	RED GROUP (42A)
20	EC-631357	RED GROUP (43 B)
21	COHF-T-1	RED GROUP (43A)
22	COHF-T-2	RED GROUP (43 B)
23	COHF-T-3	RED GROUP (43A)
24	COHF-T-4	RED GROUP (42B)
25	Solan Lalima	RED GROUP (44 B)

4.3 GENETIC VARIABILITY

Selection is considered as the most important activity in all the breeding programmes. However, the intensity of selection largely depends upon the extent of genetic variability present in the population and the heritability of the concerned character. Therefore, in order to determine the scope and response of selection for various traits in the present studies, the estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (in broad sense), genetic advance and genetic gain were worked out and have been presented in Table 4.9.

4.3.1 Phenotypic coefficient of variation

As the phenotypic variation is the outcome of genotypic, environmental and interaction between genotypic and environmental variation so, it is not completely useful in effective selection. However, measure of genotypic and phenotypic coefficient of variation can give the idea about the magnitude of variability present in a genetic population. For making effective selections, the heritable unit *i.e.*, the genetic variation precisely additive genetic variability present in population is adopted by breeders for improvement of different economic traits.

Since, phenotypic variation is the sum of genotypic variation and environmental variation or interaction between genotypic and environmental variation; therefore, it is not completely effective for the selection of the individual horticultural trait. The estimation of various genetic parameters of variation for yield and yield contributing traits are described below. The PCV and GCV for all the characters are classified as high (>30%), moderate (15-30%) and low (<15%). For all the characters studied, phenotypic coefficient of variation was higher in magnitude than genotypic coefficient of variation indicating the influence of environmental component on the character expression. However, the difference between PCV and GCV is minute revealing less influence of environmental factors on these traits. The study of table 4.9 leads to an outcome that there were a wide range of phenotypic variations in the given genotypes of tomato.

High phenotypic coefficient of variation was recorded for TSS: Acid ratio (47.66 %), yield per hectare (47.63 %), yield per plant (45.66 %), number of fruits per plant (45.58 %), number of fruit clusters per plant (37.91 %) and thousand seed weight (31.94 %).

Singh et al. (2015), Kumar et al. (2016), Dutta et al. (2018) and Panchbhaiya et al. (2018) recorded high GCV for TSS: Acid ratio, yield per hectare, yield per plant, number of fruits per plant, number of fruit clusters per plant and thousand seed weight.

Moderate PCV recorded for number of seeds per fruit (29.40 %), lycopene content (28.47 %), harvest duration (26.55 %), number of fruits per cluster (26.46 %), number of locules per fruit (24.74 %), TSS (24.17 %), titratable acidity (23.33 %), fruit width (23.13%), fruit firmness (22.18 %), average fruit weight (22.02 %), pericarp thickness (21.05 %), plant height (20.94 %), ascorbic acid (20.09 %) and fruit length (19.82 %) respectively.

These findings are in close harmony with the results obtained by Patel et al. (2017) also recorded moderate PCV for fruit length and average fruit weight. Reddy et al. (2013), Meena et al. (2015) and Singh et al. (2017) recorded moderate PCV for lycopene content, titratable acidity and ascorbic acid. Tasisa et al. (2011) and Hasan et al. (2016) recorded moderate PCV for number of seeds per fruit and number of fruits per cluster. Reddy et al. (2013) and Patel et al. (2013) recorded moderate PCV for fruit width. Kumar et al. (2016) reported for Total soluble solid. Rai et al. (2016) recorded moderate PCV for number of fruits per cluster, pericarp thickness, harvest duration, plant height and number of locules per fruit and Kumar et al. (2016) for plant height. Prajapati et al. (2015) recorded moderate PCV for number of seeds per fruit, average fruit weight and number of clusters per plant. Meena et al. (2015) and Lekshmi and Celine (2017) recorded moderate PCV for average fruit weight and plant height.

Low PCV was recorded for days to 50 per cent flowering (11.89 %), fruit shape index (10.78 %) and days to first picking (10.09 %) respectively. These were in accordance with the findings of Prashanth (2007), Meena et al. (2015), Prajapati et al. (2015) and Rai et al. (2016)

The value of phenotypic coefficient of variations were found higher in magnitude than that of genotypic coefficient of variation for all the characters showing that the environment had an important role in influencing the expression of the characters *i.e.* the apparent variation in the characters are not only due to genotype but also due to influence of environment.

Wide difference between phenotypic and genotypic coefficient of variations indicated their sensitiveness to environmental fluctuations; whereas, narrow differences showed less environmental interference on the expression of these traits. The traits which showed high phenotypic and genotypic coefficient of variations are of economic importance and there is scope for improvement of these traits through selection.

4.3.2 Genotypic coefficient of variation

High genotypic coefficient of variation was recorded for TSS: Acid ratio (47.09 %), number of fruits per plant (45.16 %), yield per hectare (44.59 %), yield per plant (43.98 %),

number of fruit clusters per plant (37.87 %) and thousand seed weight (31.84 %). The findings are in close conformity with the results obtained by Kumar et al. (2016) and Singh et al. (2018) for TSS: Acid ratio, number of fruits per plant, yield per plant and yield per hectare, Dutta et al. (2018) and Panchbhैया et al. (2018) for number of fruit clusters per plant and thousand seed weight, Dutta et al. (2018), Singh et al. (2015) and Kumar et al. (2016) for number of fruit clusters per plant and thousand seed weight.

Moderate GCV recorded for lycopene content (28.32 %), number of seeds per fruit (27.78 %), number of fruits per cluster (26.40 %), TSS (23.38 %), titratable acidity (23.12 %), fruit width (22.99 %), harvest duration (22.43 %), fruit firmness (22.06 %), average fruit weight (21.87 %), pericarp thickness (20.95 %), plant height (20.72 %), number of locules per fruit (20.43 %), fruit length (19.72 %) and ascorbic acid (19.33 %). Reddy et al. (2013), Khapte and Jansirani. (2014) and Patel et al. (2015) also recorded moderate GCV for fruit length and average fruit weight. Singh et al. (2017) for lycopene content, titratable acidity and ascorbic acid. Hasan et al. (2016) and Tasisa et al. (2011) recorded moderate GCV for number of seeds per fruit and number of fruits per cluster. Reddy et al. (2013) and Patel et al. (2013) for fruit width. Kumar et al. (2015) reported moderate GCV for Total soluble solid. Rai et al. (2016) recorded moderate GCV for number of fruits per cluster, pericarp thickness, harvest duration, plant height and number of locules per fruit and Kumar et al. (2016) for plant height. Prajapati et al. (2015) reported moderate GCV for number of seeds per fruit, average fruit weight and number of clusters per plant. Meena et al. (2015) recorded moderate GCV for average fruit weight and plant height.

Low GCV was recorded for days to 50 per cent flowering (11.48 %), fruit shape index (10.41 %) and days to first picking (9.91 %) respectively. These were in accordance with the findings of Ligade et al. (2017) and Thakur et al. (2022).

4.3.3 Heritability

Heritability is defined as a ratio of the genotypic variance to the phenotypic variance or total variance *i.e.*, heritability is that portion of phenotypic variance which is genotypic in nature. It is a good measure for inheritance of character from parents to their offspring which helps the breeder in selecting the elite genotypes from diverse genetic populations. Possibility of fixing the characters by selection becomes greater with the high heritable variation. Hence, heritability studies are of foremost importance to judge whether the observed variation for a particular character is due to genotype or due to environment. However, estimation of genetic

advance is important to have an idea about effectiveness of selection. The heritability for the characters under study are categorized as high (>80%), moderate (50-80%) and low (< 50%) as previously done by Warshamana, 2005.

In the present investigation, the range of heritability for various characters under study was observed from 66.33 to 99.81%. (table 4.9). High heritability was recorded for the characters viz., number of fruit clusters per plant (99.81 %), pericarp thickness (99.44 %), number of fruits per cluster (99.41 %), thousand seed weight (99.37 %), fruit length (99.00%), lycopene content (98.94%), fruit firmness (98.89 %), fruit width (98.84 %), average fruit weight (98.65 %), titratable acidity (98.17 %), plant height (97.93 %), number of fruits per plant (97.92 %), TSS:Acid ratio (97.62 %), days to first picking (96.46 %), fruit shape index (93.31 %), TSS (93.57 %), days to 50 % flowering (93.19 %), yield per plant (92.77 %), ascorbic acid (92.52 %) ,number of seeds per fruit (89.29 %) and yield per hectare (87.63 %) respectively.

High heritability for number of fruit clusters per plant, pericarp thickness, number of fruits per cluster, thousand seed weight, fruit length, lycopene content, fruit firmness, fruit width, average fruit weight, titratable acidity, plant height, number of fruits per plant, TSS: Acid ratio, days to first picking, fruit shape index, TSS, days to 50 % flowering, yield per plant, ascorbic acid, number of seeds per fruit and yield per hectare.

Similar findings were also reported by Ligade et al. (2017), Meena et al. (2018) and Mishra et al. (2019) for number of fruit clusters per plant, number of fruits per cluster, Shankar et al. (2013) and Sherpa et al. (2014) also reported high heritability for titratable acidity. Further, Singh et al. (2015), Ligade et al. (2017) and Meena et al. (2018) reported high heritability for fruit length, average fruit weight and ascorbic acid, Reddy et al. (2013), Kumar et al. (2015), Singh et al. (2017) and Limbani and Makati (2020) reported high heritability for plant height and fruit width. Rahaman et al. (2012), Rai et al. (2016) and Pooja et al. (2022) also reported high heritability for days to 50% flowering, pericarp thickness and total soluble solid.

Moderate heritability was observed for harvest duration (79.35 %) and number of locules (66.33 %). Similar results for moderate heritability have also been reported by Rai et al. (2016) and Pooja et al. (2022) for harvest duration and number of locules.

High value of heritability for all these characters indicated that the characters are least influenced by the environment however, the selection for such characters may not be useful,

because heritability is based on genetic variance which includes both fixable and non fixable variances. Therefore, further genetic advance and genetic gain for these characters were estimated.

4.3.4 Genetic advance and genetic gain (%)

Genetic advance is defined as an improvement in the mean genotypic value of selected plants over the parental population. The estimates of heritability when accompanied by estimates of genetic advance are of more significance from the point of expected gain and type of selection method to be followed. Genetic advance was worked out as percentage of mean for fruit yield and its components which is presented in Table 4.9. The genetic gain for the characters under study are classified as high (>50%), moderate (25-50%) and low (<25%) as previously categorized by Warshamana, 2005.

High genetic gain was recorded for TSS: Acid ratio (95.84 %), number of fruits per plant (91.94 %), yield per hectare (85.98 %), yield per plant (87.27 %), number of fruit clusters per plant (77.94 %), thousand seed weight (65.38 %), lycopene content (58.04 %), number of fruits per cluster (54.24 %) and number of seeds per fruit (54.07 %). High heritability accompanied with high genetic gain for above characters indicates that the heritability is most likely due to additive gene effect thus, selection for these characters may be effective. Bajpai et al. (2018) and Al-Aysh et al. (2012) reported high genetic gain for TSS: Acid ratio, number of fruits per plant and yield per plant. Shankar et al. (2013) studied high genetic gain for number of fruit clusters per plant, thousand seed weight, number of fruits per cluster. Prajapati et al. (2015) observed high genetic gain for lycopene content and number of fruit clusters per plant.

Moderate genetic gain was reported for titratable acidity (47.19 %), fruit width (47.09 %), TSS (46.59 %), fruit firmness (45.18 %), average fruit weight (44.75 %), pericarp thickness (43.03 %), plant height (42.33 %), fruit length (40.42 %), harvest duration (39.58 %), number of locules (39.56 %), and ascorbic acid (38.29 %). Singh et al. (2017) and Kumar et al. (2013) observed moderate genetic gain for fruit firmness, fruit length, fruit width and number of locules. Reddy et al. (2013) for harvest duration. Shankar et al. (2013) for number of fruits per cluster. Bajpai et al. (2018) for titratable acidity, ascorbic acid, average fruit weight, pericarp thickness and total soluble solids. Prajapati et al. (2015) and Thakur et al. (2022) reported moderate genetic gain for plant height, number of locules and ascorbic acid.

Table 4.9 Estimates of phenotypic and genotypic coefficients of variation, heritability, genetic advance and genetic gain in tomato for various traits

Parameters	Range		Mean	Coefficients of variability (%)		Heritability (%)	Genetic Advance	Genetic gain (%)
	Min	Max		PCV%	GCV %			
Days to 50 % flowering	26.67	40.00	33.81	11.89	11.48	93.19	7.72	22.83
Days to first picking	57.33	78.67	69.6	10.09	9.91	96.46	13.95	20.04
Plant height (cm)	64.93	127.37	100.18	20.94	20.72	97.93	42.04	42.23
Number of fruit clusters per plant	4.43	13.08	7.72	37.91	37.87	99.81	6.06	77.94
Number of fruits per cluster	2.87	6.99	4.79	26.46	26.40	99.49	2.62	54.24
Number of fruits per plant	10.24	38.51	28.31	45.58	45.10	97.92	26.03	91.94
Average fruit weight(g)	43.25	74.02	63.62	22.02	21.87	98.65	27.97	44.75
Fruit Length(mm)	32.35	57.11	42.76	19.82	19.72	99.00	17.35	40.42
Fruit Width(mm)	30.45	58.46	43.67	23.13	22.99	98.84	20.59	47.09
Fruit Shape Index	0.82	1.27	0.99	10.78	10.41	93.31	0.21	20.71
Pericarp Thickness(mm)	3.08	6.79	4.71	21.01	20.95	99.44	2.03	43.03
Fruit Firmness(g/cm ³)	603.74	1274.60	837.75	22.18	22.06	98.89	378.52	45.18
Number of locules	2.34	5.03	3.34	24.74	20.43	66.33	1.47	39.56
TSS(°B)	2.34	5.13	3.53	24.17	23.38	93.57	1.65	46.59
Titrateable Acidity (%)	0.23	0.51	0.36	23.33	23.12	98.17	0.17	47.19
TSS:Acid Ratio	4.59	20.53	10.78	47.66	47.09	97.62	10.44	95.84
Ascorbic Acid (mg/100g)	16.91	31.65	24.71	20.09	19.33	92.52	9.46	38.29
Lycopene Content (mg/100g)	3.50	7.56	5.24	28.47	28.32	98.94	3.11	58.04
Number of seeds per fruit	63.09	153.08	102.26	29.40	26.78	79.29	55.29	54.07
Thousand Seed Weight	1.88	4.83	3.36	31.94	31.84	99.37	2.22	65.38
Harvest Duration	20.33	40.33	30.64	26.65	22.43	79.35	12.15	39.58
Yield per plant (kg)	0.48	2.19	1.68	45.66	43.98	92.77	1.41	87.27
Yield per Hectare (q/ha)	116.30	579.59	352.78	47.63	44.59	87.63	303.18	85.98

Low genetic gain was reported for days to 50 % flowering (22.83 %), fruit shape index (20.71 %) and days to first picking (20.04 %) which were in accordance with the findings of Singh et al. (2017) and Kumar et al. (2013) reported low genetic gain for days to 50 % flowering and fruit shape index. Reddy et al. (2013) for days to first picking, and fruit shape index.

4.4 CORRELATION COEFFICIENT ANALYSIS

Correlation refers to the degree and direction of association between two or more than two variables. It measures the manual relationship between various plant characters and helps in determining the component characters on which selection can be based for genetic improvement in the yield. Yield, being a complex quantitative trait, is dependent on a number of component characters; therefore, knowledge of association of different components, together with their relative contributions, has immense value in selection. To estimate the association between two variables, correlation coefficient at phenotypic and genotypic levels, was worked out in all possible combination independently and further presented in the Table 4.10.

4.4.1 Days to 50 % flowering

Days to 50 % flowering showed positive and significant correlation with the traits viz. days to first picking (0.921 and 0.971), number of fruit clusters per plant, fruit length (0.814, 0.719 at genotypic levels) fruit shape index (0.450 and 0.499), titratable acidity (0.423 and 0.443) and number of locules (0.305 and 0.331) whereas, significant and negative correlation was found with yield per plant (-0.877 and -0.932), thousand seed weight (-0.833 and -0.861), plant height (-0.810 and -0.854), number of fruits per plant (-0.825 and -0.864), fruit width (-0.789 and -0.824), number of fruit clusters per plant (-0.782 at phenotypic levels), number of seeds per fruit (-0.773 and -0.858), harvest duration (-0.727 and -0.756), fruit length (-0.683 at phenotypic level), number of fruits per clusters (-0.660 and -0.693), average fruit weight (-0.527 and -0.552), pericarp thickness (-0.548 and -0.572), fruit firmness (-0.591 and -0.615), lycopene content (-0.467 and -0.479), total soluble solids (-0.274 and -0.285) and TSS: Acid ratio (-0.270 and -0.276) at phenotypic and genotypic levels, respectively. Dhankhar and Dhankar (2006), Samadia et al. (2006), Mehta and Asati (2008), Khaidem et al. (2014) and Osekita and Ademiluyi (2014) reported significantly positive association of days to 50 % flowering with fruit yield while Patel et al. (2013), Rakesh et al. (2014) and Ashish et al. (2018) reported significantly negative association of days to 50 % flowering with fruit yield.

4.4.2 Days to first picking

Days to first picking showed positive and significant correlation with the traits *viz.* fruit shape index (0.487 and 0.545), titratable acidity (0.439 and 0.444), number of locules (0.391 and 0.404), and ascorbic acid (0.254 and 0.265) whereas, negative and significant correlation was found with yield per plant (-0.844 and -0.891), thousand seed weight (-0.827 and -0.847), fruit width (-0.801 and -0.825), number of seeds per fruit (-0.798 and -0.850), number of fruits per plant (-0.773 and -0.793), plant height (-0.772 and -0.795), number of fruit clusters per plant (-0.751 and -0.764),), fruit length (-0.680 and -0.698), harvest duration (-0.667 and -0.694), fruit firmness (-0.654 and -0.671), pericarp thickness (-0.627 and -0.634), lycopene content (-0.456 and -0.468), number of fruits per clusters (-0.586 and -0.610), average fruit weight (-0.550 and -0.560 total soluble solids (-0.263 and -0.280) and TSS: Acid ratio (-0.262 and -0.269) at genotypic and phenotypic levels, respectively. Khaidem et al. (2014) reported positive association of days to first picking with fruit yield while Anjum Ara et al. (2009), Patel et al. (2013) and Shankar et al. (2016) reported negative association of days to first picking with fruit yield. Meitei et al. (2014) observed comparable outcomes in terms of days to first picking, as well as the number of fruits per cluster, number of fruits per plant, fruit diameter, and average fruit weight. Das et al. (2017) reported similar results for average fruit weight, fruit length, fruit width, pericarp thickness, number of locules per fruit, number of seeds per fruit, total soluble solids, and ascorbic acid.

4.4.3 Plant height

Plant height showed positive and significant association with number of fruits per plant (0.940 and 0.951), thousand seed weight (0.900 and 0.914), yield per plant (0.892 and 0.914), number of fruit clusters per plant (0.889 and 0.899), fruit width (0.852 and 0.865), harvest duration (0.869 and 0.887), number of fruits per clusters (0.829 and 0.8401), number of seeds per fruit (0.821 and 0.873), fruit length (0.819 and 0.838), fruit firmness (0.513 and 0.518), lycopene content (0.490 and 0.500), pericarp thickness (0.467 and 0.475), TSS: Acid ratio (0.388 and 0.400), total soluble solids (0.384 and 0.402) and average fruit weight (0.351 and 0.358) whereas, negative and significant association was found with titratable acidity (-0.477 and -0.490), fruit shape index (-0.373 and -0.398) and number of locules (-0.295 and -0.308) at genotypic and phenotypic levels, respectively. Sharma et al. (2006), Prashanth et al. (2008), Anjum Ara et al. (2009), Indurani et al. (2010), Rajaguru et al. (2010), Bernousi et al. (2011), Sajid Shokat (2013), Khaidem et al.

(2014), Osekita and Ademiluyi (2014), Rakesh et al. (2014) and Shankar et al. (2016) reported positive correlation of Plant height with fruit yield whereas, Dhankhar and Dhankhar (2006), Golani et al. (2007), Singh (2009) and Hanif and Samadia (2012) reported negative correlation of plant height with fruit yield.

4.4.4 Number of fruit clusters per plant

Positive and significant association of number of fruit clusters per plant at both genotypic and phenotypic level was observed with number of seeds per fruit (0.888 and 0.933), thousand seed weight (0.873 and 0.878), number of fruits per plant (0.856 and 0.860), harvest duration (0.850 and 0.859), number of fruits per clusters (0.839 and 0.847), fruit length (0.787 and 0.797), fruit width (0.776 and 0.783), total soluble solids (0.494 and 0.448), lycopene content (0.467 and 0.470), TSS: Acid ratio (0.444 and 0.451), pericarp thickness (0.392 and 0.397), fruit firmness (0.388 and 0.391), average fruit weight (0.350 and 0.352), and whereas, negative and significant correlation was found with titratable acidity and (-0.504 and -0.510), number of locules (-0.341 and -0.349) and fruit shape index (-0.279 and -0.299), at genotypic and phenotypic levels, respectively. Mishra et al. (2019) found a positive correlation between the number of clusters per plant and total soluble solids. Similarly, Lekshmi and Celine (2020) observed a positive correlation of the number of fruits per cluster with fruit length, average fruit weight, and fruit width. Additionally, Kousar et al. (2021) reported a positive correlation between the number of fruits per cluster, fruit length, and average fruit weight.

4.4.5 Number of fruits per cluster

Number of fruits per clusters showed positive and significant correlation with harvest duration (0.841 and 0.857), number of fruits per plant (0.831 and 0.839), thousand seed weight (0.794 and 0.802), yield per plant (0.755 and 0.776), number of seeds per fruit (0.748 and 0.799), fruit length (0.622 and 0.636), fruit width (0.689 and 0.698), lycopene content (0.378 and 0.381), pericarp thickness (0.331 and 0.337), TSS: Acid ratio (0.310 and 0.318), fruit firmness (0.307 and 0.311), total soluble solids (0.307 and 0.325), and average fruit weight (0.248 and 0.254) while, negatively significant correlations were obtained with average titratable acidity (-0.390 and -0.398), fruit shape index (-0.388 and -0.413) and fruit weight (-0.283 and -0.281) at genotypic and phenotypic levels, respectively. Mishra et al. (2019) documented comparable findings for the number of fruits per cluster, including fruit length, fruit width, pericarp thickness, average fruit weight, total soluble solids, and ascorbic

acid. Similarly, Namdev and Dongre (2019) reported similar results for fruit width, average fruit weight, and yield per plot. Additionally, Lekshmi and Celine (2020) observed analogous outcomes for fruit length, average fruit weight and fruit diameter.

4.4.6 Number of fruits per plant

Significant positive correlation of number of fruits per plant at both genotypic and phenotypic levels was observed with thousand seed weight (0.921 and 0.928), harvest duration (0.874 and 0.887), fruit width (0.855 and 0.863), number of seeds per fruit (0.840 and 0.886), fruit length (0.772 and 0.784), fruit firmness (0.604 and 0.609), pericarp thickness (0.570 and 0.578), lycopene content (0.541 and 0.547), TSS: Acid ratio (0.333 and 0.342), total soluble solids (0.332 and 0.349), average fruit weight (0.290 and 0.294). Negative significant correlation was obtained with fruit shape index (-0.457 and -0.486), titratable acidity (-0.434 and -0.441) and number of locules (-0.387 and -0.395) at both genotypic and phenotypic levels, respectively. Khapte and Jansirani (2014), Mahantagouda et al. (2017) and Meena et al. (2018) reported positive association of number of fruits per plant with fruit yield. Das et al. (2017) reported positive significant correlation of number of fruits per plant with number of locules per fruit.

4.4.7 Average fruit weight

Average fruit weight showed positive and significant correlation with yield per plant (0.644 and 0.669), fruit length (0.502 and 0.507), pericarp thickness (0.469 and 0.478), fruit width (0.449 and 0.452), fruit firmness (0.430 and 0.435), number of seeds per fruit (0.390 and 0.418), thousand seed weight (0.314 and 0.319) whereas, significant and negative correlation was found with number of locules (-0.255 and -0.263) at genotypic and phenotypic levels, respectively. Tanuja et al. (2012) and Meena et al. (2018) reported significant positive association of average fruit weight with yield however, Padma et al. (2002), Madhavi et al. (2013), Khapte and Jansirani (2014), Rahman et al. (2015) and Mahantagouda et al. (2017) reported significant negative association of average fruit weight with yield. Kousar et al. (2021) with fruit length, fruit width, pericarp thickness and total soluble solids.

4.4.8 Fruit length

This trait showed positive and significant correlation with fruit width (0.894 and 0.907), thousand seed weight (0.841 and 0.856), yield per plant (0.813 and 0.843), number of

seeds per fruit (0.788 and 0.851), harvest duration (0.731 and 0.749), fruit firmness (0.609 and 0.623), pericarp thickness (0.578 and 0.589), lycopene content (0.452 and 0.460), TSS: Acid ratio (0.420 and total soluble solids (0.401 and 0.418), and 0.429) while, negative significant correlation was found with titratable acidity (-0.462 and -0.471) and number of locules (-0.425 and -0.439) at both genotypic and phenotypic levels, respectively. Padma et al. (2002), Madhavi et al. (2013), Khapte and Jansirani (2014) and Mahantagouda et al. (2017) reported positive association of fruit length with fruit yield while Shankar et al. (2016) and Meena et al. (2018) reported negative association of fruit length with fruit yield. Das et al. (2017) observed a positive and significant correlation between fruit length and ascorbic acid. Similarly, Jogi et al. (2018) reported a positive correlation of pericarp thickness with total soluble solids. Additionally, Mishra et al. (2019) found positive and significant correlations of plant height, pericarp thickness, and ascorbic acid with fruit length. Furthermore, Namdev and Dongre (2019) observed positive correlations between total soluble solids and yield per plot.

4.4.9 Fruit width

Significant positive correlation was found with thousand seed weight (0.901 and 0.912), yield per plant (0.863 and 0.886) number of seeds per fruit (0.842 and 0.907), harvest duration (0.784 and 0.796) fruit firmness (0.706 and 0.715), pericarp thickness (0.672 and 0.682), lycopene content (0.486 and 0.491), titratable acidity (0.374 and 0.381) TSS: Acid ratio (0.287 and 0.295) and total soluble solids (0.275 and 0.288) whereas, negative and significant correlation was exhibited by fruit shape index (-0.562 and -0.576) and number of locules (-0.372 and -0.380) at genotypic and phenotypic levels, respectively. Madhavi et al. (2013), Ashish et al. (2018), Meena et al. (2018) reported positive correlation of fruit width with yield. Das et al. (2017) also observed similar findings with pericarp thickness, total soluble solids and number of seeds per fruit and Mishra et al. (2019) with pericarp thickness, plant height and total soluble solids.

4.4.10 Fruit shape index

Significant and negative association of this trait was exhibited by thousand seed weight (-0.452 and -0.483), harvest duration (-0.419 and -0.443), fruit firmness (-0.407 and -0.429), pericarp thickness (-0.404 and -0.435), number of seeds per fruit (-0.393 and -0.454), and lycopene content (-0.280 and 0.296) at both genotypic and phenotypic levels, respectively.

4.4.11 Pericarp thickness

Pericarp thickness showed positive and significant correlation with fruit firmness (0.944 and 0.954), yield per plant (0.640 and 0.661), thousand seed weight (0.584 and 0.591), number of seeds per fruit (0.554 and 0.588) and harvest duration (0.395 and 0.402) whereas, significant and negative correlation was found with number of locules (-0.711 and -0.727) at genotypic and phenotypic levels, respectively. Das et al. (2017) recorded positive correlation of pericarp thickness with number of seeds per fruit and total soluble solids and Mishra et al. (2019) with plant height and total soluble solids.

4.4.12 Fruit firmness

Significant and positive association of this trait was found with yield per plant (0.653 and 0.670), thousand seed weight (0.597 and 0.600), number of seeds per fruit (0.557 and 0.584), harvest duration (0.412 and 0.418) and ascorbic acid (0.237 and 0.250) while, negative significant correlation was found with number of locules (-0.616 and -0.635) at genotypic and phenotypic levels, respectively. Joshi and Singh (2003) reported significant and positive correlation of yield per plant with average fruit weight, fruit length, plant height and harvest duration, average fruits weight was positively correlated with fruit length, fruit breadth, stem end scar, pericarp thickness, whole fruit firmness and shelf life. Joshi and Kohli (2005) revealed that shelf life of tomato was positively and significantly associated with average fruit weight, whole fruit firmness.

4.4.13 Number of locules

Number of locules showed negative and significant association with yield per plant (-0.404 and -0.421), thousand seed weight (-0.399 and -0.408), number of seeds per fruit (-0.354 and -0.374) and harvest duration (-0.333 and -0.338) at genotypic and phenotypic levels, respectively. Similar findings were also reported by Joshi et al. (2004), Dar et al. (2011), Manna and Paul (2012), Sharma and Sharma (2013), Mishra et al. (2019) and Namdev and Dongre (2019).

4.4.14 Total soluble solids

Significant positive correlation of total soluble solids at both genotypic and phenotypic levels was observed with TSS: Acid ratio (0.988 and 0.095), lycopene content (0.780 and 0.810), thousand seed weight (0.433 and 0.445), number of seeds per fruit (0.365

and 0.405) and harvest duration (0.325 and 0.337). Negative significant correlation was obtained with titratable acidity (-0.900 and -0.941) and ascorbic acid (-0.405 and -0.432) at both genotypic and phenotypic levels, respectively. Anitha et al. (2007), Golani et al. (2007), Buckseth et al. (2012), Shankar et al. (2016), Hanif and Samadia (2012), Khapte and Jansirani (2014) and Ashish et al. (2018) reported positive correlation of total soluble solids with fruit yield. Similar results were also reported by Namdev and Dongre (2019) and Mishra et al. (2019) for total soluble solids with ascorbic acid and yield.

4.4.15 Titratable acidity

Titratable acidity showed positive and significant correlation with ascorbic acid (0.417 and 0.431) while, negative significant correlation was found with TSS: Acid ratio (-0.917 and -0.928), lycopene content (-0.805 and -0.820), thousand seed weight (-0.543 and -0.553), number of seeds per fruit (-0.468 and -0.502), harvest duration (-0.427 and -0.439) and yield per plant (-0.369 and -0.384) at both genotypic and phenotypic levels, respectively. These results were in accordance with findings of Mishra et al. (2019).

4.4.16 TSS: Acid ratio

Significant positive correlation of TSS: Acid ratio at both genotypic and phenotypic levels was observed with lycopene content (0.791 and 0.805), thousand seed weight (0.443 and 0.449), number of seeds per fruit (0.379 and 0.412), harvest duration (0.321 and 0.331), however significant negative correlation of TSS: Acid ratio at both genotypic and phenotypic levels was observed with ascorbic acid (-0.378 and -0.397).

4.4.17 Ascorbic acid

Ascorbic acid showed negative and significant correlation with lycopene content (-0.323 and -0.347). These results were in accordance with findings of Mishra et al. (2019).

4.4.18 Lycopene content

Lycopene content showed positive and significant correlation with thousand seed weight (0.586 and 0.593), number of seeds per fruit (0.511 and 0.543), harvest duration (0.422 and 0.427) and yield per plant (0.425 and 0.444) at both genotypic and phenotypic levels. Indurani et al. (2010), Madhavi et al. (2013), Ashish et al. (2018) reported positive correlation of lycopene content with yield while Kumar et al. (2006) reported negative association of lycopene content with yield.

Table 4.10 Phenotypic (P) and genotypic (G) coefficients of correlation among different characters in tomato

Traits		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22
X1	P	1																					
	G	1																					
X2	P	0.921*	1																				
	G	0.971*	1																				
X3	P	-0.810*	-0.772*	1																			
	G	-0.854*	-0.795*	1																			
X4	P	-0.782*	-0.751*	0.889*	1																		
	G	0.814*	-0.764*	0.899*	1																		
X5	P	-0.660*	-0.586*	0.829*	0.839*	1																	
	G	-0.693*	-0.610*	0.840*	0.847*	1																	
X6	P	-0.825*	-0.773*	0.940*	0.856*	0.831*	1																
	G	-0.864*	-0.793*	0.951*	0.860*	0.839*	1																
X7	P	-0.527*	-0.550*	0.351*	0.350*	0.248*	0.290*	1															
	G	-0.552*	-0.560*	0.358*	0.352*	0.254*	0.294*	1															
X8	P	-0.683*	-0.680*	0.819*	0.787*	0.622*	0.772*	0.502*	1														
	G	0.719*	-0.698*	0.838*	0.797*	0.636*	0.784*	0.507*	1														
X9	P	-0.789*	-0.801*	0.852*	0.776*	0.689*	0.855*	0.449*	0.894*	1													
	G	-0.824*	-0.825*	0.865*	0.783*	0.698*	0.863*	0.452*	0.907*	1													
X10	P	0.450*	0.487*	-0.373*	-0.279*	-0.388*	-0.457*	-0.017	-0.147	-0.562*	1												
	G	0.499*	0.545*	-0.398*	-0.299*	-0.413*	-0.486*	-0.018	-0.192	-0.577*	1												
X11	P	-0.548*	-0.627*	0.467*	0.392*	0.331*	0.570*	0.469*	0.578*	0.672*	-0.404*	1											
	G	-0.572*	-0.634*	0.475*	0.397*	0.337*	0.578*	0.478*	0.589*	0.682*	-0.435*	1											
X12	P	-0.591*	-0.654*	0.513*	0.388*	0.307*	0.604*	0.430*	0.609*	0.706*	-0.407*	0.944*	1										
	G	-0.615*	-0.671*	0.518*	0.391*	0.311*	0.609*	0.435*	0.623*	0.715*	-0.429*	0.954*	1										
X13	P	0.305*	0.391*	-0.295*	-0.341*	-0.160	-0.387*	-0.255*	-0.425*	-0.372*	0.104	-0.711*	-0.616*	1									
	G	0.331*	0.404*	-0.305*	-0.349*	-0.163	-0.395*	-0.263*	-0.439*	-0.380*	0.107	-0.727*	-0.635*	1									
X14	P	-0.274*	-0.263*	0.384*	0.434*	0.307*	0.332*	0.010	0.401*	0.275*	0.050	-0.060	-0.108	-0.084	1								
	G	-0.285*	-0.280*	0.402*	0.448*	0.325*	0.349*	0.007	0.418*	0.288*	0.051	-0.064	-0.117	-0.099	1								
X15	P	0.423*	0.439*	-0.477*	-0.504*	-0.390*	-0.434*	-0.120	-0.462*	-0.374*	0.039	-0.019	-0.015	0.073	-0.900*	1							
	G	0.443*	0.444*	-0.490*	-0.510*	-0.398*	-0.441*	-0.118	-0.471*	-0.381*	0.047	-0.021	-0.015	0.077	-0.941*	1							
X16	P	-0.270*	-0.262*	0.388*	0.444*	0.310*	0.333*	-0.001	0.420*	0.287*	0.059	-0.056	-0.108	-0.090	0.988*	-0.917*	1						
	G	-0.276*	-0.269*	0.400*	0.451*	0.318*	0.342*	-0.003	0.429*	0.295*	0.055	-0.056	-0.110	-0.099	0.095*	-0.928*	1						
X17	P	0.172	0.254*	-0.161	-0.197	-0.173	-0.076	-0.125	-0.001	-0.039	0.072	0.173	0.237*	-0.128	-0.405*	0.417*	-0.378*	1					
	G	0.211	0.265*	-0.154	-0.205	-0.187	-0.077	-0.122	0.004	-0.034	0.076	0.180	0.250*	-0.143	-0.432*	0.431*	-0.397*	1					
X18	P	-0.467*	-0.456*	0.490*	0.467*	0.378*	0.541*	0.091	0.452*	0.486*	-0.280*	0.105	0.081	-0.128	0.780*	-0.805*	0.791*	-0.323*	1				
	G	-0.479*	-0.468*	0.500*	0.470*	0.381*	0.547*	0.090	0.460*	0.491*	-0.296*	0.107	0.084	-0.130	0.810*	-0.820*	0.805*	-0.347*	1				
X19	P	-0.773*	-0.798*	0.821*	0.888*	0.748*	0.840*	0.390*	0.788*	0.842*	-0.393*	0.554*	0.557*	-0.354*	0.365*	-0.468*	0.379*	-0.139	0.511*	1			
	G	-0.858*	-0.850*	0.873*	0.933*	0.799*	0.886*	0.418*	0.851*	0.907*	-0.454*	0.588*	0.584*	-0.374*	0.405*	-0.502*	0.412*	-0.163	0.543*	1			
X20	P	-0.833*	-0.827*	0.900*	0.873*	0.794*	0.921*	0.314*	0.841*	0.901*	-0.452*	0.584*	0.597*	-0.399*	0.433*	-0.543*	0.443*	-0.123	0.586*	0.896*	1		
	G	-0.861*	-0.847*	0.914*	0.878*	0.802*	0.928*	0.319*	0.856*	0.912*	-0.483*	0.591*	0.600*	-0.408*	0.445*	-0.553*	0.449*	-0.127	0.593*	0.951*	1		
X21	P	-0.727*	-0.667*	0.869*	0.850*	0.841*	0.874*	0.184	0.731*	0.784*	-0.419*	0.395*	0.412*	-0.333*	0.325*	-0.427*	0.321*	-0.204	0.422*	0.748*	0.863*	1	
	G	-0.756*	-0.694*	0.887*	0.859*	0.857*	0.887*	0.187	0.749*	0.796*	-0.443*	0.402*	0.418*	-0.338*	0.337*	-0.439*	0.331*	-0.213	0.427*	0.799*	0.874*	1	
X22	P	-0.877*	-0.844*	0.892*	0.821	0.755*	0.888	0.644*	0.813*	0.863*	-0.390	0.640*	0.653*	-0.404*	0.247	-0.369*	0.241	-0.119	0.425*	0.812	0.854*	0.763	1
	G	-0.932*	-0.891*	0.917*	0.842	0.776*	0.915	0.669*	0.843*	0.886*	-0.406	0.661*	0.670*	-0.421*	0.262	-0.384*	0.253	-0.114	0.444*	0.883	0.874	0.785*	1

Where X1 = Days to 50 % flowering, X2 = Days to first picking, X3 = Plant height (cm), X4 = Number of fruit clusters per plant, X5 = Number of fruits per cluster , X6 = Number of fruits per plant, X7= Average fruit weight (g), X8 = Fruit length (mm), X9= Fruit Width (cm), X10 = Fruit shape index, X11 = Pericarp thickness (mm), X12 = Fruit firmness (g/cm³), X13 = Number of locules, X14 = TSS (°B), X15 = Titratable Acidity (%), X16 =TSS: Acid ratio, X17 = Ascorbic acid (mg/100g), X18 = Lycopene content (mg/100g), X19 = Number of seeds per fruit , X20 = Thousand seed weight, X21 = Harvest duration and X22 = Yield per plant (Kg)

4.4.19 Number of seeds per fruit

Significant positive correlation of number of seeds per fruit at both genotypic and phenotypic levels was observed with thousand seed weight (0.896 and 0.951) and harvest duration (0.748 and 0.799). These results were in accordance with finding of Kumar et al. (2015) and Das et al. (2017).

4.4.20 Thousand seed weight

Significant positive correlation of thousand seed weight at both genotypic and phenotypic levels was observed with harvest duration (0.863 and 0.874) and yield per plant (0.854) at phenotypic level only. The results are in accordance with Dar et al. (2011), Manna and Paul (2012) and Sharma and Sharma (2013).

4.4.21 Harvest duration

This trait showed positive and significant correlation with yield per plant (0.785) at both genotypic level only. Similar findings were reported by Harer et al. (2002), Joshi and Kohli (2005), Makesh et al. (2006), Prashanth et al. (2008), Rani et al. (2010), Manna and Paul (2012) and Kumar et al. (2016).

4.5 Path coefficient analysis

The correlation coefficients provide an information about the association of different characters among themselves, whereas the path coefficient analysis provides an insight into the cause of the association. The path coefficient analysis plays an important role in partitioning the correlation coefficients into the direct and indirect effects of various component traits towards a specific dependent variable. It is significant in determining the degree of relationship between yield and its component effects, and it also allows for critical examination of specific factors that provide a given correlation.

In the present study, the effects of yield components were investigated using path analysis for those traits that showed a significant correlation with fruit yield per plant (dependent variable). The estimates of direct and indirect effects of quantitative and quality traits on fruit yield per plant at genotypic level are presented in Table 4.11 and discussed below:

4.5.1 Days to 50 % flowering

Negative direct effect was observed on yield per plant through days to 50 % flowering (-0.359). High positive indirect effects on days to 50 % flowering was observed through fruit length (0.901) followed by days to first picking (0.563), pericarp thickness (0.411), total soluble solids (0.268), number of fruit clusters per plant (0.194), fruit shape index (0.146), titratable acidity (0.060) and lycopene content (0.034) whereas negative indirect effects were observed through fruit width (-0.848), fruit firmness (-0.417), plant height (-0.375), average fruit weight (-0.342), TSS: Acid ratio (-0.342), number of seeds per fruit (-0.264), thousand seed weight (-0.190), harvest duration (-0.125), number of fruits per plant (-0.108), number of locules (-0.093), number of fruits per cluster (-0.044) and ascorbic acid (-0.005). Similar results are observed by Haydar et al. (2007), Mehta and Asati (2008), Tiwari and Upadhyay (2011), Reddy et al. (2013), Tiwari et al. (2013) and Khaidem et al. (2014).

4.5.2 Days to first picking

Days to first picking showed positive direct effect on yield per plant (0.580). Positive indirect effects were seen via. fruit length (0.875), pericarp thickness (0.456), total soluble solids (0.263), number of fruit clusters per plant (0.183), fruit shape index (0.160), titratable acidity (0.060) and lycopene content (0.033) while negative indirect effects were observed through fruit width (-0.848), fruit firmness (-0.455), plant height (-0.349), days to 50 % flowering (0.348), average fruit weight (-0.347), TSS: Acid ratio (-0.334), number of seeds per fruit (-0.261), thousand seed weight (-0.187), harvest duration (-0.114), number of locules (-0.113), number of fruits per plant (-0.099), number of fruits per cluster (-0.038) and ascorbic acid (-0.006). Similar observations are recorded by Haydar et al. (2007), Mehta and Asati (2008), Tiwari and Upadhyay (2011), Reddy et al. (2013), Tiwari et al. (2013) and Khaidem et al. (2014).

4.5.3 Plant height (cm)

Positive direct effect was observed on yield per plant through plant height (0.438). High positive indirect effects were observed on yield per plant through fruit width (0.890), TSS: Acid ratio (0.495), fruit firmness (0.351), days to 50 % flowering (0.307), number of seeds per fruit (0.269), average fruit weight (0.222), thousand seed weight (0.202), harvest duration (0.146), number of fruits per plant (0.119), number of locules (0.085), number of fruits per cluster (0.053) and ascorbic acid (0.003) whereas, negative indirect effects were observed through fruit length (-

1.051), days to 50 % flowering (-0.461), total soluble solids (-0.378), pericarp thickness (-0.342), number of fruit clusters per plant (-0.215), fruit shape index (-0.116), titratable acidity (-0.067) and lycopene content (-0.035). Similar observations are recorded by Tiwari and Upadhyay (2011), Buckseth et al. (2012), Kumar et al. (2013), Kumari and Sharma (2013), Tiwari et al. (2013), Khaidem et al. (2014) and Rakesh et al. (2014).

4.5.4 Number of fruit clusters per plant

Number of fruit clusters per plant showed negative direct effect on yield per plant (-0.239). Positive indirect effects were seen through fruit width (0.805), TSS: Acid ratio (0.559), plant height (0.394), days to 50 % flowering (0.292), number of seeds per fruit (0.287), fruit firmness (0.265), average fruit weight (0.218), thousand seed weight (0.194), harvest duration (0.142), number of fruits per plant (0.108), number of locules (0.098), number of fruits per cluster (0.053) and ascorbic acid (0.005) while negative indirect effects were observed through fruit width (-0.999), days to first picking (-0.443), total soluble solids (-0.422), pericarp thickness (-0.285), fruit shape index (-0.087), titratable acidity (-0.069) and lycopene content (-0.033). Lekshmi and Celine (2020) also recorded the similar results for number of clusters per plant.

4.5.5 Number of fruits per clusters

Positive direct effect of number of fruits per clusters was recorded for yield per plant (0.063). Fruit width (0.718), TSS: Acid ratio (0.394), plant height (0.368), days to 50 % flowering (0.249), number of seeds per fruit (0.246), fruit firmness (0.211), thousand seed weight (0.177), average fruit weight (0.158), harvest duration (0.141), number of fruits per plant (0.105), number of locules (0.046) and ascorbic acid (0.004) showed positive indirect effects on yield per plant while fruit length (-0.797), days to first picking (-0.354), total soluble solids (-0.306), pericarp thickness (-0.243), number of fruit clusters per plant (-0.202), fruit shape index (-0.121), titratable acidity (-0.054) and lycopene content (-0.027). These results were in accordance with Reddy et al. (2013) and Alam et al. (2019).

4.5.6. Number of fruits per plant

Number of fruits per plant exhibited positive direct effect on yield per plant (0.125). Positive indirect effects were observed through fruit width (0.888), TSS: Acid ratio (0.423), plant height (0.417), fruit firmness (0.413), days to 50 % flowering (0.310), number of seeds per

fruit (0.273), thousand seed weight (0.205), average fruit weight (0.182), harvest duration (0.146), number of locules (0.111), number of fruits per cluster (0.053) and ascorbic acid (0.002) whereas negative indirect effects were observed through fruit length (-0.983), days to first picking (-0.460), pericarp thickness (0.416), total soluble solids (-0.328), number of fruit clusters per plant (-0.206), fruit shape index (-0.142), titratable acidity (-0.060) and lycopene content (-0.038). Similar results were also recorded by Islam et al. (2010), Buckseth et al. (2012), Kumar et al. (2013), Reddy et al. (2013), Saleem et al. (2013), Khapte and Jhansirani (2014), Ritonga et al. (2018) and Mishra et al. (2019).

4.5.7 Average fruit weight

Average fruit weight showed positive direct effect on yield per plant (0.620). Positive indirect effect were seen through fruit width (0.465), fruit firmness (0.295), days to 50 % flowering (0.198), plant height (0.157), number of seeds per fruit (0.129), number of locules (0.074), thousand seed weight (0.070), number of fruits per plant (0.037), harvest duration (0.031), number of fruits per cluster (0.016) and ascorbic acid (0.003), however negative indirect effects were seen through fruit length (-0.635), pericarp thickness (-0.343), days to first picking (-0.325), number of fruit clusters per plant (-0.084), titratable acidity (-0.016), lycopene content (-0.006), total soluble solids (-0.006), fruit shape index (-0.005) and TSS: Acid ratio (-0.004) as observed by Kumar and Thakur (2007), Anjum Ara et al. (2009), Sharma and Singh (2012), Reddy et al. (2013), Khaidem et al. (2014), Anuradha et al. (2020), Namdev and Dongre (2019) and Lekshmi and Celine (2020).

4.5.8 Fruit length

Positive direct effect of fruit length was recorded for yield per plant (0.454). Fruit width (0.933), TSS: Acid ratio (0.531), fruit firmness (0.422), plant height (0.367), average fruit weight (0.314), number of seeds per fruit (0.262), days to 50 % flowering (0.258), thousand seed weight (0.189), harvest duration (0.123), number of locules (0.123), number of fruits per plant (0.098), number of fruits per cluster (0.040) and ascorbic acid (0.000) showed positive indirect effects on yield per plant while pericarp thickness (-0.424), days to first picking (-0.405), total soluble solids (-0.393), number of fruit clusters per plant (-0.190), titratable acidity (-0.064), fruit shape index (-0.056) and lycopene content (-0.032) showed negative indirect effects. Similar results are found by Kumar and Thakur (2007), Islam et al. (2010), Reddy et al. (2013) and Namdev and Dongre (2019).

4.5.9 Fruit width

Fruit width exhibited positive direct effect on yield per plant (0.429). Positive indirect effects were observed through fruit firmness (0.485), plant height (0.379), TSS: Acid ratio (0.365), days to 50 % flowering (0.296), average fruit weight (0.280), number of seeds per fruit (0.279), thousand seed weight (0.201), harvest duration (0.131), number of fruits per plant (0.108), number of locules (0.106), number of fruits per cluster (0.044) and ascorbic acid (0.001), whereas negative indirect effects were observed through fruit length (-1.137), pericarp thickness (-0.491), days to first picking (-0.478), total soluble solids (-0.271), number of fruit clusters per plant (-0.187), fruit shape index (-0.169), titratable acidity (-0.052) and lycopene content (-0.034). Similar findings by obtained by Islam et al. (2010), Tiwari and Upadhyay (2011), Reddy et al. (2013), Tiwari et al. (2013), Khaidem et al. (2014), Rakesh et al. (2014) and Mishra et al. (2019).

4.5.10 Fruit shape index

Fruit shape index showed positive direct effect on yield per plant (0.293). Positive indirect effects were seen through days to first picking (0.316), pericarp thickness (0.313), fruit length (0.240), number of fruit clusters per plant (0.071), TSS: Acid ratio (0.068), lycopene content (0.021) and titratable acidity (0.006), however negative indirect effects were seen through fruit width (-0.594), fruit firmness (-0.291), days to 50 % flowering (-0.179), plant height (-0.174), number of seeds per fruit (-0.140), thousand seed weight (-0.107), harvest duration (-0.073), number of fruits per plant (-0.061), total soluble solids (-0.048), number of locules (-0.030), number of fruits per cluster (-0.026), average fruit weight (-0.011) and ascorbic acid (-0.002). Similar findings by obtained by Khapte and Jansirani (2014) for fruit shape index.

4.5.11 Pericarp thickness

Negative direct effect of pericarp thickness was observed for yield per plant (-0.719). Positive indirect effects were seen through fruit width (0.701), fruit firmness (0.647), average fruit weight (0.296), plant height (0.208), days to 50 % flowering (0.205), number of locules (0.204), number of seeds per fruit (0.181), thousand seed weight (0.131), number of fruits per plant (0.072), harvest duration (0.066), total soluble solids (0.060) and number of fruits per cluster (0.021). Whereas, negative indirect effects were seen through fruit length (-0.739), days to first picking (-0.368), fruit shape index (-0.127), number of fruit clusters per plant (-0.095),

TSS: Acid ratio (-0.070), lycopene content (-0.008), ascorbic acid (-0.004) and titratable acidity (-0.003). Similar results were also observed by Islam et al. (2010) and Alam et al. (2019).

4.5.12 Fruit firmness

Fruit firmness exhibited positive direct effect on yield per plant (0.678). High positive indirect effects on yield per hectare were observed through fruit width (0.735), average fruit weight (0.270), plant height (0.227), days to 50 % flowering (0.221), number of seeds per fruit (0.180), number of locules (0.178), thousand seed weight (0.133), total soluble solids (0.110), number of fruits per plant (0.076), harvest duration (0.069) and number of fruits per cluster (0.020) whereas, negative indirect effects were observed through fruit length (-0.780), pericarp thickness (-0.686), days to first picking (-0.389), TSS: Acid ratio (-0.137), fruit shape index (-0.126), number of fruit clusters per plant (-0.093), ascorbic acid (-0.006), lycopene content (-0.006) and titratable acidity (-0.002).

4.5.13 Number of locules

Negative direct effect of average seed weight per fruit was observed on yield per plant (-0.280). Positive indirect effects were seen through fruit length (0.551), pericarp thickness (0.523), days to first picking (0.234), total soluble solids (0.093), number of fruit clusters per plant (0.083), fruit shape index (0.031), titratable acidity (0.010), lycopene content (0.009) and ascorbic acid (0.003). While negative indirect effects were seen through fruit firmness (-0.431), fruit width (-0.391), average fruit weight (-0.163), plant height (-0.134), TSS: Acid ratio (-0.122), days to 50 % flowering (-0.119), number of seeds per fruit (-0.115), thousand seed weight (-0.090), harvest duration (-0.056), number of fruits per plant (-0.049) and number of fruits per cluster (-0.010). These results were in accordance with Tiwari and Upadhyay (2011) and Mishra et al. (2019).

4.5.14 Total soluble solids

Total soluble solids showed negative direct effect on yield per plant (-0.941). High positive indirect effects were observed through TSS: Acid ratio (1.240), fruit width (0.297), plant height (0.176), number of seeds per fruit (0.125), days to 50 % flowering (0.102), thousand seed weight (0.098), harvest duration (0.056), pericarp thickness (0.046), number of fruits per plant (0.044), number of locules (0.028), number of fruits per cluster (0.021), fruit shape index (0.015), ascorbic acid (0.010) and average fruit weight (0.004). Negative indirect

effects were observed through fruit length (-0.524), days to first picking (-0.162), titratable acidity (-0.128), number of fruit clusters per plant (-0.107), fruit firmness (-0.079) and lycopene content (-0.057). Golani et al. (2007), Kumar and Thakur (2007), Indurani et al. (2010), Buckseth et al. (2012), Izge and Garba (2012), Kumari and Sharma (2013), Monamodi et al. (2013) and Rakesh et al. (2014) also reported similar findings.

4.5.15 Titratable acidity

Titratable acidity showed positive direct effect on yield per plant (0.136). Positive indirect effects were seen via total soluble solids (0.885), fruit length (0.590), days to first picking (0.258), number of fruit clusters per plant (0.122), lycopene content (0.057), pericarp thickness (0.015) and fruit shape index (0.014) while negative indirect effects were seen through TSS: Acid ratio (-1.151), fruit width (-0.392), plant height (-0.215), days to 50 % flowering (-0.159), number of seeds per fruit (-0.154), thousand seed weight (-0.122), average fruit weight (-0.073), harvest duration (-0.072), number of fruits per plant (-0.055), number of fruits per cluster (-0.025), number of locules (-0.022), fruit firmness (-0.010) and ascorbic acid (-0.010). Similar results were also reported by Singh (2009).

4.5.16 TSS: Acid ratio

Positive direct effect of TSS: Acid ratio was recorded for yield per plant (1.024). Fruit width (0.303), plant height (0.175), number of seeds per fruit (0.127), thousand seed weight (0.099), days to 50 % flowering (0.099), harvest duration (0.055), number of fruits per plant (0.043), pericarp thickness (0.041), number of locules (0.028), number of fruits per cluster (0.020), fruit shape index (0.016) and ascorbic acid (0.009) showed positive indirect effects while total soluble solids (-0.941), fruit length (-0.537), days to first picking (-0.156), titratable acidity (-0.126), number of fruit clusters per plant (-0.108), fruit firmness (-0.075), lycopene content (-0.056) and average fruit weight (-0.002) showed negative indirect effects.

4.5.17 Ascorbic acid

Ascorbic acid showed negative direct effect on yield per plant (-0.022). Positive indirect effects were observed through total soluble solids (0.406), fruit firmness (0.169), days to first picking (0.154), titratable acidity (0.059), number of fruit clusters per plant (0.049), number of locules (0.040), lycopene content (0.024) and fruit shape index (0.022) whereas, negative indirect effects were seen through TSS: Acid ratio (-0.493), pericarp

thickness (-0.129), days to 50 % flowering (-0.076), average fruit weight (-0.075), plant height (-0.067), number of seeds per fruit (-0.050), fruit width (-0.035), harvest duration (-0.035), thousand seed weight (-0.028), number of fruits per cluster (-0.012), number of fruits per plant (-0.010) and fruit length (-0.005). Indurani et al. (2010), Kumari and Sharma (2013) and Reddy et al. (2013) also reported similar findings.

4.5.18 Lycopene content

Lycopene content showed negative direct effect on yield per plant (-0.070). Positive indirect effects were seen via TSS: Acid ratio (0.998), fruit width (0.505), plant height (0.219), days to 50 % flowering (0.172), number of seeds per fruit (0.167), thousand seed weight (0.131), harvest duration (0.070), number of fruits per plant (0.068), fruit firmness (0.057), average fruit weight (0.056), number of locules (0.036), number of fruits per cluster (0.024) and ascorbic acid (0.008) while negative indirect effects were seen through total soluble solids (-0.762), fruit length (-0.577), days to first picking (-0.271), number of fruit clusters per plant (-0.112), titratable acidity (-0.111), fruit shape index (-0.087) and pericarp thickness (-0.077). Indurani et al. (2010) and Gillani et al. (2019) also reported similar results for lycopene content.

4.5.19 Number of seeds per fruit

Positive direct effect was observed on yield per plant through number of seeds per fruit (0.308). High positive indirect effects were observed on yield per plant through fruit width (0.933), TSS: Acid ratio (0.511), fruit firmness (0.396), plant height (0.383), days to 50 % flowering (0.308), average fruit weight (0.259), thousand seed weight (0.210), harvest duration (0.132), number of fruits per plant (0.111), number of locules (0.105), number of fruits per cluster (0.050) and ascorbic acid (0.004) whereas, negative indirect effects were observed through fruit length (-1.067), days to first picking (-0.493), pericarp thickness (-0.423), total soluble solids (-0.381), number of fruit clusters per plant (-0.223), fruit shape index (-0.133), titratable acidity (-0.068) and lycopene content (-0.038).). These results were in accordance with Tiwari and Upadhayay (2011) and Mishra et al. (2019).

4.5.20 Thousand seed weight

Thousand seed weight showed positive direct effect on yield per plant (0.221). Positive indirect effects were observed through fruit width (0.938), TSS: Acid ratio (0.557),

Table 4.11 Path coefficient analysis showing the direct and indirect effects of characters on yield per plant at genotypic level.

Traits	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22
X1	-0.359	0.563	-0.375	0.194	-0.044	-0.108	-0.342	0.901	-0.848	0.146	0.411	-0.417	-0.093	0.268	0.060	-0.342	-0.005	0.034	-0.264	-0.190	-0.125	-0.932*
X2	-0.348	0.580	-0.349	0.183	-0.038	-0.099	-0.347	0.875	-0.848	0.160	0.456	-0.455	-0.113	0.263	0.060	-0.334	-0.006	0.033	-0.261	-0.187	-0.114	-0.891*
X3	0.307	-0.461	0.438	-0.215	0.053	0.119	0.222	-1.051	0.890	-0.116	-0.342	0.351	0.085	-0.378	-0.067	0.495	0.003	-0.035	0.269	0.202	0.146	0.917*
X4	0.292	-0.443	0.394	-0.239	0.053	0.108	0.218	-0.999	0.805	-0.087	-0.285	0.265	0.098	-0.422	-0.069	0.559	0.005	-0.033	0.287	0.194	0.142	0.842
X5	0.249	-0.354	0.368	-0.202	0.063	0.105	0.158	-0.797	0.718	-0.121	-0.243	0.211	0.046	-0.306	-0.054	0.394	0.004	-0.027	0.246	0.177	0.141	0.776*
X6	0.310	-0.460	0.417	-0.206	0.053	0.125	0.182	-0.983	0.888	-0.142	-0.416	0.413	0.111	-0.328	-0.060	0.423	0.002	-0.038	0.273	0.205	0.146	0.915
X7	0.198	-0.325	0.157	-0.084	0.016	0.037	0.620	-0.635	0.465	-0.005	-0.343	0.295	0.074	-0.006	-0.016	-0.004	0.003	-0.006	0.129	0.070	0.031	0.669*
X8	0.258	-0.405	0.367	-0.190	0.040	0.098	0.314	0.454	0.933	-0.056	-0.424	0.422	0.123	-0.393	-0.064	0.531	0.000	-0.032	0.262	0.189	0.123	0.843*
X9	0.296	-0.478	0.379	-0.187	0.044	0.108	0.280	-1.137	0.429	-0.169	-0.491	0.485	0.106	-0.271	-0.052	0.365	0.001	-0.034	0.279	0.201	0.131	0.886*
X10	-0.179	0.316	-0.174	0.071	-0.026	-0.061	-0.011	0.240	-0.594	0.293	0.313	-0.291	-0.030	-0.048	0.006	0.068	-0.002	0.021	-0.140	-0.107	-0.073	-0.406
X11	0.205	-0.368	0.208	-0.095	0.021	0.072	0.296	-0.739	0.701	-0.127	-0.719	0.647	0.204	0.060	-0.003	-0.070	-0.004	-0.008	0.181	0.131	0.066	0.661*
X12	0.221	-0.389	0.227	-0.093	0.020	0.076	0.270	-0.780	0.735	-0.126	-0.686	0.678	0.178	0.110	-0.002	-0.137	-0.006	-0.006	0.180	0.133	0.069	0.670*
X13	-0.119	0.234	-0.134	0.083	-0.010	-0.049	-0.163	0.551	-0.391	0.031	0.523	-0.431	-0.280	0.093	0.010	-0.122	0.003	0.009	-0.115	-0.090	-0.056	-0.421*
X14	0.102	-0.162	0.176	-0.107	0.021	0.044	0.004	-0.524	0.297	0.015	0.046	-0.079	0.028	-0.941	-0.128	1.240	0.010	-0.057	0.125	0.098	0.056	0.262
X15	-0.159	0.258	-0.215	0.122	-0.025	-0.055	-0.073	0.590	-0.392	0.014	0.015	-0.010	-0.022	0.885	0.136	-1.151	-0.010	0.057	-0.154	-0.122	-0.072	-0.384*
X16	0.099	-0.156	0.175	-0.108	0.020	0.043	-0.002	-0.537	0.303	0.016	0.041	-0.075	0.028	-0.941	-0.126	1.024	0.009	-0.056	0.127	0.099	0.055	0.253
X17	-0.076	0.154	-0.067	0.049	-0.012	-0.010	-0.075	-0.005	-0.035	0.022	-0.129	0.169	0.040	0.406	0.059	-0.493	-0.022	0.024	-0.050	-0.028	-0.035	-0.114
X18	0.172	-0.271	0.219	-0.112	0.024	0.068	0.056	-0.577	0.505	-0.087	-0.077	0.057	0.036	-0.762	-0.111	0.998	0.008	-0.070	0.167	0.131	0.070	0.444*
X19	0.308	-0.493	0.383	-0.223	0.050	0.111	0.259	-1.067	0.933	-0.133	-0.423	0.396	0.105	-0.381	-0.068	0.511	0.004	-0.038	0.308	0.210	0.132	0.883
X20	0.309	-0.491	0.401	-0.210	0.051	0.116	0.198	-1.073	0.938	-0.142	-0.425	0.407	0.114	-0.419	-0.075	0.557	0.003	-0.042	0.293	0.221	0.144	0.874
X21	0.271	-0.402	0.389	-0.205	0.054	0.111	0.116	-0.939	0.819	-0.130	-0.289	0.283	0.095	-0.317	-0.060	0.410	0.005	-0.030	0.246	0.193	0.165	0.785*

Residual effect at genotypic level (G) = 0.00902; Bold values indicate direct effects

*Significant at $P \leq 0.05$

where X1 = Days to 50 % flowering, X2 = Days to first picking, X3 = Plant height (cm), X4 = Number of fruit clusters per plant, X5 = Number of fruits per cluster, X6 = Number of fruits per plant, X7= Average fruit weight (g), X8 = Fruit length (mm), X9= Fruit Width (cm), X10 = Fruit shape index, X11 = Pericarp thickness (mm), X12 = Fruit firmness (g/cm³), X13 = Number of locules, X14 = TSS (°B), X15 = Titratable Acidity (%), X16 =TSS: Acid ratio, X17 = Ascorbic acid (mg/100g), X18 = Lycopene content (mg/100g), X19 = Number of seeds per fruit, X20 = Thousand seed weight, X21 = Harvest duration and X22 = Yield per plant (Kg).

(0.407), fruit firmness (0.401), plant height (0.309), days to 50 % flowering (0.293), number of seeds per fruit (0.198), average fruit weight (0.144), harvest duration (0.116), number of fruits per plant (0.114), number of fruits per cluster (0.051) and ascorbic acid (0.003) while, negative indirect effects were observed through fruit length (-1.073), days to first picking (-0.491), pericarp thickness (-0.425), total soluble solids (-0.419), number of fruit clusters per plant (-0.210), fruit shape index (-0.142), titratable acidity (-0.075) and lycopene content (-0.042). These results were in accordance with Reddy et al. (2013) and Alam et al. (2019).

4.5.21 Harvest duration

Harvest duration exhibited positive direct effect on yield per plant (0.165). High positive indirect effects on fruit yield per plant were observed through fruit width (0.819), TSS: Acid ratio (0.410), plant height (0.389), fruit firmness (0.283), days to 50 % flowering (0.271), number of seeds per fruit (0.246), thousand seed weight (0.193), average fruit weight (0.116), number of fruits per plant (0.111), number of locules (0.095), number of fruits per cluster (0.054) and ascorbic acid (0.005) whereas, negative indirect effects were observed through fruit length (-0.939), days to first picking (-0.402), total soluble solids (-0.317), pericarp thickness (-0.289), number of fruit clusters per plant (-0.205), fruit shape index (-0.130), titratable acidity (-0.060) and lycopene content (-0.030). In path coefficient analysis, harvest duration showed positive direct effect on yield. Anjum et al. (2009) and Reddy et al. (2013) also reported positive direct effect of harvest duration on yield.

EXPERIMENT-II

STABILITY ANALYSIS

The present investigation entitled “Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)” was conducted at three different locations namely, (i) Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP) (ii) Experimental Research Farm, Dr YSP UHF COHF Neri, Hamirpur (HP) (iii) Experimental Research Farm, Dr YSP UHF RHR&TS, Bajaura, Kullu (HP) 2023 to evaluate genotypes in comparison to check variety. The experimental results obtained are presented and discussed here under the following heads:

4.6 ANALYSIS OF VARIANCE FOR INDIVIDUAL ENVIRONMENT

4.7 MEAN PERFORMANCE OF THE ELITE GENOTYPES

4.8 STABILITY ANALYSIS

4.8.1 Joint regression analysis

4.8.2 Individual regression analysis and estimation of stability parameters for individual genotype

4.9 Genotype + (Genotype × Environment) GGE biplot analysis

4.6 ANALYSIS OF VARIANCE FOR INDIVIDUAL ENVIRONMENT

The analysis of variance was conducted for three environments during 2022-23 viz., E1 (UHF, Nauni, Solan), E2 (COHF, Neri, Hamirpur (HP) and E3 (RHR&TS, Bajaura, Kullu (HP). Analysis of variance for individual environment (Appendix-VI) showed that the mean sum of squares attributed to genotypes is highly significant across the environments for all traits. The significance of mean sum of squares revealed that the genotypes varied among themselves and showed high variability for all the features taken under examination irrespective of the effect of environments. Kalloo et al. (1998), Fayaz et al. (2007) Shankar et al. (2014), Basavaraj et al. (2015), Kumar et al. (2016) and Triveni et al. (2017) have also observed variability present in tomato. The presence of significant genetic variation for majority of the traits indicates high possibility of selecting superior genotypes with desirable traits.

4.7 Mean performance of the genotypes

The mean performance of different genotypes revealed a variable performance with respect to various yield and yield component traits. The range of variations showed a greater extent of diversity among genotypes and provided enormous scope for improvement of tomato. The mean performances of different genotypes in comparison to check variety for different characters have been explained here under:

4.7.1 Days to 50% flowering

Earliness in flowering is an important character especially in multiple harvest crops like tomato to obtain early harvest and to catch market early in the season to

harness better price. The mean performance of genotypes for days to 50% flowering (Table 4.12) revealed that genotypes namely, EC-654289 (30.67 days) in E1, COHF-T-3 (26.33 days in E2 and 28.00 days in E3), in pooled environments COHF-T-3 (28.89) followed by COHF-T-4 (28.89) were found to be the earliest for flowering. Similarly, EC-654289, COHF-T-3 and COHF-T-4 in E1, COHF-T-1 and COHF-T-3 in E2, COHF-T-2, COHF-T-3 and COHF-T-4 in E3 were significantly earlier than the check Solan Lalima (Table 4.12). The performance of different tomato genotypes for days to 50% flowering have also been reported by Shankar et al. (2014) and Triveni et al. (2017) in wide-ranging agro-climatic conditions.

Table 4.12 Mean performance of the genotypes for days to 50% flowering

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	30.67	32.00	34.33	32.33
EC-687604	36.67	28.00	32.67	32.44
EC-687423	37.33	31.33	33.67	34.11
EC-635526	34.00	28.33	31.00	31.11
EC-654286	33.00	29.33	30.67	31.00
COHF-T-1	35.00	26.67	31.33	31.00
COHF-T-2	33.33	27.33	30.00	30.22
COHF-T-3	32.33	26.33	28.00	28.89
COHF-T-4	31.00	27.33	28.33	28.89
Solan Lalima (C)	36.00	31.00	34.67	33.89
Mean	33.93	28.77	31.47	31.39
Range	30.67-37.33	26.33-32.00	28.00-34.67	28.89-34.11
SE (m)±	1.14	1.27	1.40	0.91
CD (0.05)	3.41	3.79	4.19	2.73

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.2 Days to first picking

The perusal of mean performance of the genotypes for days to first picking (Table 4.13) revealed that early genotypes viz, EC-654289 (65.00 days) in E1, COHF-T-1 (57.67 in E2) and COHF-T-3 (61.33 days in E3) were top ranking for first picking. Pooled data over environment revealed that COHF-T-1 (61.89 days) was found to be the earliest for days to first picking. Similarly, data over environment revealed that EC-654289, EC-687604, COHF-T-1 and COHF-T-3 in E1, COHF-T-1 and COHF-T-3 in E2, COHF-T-3 in E3 significantly earlier than check. The performance of different tomato genotypes for days to first picking have been also reported by in varied agro-climatic conditions. It confirms with the findings of Savitha and Singh (2017).

Table 4.13 Mean performance of the genotypes for days to first picking

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	65.00	63.67	68.67	65.78
EC-687604	66.00	60.33	65.00	63.78
EC-687423	70.33	63.00	66.67	66.67
EC-635526	67.33	60.00	63.33	63.56
EC-654286	69.67	61.33	65.33	65.44
COHF-T-1	65.33	57.67	62.67	61.89
COHF-T-2	68.00	60.00	64.00	64.00
COHF-T-3	66.33	58.33	61.33	62.00
COHF-T-4	66.67	59.33	63.33	63.11
Solan Lalima (C)	70.00	62.00	64.33	65.44
Mean	67.47	60.57	64.47	64.17
Range	65.00-70.33	57.67-63.67	61.33-68.67	61.89 -66.67
SE (m)±	1.18	1.00	0.90	0.82
CD (0.05)	3.53	2.99	2.68	2.47

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.3 Plant height (cm)

Plant height plays a critical role in the areas with high rainfall as comparatively less incidence of fruit rot is observed in tall plants. EC-635526 in E1 (116.81cm), COHF-T-3 in E2 (126.29cm) and COHF-T-1 in E3 (120.49cm) and for pooled data COHF-T-3 (120.74cm) had the maximum plant height. EC-687423, EC-635526, COHF-T-2 and COHF-T-3 in E1, EC-635526, EC-654286, COHF-T-1, COHF-T-2 and COHF-T-4 in E2, EC-687604, EC-687423, COHF-T-2 and COHF-T-3 in E3 were significantly at par for plant height than the

Table 4.14 Mean performance of the genotypes for plant height (cm)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	98.21	103.54	112.54	104.76
EC-687604	101.81	106.47	108.25	105.51
EC-687423	114.78	107.48	112.81	111.69
EC-635526	116.81	122.54	119.23	119.53
EC-654286	103.62	116.51	105.64	108.59
COHF-T-1	107.18	116.84	120.49	114.84
COHF-T-2	115.05	122.32	110.02	115.80
COHF-T-3	115.18	126.29	113.92	120.74
COHF-T-4	107.38	114.27	103.02	108.22
Solan Lalima (C)	115.67	118.34	110.44	114.82
Mean	109.569	115.46	111.63	112.45
Range	98.21-116.81	103.54-126.29	103.02-120.49	104.76-120.74
SE (m)±	1.64	2.09	1.53	2.89
CD (0.05)	4.91	6.25	4.59	8.64

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

check Solan Lalima (Table 4.14). Results are confirmed with earlier reports of Kalloo et al. (1998), Fayaz et al. (2007), Kumar et al. (2016) and Triveni et al. (2017) and have revealed significant differences in their material for plant height.

4.7.4 Number of fruit clusters per plant

Number of fruit clusters per plant is an essential yield contributing character that affects the final yield of the genotypes. COHF-T-2 in E1 (12.61), COHF-T-3 in E2 (15.06) and COHF-T-3 in E3 (16.74) further, pooled data over environments revealed that COHF-T-3 (14.57) shows maximum number of fruit clusters per plant. EC-687423, EC-635526, COHF-T-1, COHF-T-2 and COHF-T-3 were found to be significantly superior than the check in all the environments (Table 4.15). The earlier researchers namely, Joshi and Singh (2003) and Kumar et al. (2013) have also reported a wide range of variability under different environments in their research for number of fruit clusters per plant.

Table 4.15 Mean performance of the genotypes for number of fruit clusters per plant

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	6.50	8.00	7.50	7.33
EC-687604	8.05	7.56	9.64	8.42
EC-687423	10.26	12.31	11.06	11.21
EC-635526	9.67	11.45	12.06	11.06
EC-654286	8.16	9.18	8.59	8.64
COHF-T-1	10.08	14.02	13.67	12.59
COHF-T-2	12.61	13.09	15.61	13.77
COHF-T-3	11.92	15.06	16.74	14.57
COHF-T-4	7.20	8.67	9.02	8.30
Solan Lalima (C)	8.92	9.08	9.83	9.28
Mean	9.34	10.84	11.37	10.52
Range	6.50-12.61	7.56-15.06	7.50-16.74	7.33-14.57
SE (m)±	0.18	0.21	0.20	0.54
CD (0.05)	0.53	0.63	0.60	1.63

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.5 Number of fruits per cluster

The scrutiny of data revealed that COHF-T-1 excelled across all environment i.e. in E1 (9.54), E2 (8.29) and E3 (9.05) respectively for number of fruits per cluster. Further, pooled data over environments revealed that COHF-T-1 (8.96) significantly performed better for number of fruits per cluster over other genotypes that were followed

by EC-654286 (8.25), EC-687423 (7.19) and EC-635526 (7.13). On the other hand, the genotypes EC-654289, EC-687604, EC-687423, EC-635526, EC-654286 and COHF-T-1 were significantly superior than the check in all the environments. EC-687604 and COHF-T-2 in E2 and COHF-T-3 in E3 are statistically at par to check Solan Lalima (Table 4.16). Joshi et al. (2004), Sivaprasad (2008), Basavaraj et al. (2015) have also reported a wide range of variability under different environments.

Table 4.16 Mean performance of the genotypes for number of fruits per cluster

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	5.92	7.09	6.95	6.65
EC-687604	5.82	5.02	6.33	5.72
EC-687423	6.29	7.82	7.45	7.19
EC-635526	8.29	6.01	7.09	7.13
EC-654286	8.06	7.88	8.81	8.25
COHF-T-1	9.54	8.29	9.05	8.96
COHF-T-2	5.28	4.98	4.29	4.85
COHF-T-3	4.92	6.92	5.67	5.84
COHF-T-4	4.03	4.83	4.21	4.36
Solan Lalima (C)	5.54	5.09	5.89	5.51
Mean	6.369	6.393	6.574	6.45
Range	4.03-9.54	4.83-8.29	4.21-9.05	4.36-8.96
SE (m)±	0.08	0.07	0.11	0.43
CD (0.05)	0.24	0.21	0.31	1.28

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.6 Number of fruits per plant

Number of fruits per plant is the most important component trait which is directly related to increased fruit yield per plant. A critical examination of the data revealed that COHF-T-1 followed by COHF-T-2, EC-687423, EC-654286 and EC-654286 at E1, all genotypes at E2 while in E3 all genotypes except EC-654289 and EC-635526 showed significantly higher number of fruits per plant over the check (Table 4.17). Pooling data over environments showed that EC-687423(45.92) had maximum number of fruit per plant over rest of the other genotypes. Jaha and Krishni (2001), Joshi and Singh (2003), Joshi et al. (2004), Veershetty (2004), Fayaz et al. (2007), Mehta and Asati, (2008), Basavaraj et al. (2015) have also revealed variable mean performances of different genotypes for number of fruits per plant.

Table 4.17 Mean performance of the genotypes for number of fruits per plant

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	26.01	28.15	24.69	26.15
EC-687604	30.38	31.42	29.97	30.59
EC-687423	33.61	29.99	35.16	45.92
EC-635526	32.92	40.63	36.91	38.49
EC-654286	34.01	31.21	37.11	34.21
COHF-T-1	32.10	39.01	34.20	48.57
COHF-T-2	28.90	34.47	30.88	43.08
COHF-T-3	31.22	33.48	35.12	39.61
COHF-T-4	28.63	31.92	27.64	25.06
Solan Lalima (C)	30.85	25.18	28.66	28.90
Mean	36.06	39.04	41.74	36.06
Range	26.01-34.01	25.18-40.63	24.69-37.11	26.29-45.92
SE (m)±	0.54	0.39	0.47	1.54
CD (0.05)	1.62	1.17	1.41	4.62

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.7 Average fruit weight (g)

Average fruit weight and number of fruits per plant have direct contribution towards yield. Average fruit weight and number of marketable fruits per plant are negatively correlated with each other which means that breeders have to keep a balance to meet productivity requirement and consumer preference. The evaluation of data for average fruit weight revealed that EC-687604 (68.92g) (78.82 g) (72.31g) across all the environments

Table 4.18 Mean performance of the genotypes for average fruit weight (g)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	62.29	72.78	65.29	66.79
EC-687604	68.92	65.91	71.53	68.79
EC-687423	62.31	78.82	72.31	71.15
EC-635526	55.14	50.60	58.91	54.88
EC-654286	51.39	57.28	60.18	56.28
COHF-T-1	52.29	68.72	63.06	61.36
COHF-T-2	59.37	72.94	64.92	65.74
COHF-T-3	55.18	68.33	62.03	61.85
COHF-T-4	65.77	75.71	69.62	70.37
Solan Lalima (C)	67.38	73.22	64.36	68.32
Mean	60.00	68.43	65.22	64.55
Range	51.39-68.92	50.60-78.82	58.91-72.31	54.88-71.15
SE (m)±	0.96	0.85	0.76	2.49
CD (0.05)	2.87	2.55	2.29	7.46

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

was found to have significantly maximum average fruit weight. Similarly, pooling data over environments revealed that EC-687604 (71.15g) (73.37g) had maximum average fruit weight (Table 4.18). EC-687604, COHF-T-4 in E1, COHF-T-2 in E2 and EC-687604 in E3 were found to be statistically similar for average fruit weight in their respective environments. Jaha and Krishi (2001), Fayaz et al. (2007), Gul et al. (2010) and Triveni et al. (2017) have also revealed wider range of variability of the genotypes under various environments for average fruit weight involved in their respective studies.

4.7.8 Fruit Length (cm)

Fruit length significantly contributes towards fruit yield and therefore, it is one of the most important traits. EC-687423 got maximum value in E1 and E3 and pooled environment with the value of 54.30 mm, 56.27 mm and 54.49 mm respectively. COHF-T-4 got top position over E2 with the value of 55.08 mm. A critical analysis of fruit length over environments revealed that EC-687604, EC-687423, EC-635526, EC-654286, COHF-T-2, COHF-T-3 and COHF-T-4 at E1, EC-687423, EC-635526, COHF-T-2 and COHF-T-4 at E2, EC-687423, EC-635526, COHF-T-2, COHF-T-3 and COHF-T-4 at E3 were found to be significantly superior for fruit length over the check (Table 4.19). Pandey et al. (2000), Patel et al. (2017), Lekshmi and Celine (2017), Ahmad et al. (2016) have also reported significant differences for fruit length.

Table 4.19 Mean performance of the genotypes for fruit length (mm)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	39.88	45.62	42.36	42.62
EC-687604	52.92	46.02	47.92	48.95
EC-687423	54.30	52.91	56.27	54.49
EC-635526	49.33	53.87	51.61	51.60
EC-654286	47.31	45.33	45.62	46.09
COHF-T-1	39.06	42.33	40.13	40.51
COHF-T-2	52.61	53.06	55.37	53.68
COHF-T-3	47.83	48.06	51.27	49.05
COHF-T-4	51.22	55.08	54.26	53.52
Solan Lalima (C)	47.06	50.33	49.35	48.91
Mean	48.152	49.261	49.416	48.94
Range	39.06-54.30	42.33-55.08	40.13-56.27	40.51-54.49
SE (m)±	0.62	0.81	0.60	1.23
CD (0.05)	1.86	2.42	1.80	3.69

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.9 Fruit width (mm)

The mean performance for the fruit width revealed that maximum fruit width is observed in EC-687604 in E1 having values 55.61 mm. COHF-T-4 (56.41 mm) in E2 and COHF-T-2 (57.09 mm) in E3 were found to have significantly maximum fruit width. A critical observation for fruit width over environments revealed that five genotypes in E1, six genotypes in E2 and E3 had significantly better fruit width than the check. Pooling data over environments revealed that eight genotypes significantly surpassed Solan Lalima (50.46 mm) for fruit width and among these COHF-T-2 (55.67 mm), COHF-T-4 (54.39 mm) and EC-635526 (52.09 mm) were the top ranked genotypes (Table 4.20). Prashanth et al. (2006), Sherpa et al. (2014), Meena and Bahadur (2015) and Kumar et al. (2016) have also found significantly superior genotypes for fruit width in their respective studies.

Table 4.20 Mean performance of the genotypes for fruit width (mm)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	46.28	50.57	47.61	48.15
EC-687604	55.61	52.61	54.37	54.20
EC-687423	48.02	52.73	50.81	50.52
EC-635526	47.38	55.37	53.51	52.09
EC-654286	53.61	49.38	50.28	51.09
COHF-T-1	47.95	50.18	56.91	51.68
COHF-T-2	54.85	55.06	57.09	55.67
COHF-T-3	50.67	51.28	53.37	51.77
COHF-T-4	54.70	56.41	52.06	54.39
Solan Lalima (C)	49.34	51.15	50.88	50.46
Mean	50.84	52.47	52.69	52.00
Range	46.28-55.61	49.38-56.41	47.61-57.09	48.15-55.67
SE (m)±	0.57	0.65	0.60	1.44
CD (0.05)	1.70	1.94	1.81	2.34

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.10 Fruit shape index

The fruit shape index is defined as the ratio of the polar diameter to the equatorial diameter of the fruit. Generally, round-shaped fruits are preferred for table purposes, while oval-shaped fruits are preferred for processing. EC-687423 had maximum fruit shape index in all the respective environments and also in pooling data over environments having value 1.13, 1.00, 1.11 and 1.08 respectively. Evaluation of data for fruit shape index revealed that

EC-687604, COHF-T-2, COHF-T-3 and COHF-T-4 in E1, EC-687423, EC-635526, COHF-T-2, COHF-T-3 and COHF-T-4 in E2, EC-635526 COHF-T-2 and COHF-T-3 in E3 were found to be statistically similar for fruit shape index in their respective environments (Table 4.21). The performance of different tomato genotypes for fruit shape index have been also reported by Kumar et al. (2013) and Singh et al. (2017) in varied agro-climatic conditions.

Table 4.21 Mean performance of the genotypes for fruit shape index

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	0.86	0.90	0.89	0.88
EC-687604	0.95	0.87	0.88	0.90
EC-687423	1.13	1.00	1.11	1.08
EC-635526	1.04	0.97	0.97	0.99
EC-654286	0.88	0.92	0.91	0.90
COHF-T-1	0.81	0.84	0.71	0.79
COHF-T-2	0.97	0.96	0.97	0.97
COHF-T-3	0.94	0.94	0.96	0.95
COHF-T-4	0.94	0.98	1.04	0.99
Solan Lalima (C)	0.97	0.98	0.97	0.97
Mean	0.95	0.94	0.94	0.94
Range	0.81-1.13	0.84-1.00	0.71-1.11	0.79-1.08
SE (m)±	0.02	0.02	0.01	0.11
CD (0.05)	0.04	0.05	0.04	0.04

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.11 Pericarp thickness (mm)

Fruits having high pericarp thickness can withstand shipping and remain firm for more number of days as compared to thin fleshed fruits. The mean performance revealed that maximum pericarp thickness is observed in EC-654286 in E1 having values 6.63 mm. COHF-T-4 was found to have significantly maximum pericarp thickness in E2 and E3 i.e. 7.03 and 6.88 mm respectively. Pooling data over environments revealed that seven genotypes significantly surpassed Solan Lalima (4.80 mm) for pericarp thickness and among these EC-635526 (5.75 mm), EC-687604 (5.43 mm) and COHF-T-3 (5.43 mm) were the top ranked genotypes. A critical observation for pericarp thickness fruit over environments revealed that seven genotypes in E1, six genotypes in E2 and six genotypes in E3 had significantly superior better pericarp thickness than the check (Table 4.22). The earlier researchers namely Amarjeet et al. (2016) have also reported a wide range of variability under different environments in their research for pericarp thickness.

Table 4.22 Mean performance of the genotypes for pericarp thickness (mm)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	5.19	5.34	4.94	5.16
EC-687604	5.68	4.88	5.72	5.43
EC-687423	5.18	5.27	4.84	5.10
EC-635526	6.01	5.78	5.46	5.75
EC-654286	6.63	6.22	5.75	6.20
COHF-T-1	4.45	4.28	4.02	4.25
COHF-T-2	3.93	4.32	4.58	4.28
COHF-T-3	5.92	5.68	4.68	5.43
COHF-T-4	6.50	7.03	6.88	6.80
Solan Lalima (C)	4.76	5.10	4.55	4.80
Mean	5.43	5.39	5.14	5.32
Range	3.93-6.63	4.28-7.03	4.02-6.88	4.25-6.20
SE (m)±	0.08	0.08	0.09	0.20
CD (0.05)	0.24	0.23	0.27	0.60

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.12 Fruit firmness (g/cm³)

Fruit firmness becomes especially important when resistance during bulk transportation is an issue, independently of the tomato end use. The scrutiny of data revealed that EC-635526 (1249.46 g/cm³) produced maximum fruit firmness followed by EC-654286 (1194.29 g/cm³) and COHF-T-4 (1158.25 g/cm³) in E1, COHF-T-4 (1264.32 g/cm³) followed by EC-654286 (1182.27 g/cm³) and EC-635526 (1122.49 g/cm³) in E2 whereas, COHF-T-4 (1221.02 g/cm³) followed by

Table 4.23 Mean performance of the genotypes for fruit firmness (g/cm³)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	912.18	926.29	905.61	914.69
EC-687604	1035.81	1023.61	1048.51	1035.98
EC-687423	838.57	860.19	825.33	841.36
EC-635526	1249.46	1122.49	1132.18	1168.04
EC-654286	1194.29	1182.27	1176.27	1184.28
COHF-T-1	758.34	742.11	736.51	745.65
COHF-T-2	719.48	725.38	742.13	729.00
COHF-T-3	1127.24	1111.02	1109.21	1115.82
COHF-T-4	1158.25	1264.32	1221.017	1214.53
Solan Lalima (C)	832.17	850.37	843.33	841.96
Mean	982.58	980.81	974.01	979.13
Range	719.48-1249.46	725.38-1264.32	736.51-1221.02	745.65-1214.53
SE (m)±	9.43	12.12	7.53	18.00
CD (0.05)	28.23	36.28	22.54	53.89

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

EC-654286 (1176.27 g/cm³) and EC-635526 (1132.18 g/cm³) in E3. Further, pooled data over years revealed that COHF-T-4 (1214.53 g/cm³) followed by EC-654286 (1184.28 g/cm³) and EC-635526 (1168.04 g/cm³) significantly produced more fruit firmness than check Solan Lalima (841.96 g/cm³) (Table 4.23). Wider variability had also been observed by Hedau et al. (2008), Yogendra and Gowda (2013) and Renuka et al. (2017) for fruit firmness.

4.7.13 Number of locules per fruit

Locules are the chambers inside the fruit that contain the seeds. Number of locules per fruit in tomato depicts the juice content and shelf life of the genotypes. If there is more number of locules then fruit will have more juice content. The mean performance for the number of locules per fruit revealed that minimum number of locules per fruit is observed in EC-654286 in E1 having values (2.00), COHF-T-4 and Solan Lalima (2.20) in E2 and COHF-T-3 and COHF-T-4 (2.40) in E3 were found to have minimum number of locules per fruit. A critical observation for number of locules per fruit over environments revealed that four genotypes in E1, three genotypes in E3 had better number of locules per fruit than the check. Pooling data over environments revealed that four genotypes significantly surpassed Solan Lalima (2.6) for number of locules per fruit (Table 4.24). The performance of different tomato genotypes for number of locules per fruit have been also reported by Amarjeet et al. (2016) in varied agro-climatic conditions.

Table 4.24 Mean performance of the genotypes for number of locules per fruit.

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	4.20	4.00	4.80	4.33
EC-687604	4.80	4.60	4.20	4.53
EC-687423	3.60	3.40	3.80	3.60
EC-635526	2.20	2.80	2.60	2.53
EC-654286	2.00	2.40	2.80	2.40
COHF-T-1	3.80	4.00	4.20	4.00
COHF-T-2	3.60	3.80	3.20	3.53
COHF-T-3	2.20	2.80	2.40	2.47
COHF-T-4	2.40	2.20	2.40	2.33
Solan Lalima (C)	2.80	2.20	2.80	2.60
Mean	3.16	3.22	3.32	3.23
Range	2.00-4.80	2.20-4.60	2.40-4.80	2.33-4.53
SE (m)±	0.06	0.04	0.05	0.25
CD (0.05)	0.19	0.13	0.16	0.75

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.14 Total soluble solids (°B)

Examination of data for maximum Total Soluble Solids over environment revealed that EC-687423 (4.71°B) in E1, COHF-T-2 having value (5.02 and 5.10°B) in E2 and E3 respectively. Observation recorded also revealed that only three genotypes shows more TSS than check Solan Lalima (3.62°B) in E1, four genotypes shows more TSS than check Solan Lalima (3.55°B) in E2, three genotypes in E3 had more TSS than check Solan Lalima (3.57°B). Similarly, pooling data over environments revealed that genotype COHF-T-2 (4.68°B) followed by EC-687423 (4.25°B) shows more TSS than check Solan Lalima (3.62°B) (Table 4.25). Present findings are in accordance with the reports of Shankar et al. (2014), Amarjeet et al. (2016) and Kumar et al. (2019).

Table 4.25 Mean performance of the genotypes for TSS (°B)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	3.48	3.20	3.27	3.48
EC-687604	2.99	3.15	3.09	2.99
EC-687423	4.71	4.80	4.95	4.71
EC-635526	4.35	4.26	4.14	4.35
EC-654286	3.40	3.12	3.02	3.40
COHF-T-1	3.34	3.45	3.36	3.34
COHF-T-2	4.68	5.02	5.10	4.68
COHF-T-3	3.42	3.61	3.45	3.42
COHF-T-4	3.12	3.02	3.25	3.12
Solan Lalima (C)	3.62	3.55	3.57	3.62
Mean	3.71	3.72	3.72	3.71
Range	2.99-4.71	3.02-5.02	3.02-5.10	3.08-4.93
SE (m)±	0.07	0.06	0.04	0.08
CD (0.05)	0.19	0.18	0.12	0.24

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.15 Titrable acidity

Observation recorded for titrable acidity across the environment revealed that genotypes EC-687604 (0.44) in E1, COHF-T-4 (0.47) in E2 and EC-654286 (0.45) in E3 had maximum titrable acidity. Similarly, pooling data over environments revealed that genotype COHF-T-4 (0.41) followed by EC-687604 (0.40) and COHF-T-1 (0.36) shows more titrable acidity than check Solan Lalima (0.32). Examination for titrable acidity also revealed that genotypes EC-654289, EC-654286, COHF-T-1, COHF-T-3 and COHF-T-4 in E1, EC-654289, EC-654286 and COHF-T-4 in E2 and E3 are significantly superior than check (Table 4.26). Kumar et al. (2001) indicated that the genotypes showed a differential response due to the environments for titrable acidity.

Table 4.26 Mean performance of the genotypes for titrable acidity (%)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	0.30	0.37	0.36	0.34
EC-687604	0.44	0.37	0.40	0.40
EC-687423	0.20	0.28	0.23	0.24
EC-635526	0.24	0.29	0.25	0.26
EC-654286	0.35	0.40	0.45	0.40
COHF-T-1	0.38	0.36	0.35	0.36
COHF-T-2	0.18	0.26	0.22	0.22
COHF-T-3	0.33	0.30	0.35	0.33
COHF-T-4	0.39	0.47	0.37	0.41
Solan Lalima (C)	0.28	0.35	0.34	0.32
Mean	0.31	0.34	0.33	0.33
Range	0.18-0.44	0.26-0.47	0.22-0.45	0.22-0.41
SE (m)±	0.006	0.005	0.005	0.02
CD (0.05)	0.017	0.015	0.016	0.06

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.16 TSS: Acid ratio (%)

The mean performance for the TSS: Acid ratio revealed that maximum fruit width is observed in EC-687423 in E1 having value 26.17, COHF-T-2 in E2 and E3 having values (19.49 and 23.86) whereas, pooling data over environments revealed that three genotypes significantly surpassed Solan Lalima (11.16) and among these COHF-T-2 (22.25), EC-687423

Table 4.27 Mean performance of the genotypes for TSS: Acid Ratio

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	11.60	8.65	9.08	9.78
EC-687604	6.80	8.56	7.73	7.70
EC-687423	26.17	17.24	21.52	21.64
EC-635526	18.38	14.63	16.56	16.52
EC-654286	9.81	7.85	6.71	8.13
COHF-T-1	8.79	9.48	9.60	9.29
COHF-T-2	23.39	19.49	23.86	22.25
COHF-T-3	10.36	11.90	9.86	10.71
COHF-T-4	8.00	6.49	8.78	7.76
Solan Lalima (C)	12.93	10.08	10.46	11.16
Mean	13.62	11.44	12.42	12.49
Range	6.80-26.17	6.49-19.49	6.71-23.86	7.70-22.25
SE (m)±	0.25	0.17	0.22	1.02
CD (0.05)	0.76	0.51	0.65	3.05

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

(21.63) and EC-635526 (16.52) were the top ranked genotypes. A critical observation for TSS: Acid ratio over environments revealed that three genotypes viz. EC-687423, EC-635526 and COHF-T-2 in E1 and E3 whereas four genotypes viz. EC-687423, EC-635526, COHF-T-2 and COHF-T-3 in E2 and three genotypes viz. EC-687423, EC-635526, COHF-T-2 in E3 had significantly superior TSS: Acid ratio than the check (Table 4.27). Present findings are in accordance with the reports of Shankar et al. (2014), Amarjeet et al. (2016) and Kumar et al. (2019).

4.7.17 Ascorbic acid (mg/100g)

Ascorbic acid is a precursor of vitamin C and is one of the most important quality parameter in tomato. Ascorbic acid is an important trait, which contributes to the nutritional value of tomato. The mean performance for ascorbic acid revealed that maximum ascorbic acid is observed in EC-635526 in E1, E2 and E3 having values 30.92 mg/100g, 32.18 mg/100g and 34.29 mg/100g and were found to have significantly maximum ascorbic acid. A critical observation for ascorbic acid over environments revealed that four viz. EC-687604, EC-635526, EC-654286 and COHF-T-3 genotypes in E1, one genotypes viz. EC-635526 in E2 and two genotypes viz. EC-635526 and COHF-T-4 in E3 had significantly better ascorbic acid than the check. Whereas, one genotype viz. COHF-T-3 in E1, four genotypes viz. EC-654289, EC-654286, COHF-T-3 and COHF-T-4 in E2, three genotypes viz. EC-687604, EC-

Table 4.28 Mean performance of the genotypes for ascorbic acid (mg/100g)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	20.36	25.64	22.37	22.79
EC-687604	28.91	24.19	26.18	26.43
EC-687423	21.29	18.39	19.07	19.58
EC-635526	30.92	32.18	34.29	32.46
EC-654286	27.29	25.39	24.11	25.60
COHF-T-1	17.29	18.39	20.48	18.72
COHF-T-2	16.24	19.48	17.54	17.75
COHF-T-3	28.37	26.19	25.39	26.65
COHF-T-4	25.39	27.29	29.48	27.39
Solan Lalima (C)	24.48	26.59	25.09	25.39
Mean	24.05	24.37	24.40	24.28
Range	16.24-30.92	18.39-32.18	17.54-34.29	17.75-32.46
SE (m)±	0.41	0.43	0.38	1.11
CD (0.05)	1.23	1.28	1.14	3.32

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

654286 and COHF-T-3 in E3, were found to be statistically similar to check for ascorbic acid in their respective environments (Table 4.28). The results are in agreement with the results of Shankar et al. (2014), Basavaraj et al. (2015) and Kumar et al. (2016).

4.7.18 Lycopene content (mg/100g)

Lycopene is a carotenoid pigment, primarily responsible for the deep-red colour of ripe tomato fruits. The evaluation of data for the lycopene content revealed that maximum lycopene content is observed in EC-635526 in E1 having value 7.12 mg/100g, COHF-T-2 in E2 having value 8.14 mg/100g and, COHF-T-1 in E3 having value 7.91 mg/100g were found to have significantly maximum lycopene content. Pooling data over environments revealed that three genotypes significantly surpassed Solan Lalima (5.50 mg/100g) for lycopene content and among these EC-635526 (7.42 mg/100g), COHF-T-2 (7.16 mg/100g) and COHF-T-1 (6.64 mg/100g) were the top ranked genotypes. A critical observation for lycopene content over environments revealed that three genotypes viz. EC-635526, COHF-T-1 and COHF-T-2 in E1, E2 and E3 had significantly superior better lycopene content than the check (Table 4.29). The present results are getting support from the findings of Shankar et al. (2014), Amarjeet et al. (2016), Kumar et al. (2016) and Kumar et al. (2019).

Table 4.29 Mean performance of the genotypes for lycopene content (mg/100g)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	4.28	5.31	5.06	4.88
EC-687604	4.72	4.29	4.94	4.65
EC-687423	5.20	4.98	5.16	5.11
EC-635526	7.12	7.77	7.36	7.42
EC-654286	5.05	4.88	5.01	4.98
COHF-T-1	5.88	6.12	7.91	6.64
COHF-T-2	7.11	8.14	6.24	7.16
COHF-T-3	4.30	4.38	4.32	4.33
COHF-T-4	4.19	3.50	4.85	4.18
Solan Lalima (C)	5.17	5.84	5.49	5.50
Mean	5.30	5.52	5.63	5.49
Range	4.19-7.12	3.50-8.14	4.32-7.91	4.18-7.42
SE (m)±	0.09	0.06	0.08	0.33
CD (0.05)	0.27	0.19	0.23	0.99

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.19 Number of seeds per fruit

Number of seeds per fruit is an important character because seed is a propagating material and is also responsible for early stage growth and development of the plant. COHF-T-1 in E1 having value 134.33, EC-635526 in E2 having value 155.45 and COHF-T-3 in E3 having value 147.53 were found to top ranked for maximum number of seeds per fruit. Six genotypes viz. EC-687604, EC-635526, EC-654286, COHF-T-1, COHF-T-2 and COHF-T-3 in E1, seven genotypes viz. EC-654289, EC-687604, EC-687423, EC-635526, COHF-T-1, COHF-T-2 and COHF-T-3 in E2 and eight genotypes viz. EC-687604, EC-687423, EC-635526, EC-654286, COHF-T-1, COHF-T-2, COHF-T-3 and COHF-T-4 in E3 had significantly superior for number of seeds per fruit than the check (Table 4.30). Pooled data over the environments revealed that eight genotypes surpassed the check Solan Lalima and among these COHF-T-3, COHF-T-1 and COHF-T-2 were top ranked genotypes. The present results are getting support from the findings of Kumar et al. (2016) and Thakur et al. (2022).

Table 4.30 Mean performance of the genotypes for number of seed per fruit

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	90.39	115.67	102.69	102.92
EC-687604	132.58	125.64	118.92	125.71
EC-687423	115.49	118.24	133.68	122.47
EC-635526	130.15	155.45	145.38	143.66
EC-654286	123.49	112.82	127.66	121.32
COHF-T-1	134.33	137.39	142.49	138.07
COHF-T-2	128.39	145.25	139.98	137.87
COHF-T-3	133.28	151.26	147.53	144.02
COHF-T-4	95.39	103.58	123.49	107.49
Solan Lalima (C)	113.68	107.39	98.58	106.55
Mean	119.717	127.269	128.04	125.01
Range	90.39-134.33	103.58-155.45	98.58-147.53	102.92-144.02
SE (m)±	1.53	1.97	2.21	5.30
CD (0.05)	4.59	5.89	6.60	15.88

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.20 Thousand seed weight (g)

Evaluation of data over environments revealed that COHF-T-3 in E1 (5.25) and E3 (5.11) and EC-635526 in E2 (5.27) had maximum thousand seed weight respectively. Observation recorded also revealed that seven genotypes showed more thousand seed weight

than check Solan Lalima in E1 and four genotypes in E2 and six genotypes in E3. Similarly, pooling data over environments revealed that EC-635526 (5.16) had maximum thousand seed weight followed by COHF-T-3 (5.11) and COHF-T-1 (4.42) (Table 4.31). The results are in agreement with the results of Farshadfar et al. (2012), Shankar et al. (2014) and Kumar et al. (2016).

Table 4.31 Mean performance of the genotypes for thousand seed weight

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	3.92	4.07	4.15	4.05
EC-687604	4.27	4.02	4.19	4.16
EC-687423	4.25	4.15	4.02	4.14
EC-635526	5.17	5.27	5.05	5.16
EC-654286	3.98	4.18	4.05	4.07
COHF-T-1	4.64	4.27	4.34	4.42
COHF-T-2	4.14	4.59	4.25	4.33
COHF-T-3	5.25	4.98	5.11	5.11
COHF-T-4	4.34	4.15	3.94	4.14
Solan Lalima (C)	4.03	4.27	4.15	4.15
Mean	4.40	4.40	4.33	4.37
Range	3.92-5.25	4.02-5.07	3.94-5.11	4.05-5.16
SE (m)±	0.07	0.06	0.05	0.09
CD (0.05)	0.20	0.18	0.15	0.27

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.21 Harvest duration (days)

Long harvest duration has direct impact on enhancing total yield. Evaluation of data over environments for harvest duration revealed that COHF-T-3 (40.00 days) in E1, COHF-T-2 (39.00 days) in E2 and COHF-T-1 (38.33 days) in E3 had the longest harvest duration. Further, EC-635526 and COHF-T-1 in E1, EC-635526, EC-654286, COHF-T-1 and COHF-T-3 in E2, EC-654289, EC-654286, COHF-T-3 and COHF-T-4 in E3, were found to be statistically similar for harvest duration in their respective environments. Similarly, pooling data over environments revealed that COHF-T-2 had the longest harvest duration and followed by COHF-T-3 and EC-687423 (Table 4.32). Firas et al. (2012) have also revealed wider range of variability of the genotypes under various environments for harvest durations involved in their respective studies.

Table 4.32 Mean performance of the genotypes for harvest duration

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	20.67	26.33	29.33	25.44
EC-687604	22.00	24.67	27.67	24.78
EC-687423	39.67	33.33	37.67	36.89
EC-635526	33.67	36.67	35.00	35.11
EC-654286	31.33	35.67	34.33	33.78
COHF-T-1	32.67	35.00	38.33	35.33
COHF-T-2	38.67	39.00	36.00	37.89
COHF-T-3	40.00	38.00	34.33	37.44
COHF-T-4	28.00	33.33	30.67	30.67
Solan Lalima (C)	34.67	36.00	31.33	34.00
Mean	32.13	33.80	33.47	33.13
Range	20.67-40.00	24.67-39.00	27.67-38.33	24.78-37.89
SE (m)±	0.95	0.82	1.19	1.60
CD (0.05)	2.84	2.47	3.55	4.80

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

4.7.22 Fruit yield per plant (kg)

A critical examination of the data over the locations revealed that majority of the genotypes were found to have more fruit yield than the check Solan Lalima. EC-687423 (2.03 kg) remained top ranked in E1, COHF-T-1 (2.54 kg) in E2 and EC-654286 (2.23 kg) in E3 environment. Pooling of data over environments showed that EC-687423 (2.12 kg) had the highest fruit yield per plant and followed by COHF-T-1 (2.09 kg) and COHF-T-4 (2.08 kg)

Table 4.33 Mean performance of the genotypes for yield per plant (kg)

Genotypes	E1	E2	E3	Pooled Mean
EC-654289	1.32	1.88	1.52	1.57
EC-687604	2.01	1.95	2.11	2.02
EC-687423	2.03	2.10	2.22	2.12
EC-635526	1.52	2.03	2.15	1.90
EC-654286	1.75	1.79	2.23	1.92
COHF-T-1	1.60	2.54	2.14	2.09
COHF-T-2	1.72	2.40	1.90	2.01
COHF-T-3	1.70	2.29	2.14	2.04
COHF-T-4	1.85	2.40	1.98	2.08
Solan Lalima (C)	1.72	1.80	1.54	1.67
Mean	1.72	2.12	1.99	1.94
Range	1.32-2.03	1.79-2.54	1.52-2.23	1.57-2.12
SE (m)±	0.04	0.06	0.05	0.09
CD (0.05)	0.11	0.17	0.16	0.27

Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

had yield over check Solan Lalima. (2.22 kg) (Table 4.33). Fayaz et al. (2007), Kumar et al. (2016) and Kumari et al. (2020) also recorded variable performance of genotypes for fruit yield per plant.

4.8 Stability analysis

Plant breeders all across the world are working continuously to identify high-yielding and stable genotypes or a substitute over the exceeding varieties/hybrids in a variable environment of conditions. The widespread occurrence of genotype environment interactions (GEI) complicates the classification of stable genotypes. GEI affects the relative yield of genotypes in different environments, making superior genotype selection harder (Gauch 2006). Different genotypes perform differently in general attributed to variances in gene responsiveness or potential performance in different environments (Shiri, 2013). GEI diminishes the correlation between genotype and phenotype and delaying the development of genotype selection. With rigorous tests and subsequent selections, genotype environment interaction, or genotypes failing to behave consistently relative to environments, remains a key issue. Sharma and Sharma (2016) and Sharma et al. (2006) found that $G \times E$ interaction reduces genotype utility by confounding yield performance. To handle the GEI issue, plant breeders analyse genotypes in multi-environment trials (MET) inclusive of favourable as well as unfavourable environments (Alwala et al. 2010). The MET analysis of variance provides reliable forecasts of the main effects and GEI effects of genotype (G) and environment (E) Sharma et al. (2006). G and GEI are the most important impacts for cultivar evaluation. A substantial GEI not only involves alterations in genotype relative ranking or performance from one environment to the next, but it also inhibits breeding progress when choosing and advancing genotypes to later phases of selection (Kang, 1988). Furthermore, increasing GEI is frequently linked with a lower correlation between genotypic and phenotypic values which diminishes selection gain.

Stability analysis is the most significant approach used to uncover the nature of $G \times E$ interaction through which stable and consistent genotypes may be found and selected Cornelius et al. (1996), Perkins and Jinks (1973). A genotype is considered stable if its performance remains relatively constant in varying environments. According to Becker and Leon's (1988) idea of biological or static stability, a stable genotype has the least variation in yield across different environments. However, breeders and agronomists who prefer genotypes with significantly higher mean yield and the ability to respond to strong agronomic

treatments and favourable environmental conditions pay little attention to this concept (Becker, 1981). The cultivar or hybrid with a steady high yield, referred to as dynamic stability, is the most favoured choice in commercial plant breeding. Plant breeders must understand genotype $\times$ environment interaction in order to evaluate breeding material and generate superior varieties. The findings on genotype environment interaction and stability factors are described further below.

4.8.1 Joint regression analysis

The results of joint regression analysis proposed by Eberhart and Russell (1966) revealed that the mean sum of squares owing to genotypes and environments were extremely significant for all of the features under evaluation (Table 4.34 to 4.36), indicating a lot of diversity between genotypes and environments. The differences in different traits might be related to variances in environmental elements between the habitats (Alake and Ariyo 2012). When evaluated against pooled error, the mean sum of squares due to genotype $\times$ environment interaction were significant for all the traits, indicating that the genotypes interact strongly with the environments for all the characters and that the genotypes. The significant $G \times E$ interaction also suggested that the genotypes were suited for applying stability parameters.

Combined environment and genotype $\times$ environment interaction ($E + (G \times E)$) component of variance when tested against pooled error evaluated the significance of majority of the traits except days to 50 % flowering, titratable acidity (%) and ascorbic acid (mg/100g) indicating that the environments and their interaction with genotypes played an important role in determining the studied traits (Senapati and Sarkar 2002). Combined environment and genotype environment interaction $E + (G \times E)$ when tested against pooled deviation were also found significant for the traits viz. days to 50 % flowering, days to first picking, number of fruit clusters per plant, number of fruits per plant, TSS:Acid ratio, yield per plant (kg) and yield per hectare(q/ha). In their respective research at various environments with diverse genetic material, Kalloo et al. (1998), Sonam et al. (2017) and Kumari et al. (2020) also reported significant genotype $\times$ environment interaction for various traits.

When $G \times E$ (linear) was tested against pooled error mean sum of squares; it was found to be significant for majority of traits except days to 50% flowering, days to first picking, plant height (cm), fruit firmness (g/cm³) and number of seeds per fruit. Further, $G \times E$ (linear) when tested against pooled deviation, also showed significant differences for days

Table 4.34 Joint regression analysis of variance for days to 50 % flowering, days to first picking, plant height (cm), number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight (g) over the environment in tomato

S. No	Characters Source	df	Days to 50 % flowering	Days to first picking	Plant height (cm)	Number of fruit clusters per plant	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)
1	Genotypes	9	9.969 ⁺⁺	7.887 ⁺⁺	82.947 ⁺⁺	18.884 ⁺⁺	6.441 ⁺⁺	224.248 ⁺⁺	205.66 ⁺⁺
2	Environments	2	66.79 ⁺⁺	119.7 ⁺⁺	89.352 ⁺⁺	11.148 ⁺⁺	0.127 [*]	80.723 ⁺⁺	75.771 ⁺⁺
3	G × E	18	2.498 ⁺	2.037	25.000 [*]	0.89 [*]	0.546 [*]	5.352 [*]	12.899 [*]
4	Environments + G × E	20	8.927 ⁺	13.804 ⁺⁺	31.435 [*]	1.916 ⁺⁺	0.504 [*]	12.889 ⁺⁺	19.186 [*]
5	Environments (Linear)	1	133.58 ⁺⁺	239.4 ⁺⁺	178.704 ⁺⁺	22.296 ⁺⁺	0.253 [*]	161.446 ⁺⁺	151.5428 ⁺⁺
6	G × E (Linear)	9	3.907 ⁺	1.909	17.51	1.016 [*]	0.201 [*]	4.493 [*]	12.552 [*]
7	Pooled Deviation (Non-Linear)	10	0.979	1.95	29.241	0.688	0.802	5.59	11.921
8	Pooled error	54	4.852	3.191	9.392	0.115	0.022	0.86	1.667

* Significant at 5% level of significance (p=0.05) tested against pooled error; + significant at 5% level of significance (p=0.05) tested against pooled deviation.

Table 4.35 Joint regression analysis of variance for fruit length (mm), fruit width (mm), fruit shape index, pericarp thickness (mm), fruit firmness (g/cm³), number of locules, TSS (°B), titratable acidity (%) over the environment in tomato

S. No	Characters Source	df	Fruit length (mm)	Fruit width (mm)	Fruit shape index	Pericarp thickness (mm)	Fruit firmness (g/cm ³)	Number of locules	TSS(°B)	Titratable acidity (%)
1	Genotypes	9	66.869 ⁺⁺	14.782 ⁺⁺	0.018 ⁺⁺	1.923 ⁺⁺	104709.39 ⁺⁺	2.156 ⁺⁺	1.454 ⁺⁺	0.015 ⁺⁺
2	Environments	2	4.747 [*]	10.223 ⁺⁺	0.001	0.24 ⁺⁺	204.652	0.087 [*]	0.001	0.003 ⁺⁺
3	G × E	18	4.558 [*]	6.221 [*]	0.0028 [*]	0.12 [*]	971.686 [*]	0.101 [*]	0.019 ⁺⁺	0.001
4	Environments + G × E	20	4.577 [*]	6.621 [*]	0.002 [*]	0.132 [*]	894.983 [*]	0.100 [*]	0.017 ⁺	0.001
5	Environments (Linear)	1	9.495 ⁺⁺	20.445 ⁺⁺	0.001	0.48 ⁺⁺	409.304	0.174 [*]	0.001	0.007 ⁺⁺
6	G × E (Linear)	9	5.657 [*]	7.378 [*]	0.002 [*]	0.16 ⁺⁺	555.596	0.082 [*]	0.03 ⁺⁺	0.002 ⁺⁺
7	Pooled Deviation (Non-Linear)	10	3.113	4.558	0.002	0.072	1249	0.108	0.007	0.001
8	Pooled error	54	1.399	1.104	0.001	0.02	412.304	0.008	0.009	0.001

* Significant at 5% level of significance (p=0.05) tested against pooled error; + significant at 5% level of significance (p=0.05) tested against pooled deviation.

Table 4.36 Joint regression analysis of variance TSS:Acid ratio, ascorbic acid (mg/100g), lycopene content (mg/100g), harvest duration, number of seeds per fruit, thousand seed weight and yield per plant (kg) over the environment in tomato

S. No	Characters Source	df	TSS:Acid ratio	Ascorbic acid (mg/100g)	Lycopene content (mg/100g)	Harvest duration	Number of seeds per fruit	Thousand seed weight	Yield per plant (kg)
1	Genotypes	9	94.059 ^{*+}	62.553 ^{*+}	4.117 ^{*+}	733.933 ^{*+}	0.527 ^{*+}	2.156 ^{*+}	0.28 ^{*+}
2	Environments	2	11.979 ^{*+}	0.370	0.285 [*]	211.497 ^{*+}	0.017	0.087 [*]	0.514 ^{*+}
3	G × E	18	3.126 ^{*+}	3.684 [*]	0.328 [*]	84.41 [*]	0.024 [*]	0.101 [*]	0.025 [*]
4	Environments + G × E	20	4.011 ^{*+}	3.353 [*]	0.324 [*]	97.118 [*]	0.023 [*]	0.100 [*]	0.074 ^{*+}
5	Environments (Linear)	1	23.958 ^{*+}	0.739	0.569 [*]	422.993 ^{*+}	0.035 [*]	0.174 [*]	1.027 ^{*+}
6	G × E (Linear)	9	4.971 ^{*+}	5.238 ^{*+}	0.214 [*]	96.146 [*]	0.012	0.082 [*]	0.017 [*]
7	Pooled Deviation (Non-Linear)	10	1.152	1.918	0.397	65.406	0.032	0.108	0.03
8	Pooled error	54	0.14	0.494	0.018	11.077	0.01	0.008	0.008

* Significant at 5% level of significance (p=0.05) tested against pooled error; + significant at 5% level of significance (p=0.05) tested against pooled deviation.

to 50% flowering, pericarp thickness (mm), titratable acidity (%) and ascorbic acid (mg/100g). Therefore, indicating that the behavior of the genotypes could be predicted over the environments more precisely and accurately as the G×E (Linear) was the outcome of the linear function of the environmental components. The linear response of the environment accounted for the majority of total variation for all the studied characters and may be the cause of high adaptation in relation to yield and other traits, as evidenced by the higher magnitude of mean squares for environments (linear) compared to genotypes × environments (linear). Therefore, it would be imperative to proceed for stability analysis (Eberhart and Russel 1966). A significant contribution of linear component of GEI was also observed by Alok and Singh (2009), Jyothi et al. (2012), Shankar et al. (2017) and Kumar et al. (2019) in variable genetic material and environments for different traits in in tomato.

4.8.2 Individual regression analysis and estimation of stability parameters of individual genotypes

Individual regression analysis and estimates of stability parameters involving average performance ($\bar{x}$), regression coefficient (b_i) and deviation from regression (S^2_{di}) as per Eberhart and Russell model (1966) are presented in Table 4.37 to 4.43 for different traits. The measure for responsiveness to environmental changes was considered to be the regression coefficient or phenotypic regression (b_i), while the value for stability was thought to be. The genotypes with significant S^2_{di} were designated as unpredictable genotypes because of non-linear type of $G \times E$ interactions, whereas non-significance of S^2_{di} showed their predictability without non-linear type of $G \times E$ interactions. Among the predictable genotypes, phenotypic regression (b_i) was tested against unity.

The genotypes with $b_i = 1$ were classified as average responsive and constant. The genotypes that were significant for $b_i=1$ were further divided as above average responsive ($b_i>1$, appropriate for favourable conditions) and as below average responsive ($b_i<1$, appropriate for unfavourable conditions). Thus, according to Eberhart and Russell (1966), a steady genotype is one which has high mean with regression coefficient (b_i) near unity and deviation from regression (S^2_{di}) is close to zero. If regression coefficient (b_i) is considerably more or less than one, the genotype is considered more suited to favourable and unfavourable environments, respectively with respect to the site mean yield. The results with regard to stability parameters are described and discussed trait-by-trait as follows:

4.8.2.1 Days to 50% flowering

Evaluation of genotypes for stability indicated that six genotypes were earlier for days to 50% flowering than population mean (Table 4.37). Among, these desirable genotypes with early flowering, EC-635526 and COHF-T-3 were stable for all environments with average response ($b_i=1$) and non-significant deviation from regression ($S^2_{di}=0$). Further, genotype COHF-T-1 and COHF-T-2 with early flowering had regression coefficient value more than one ($b_i>1$) indicating that genotype would respond better under favourable conditions. EC-654286 and COHF-T-2 had regression coefficient value less than one ($b_i<1$) which showed that they may respond better under unfavorable environments. While check register mean value higher than population mean along with regression coefficient (b_i) value near unity and non-significant deviation from regression ($S^2_{di}=0$) indicating performance under lower input environments. Pandey et al. (2000), Joshi (2004), Alok and Singh (2009), Kumar et al. (2018), Asilo et al. (2019) and Kumar et al. (2019) had also recorded stability for days to 50% flowering in their germplasm.

Table 4.37 Individual regression analysis and estimates of stability parameters for days to 50% flowering, days to first picking and plant height (cm)

Genotypes	Days to 50% flowering			Days to first picking			Plant height (cm)		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	32.33	-0.24±0.46	4.50	65.78	0.25±0.51	10.89	104.76	0.50±5.63	97.39*
EC-687604	32.44	1.68±0.00	-1.61	63.78	0.84±0.06	0.36	105.51	0.63±0.84	11.85
EC-687423	34.11	1.16±0.33	-1.19	66.67	1.06±0.01	-0.91	111.69	-1.26±0.01*	-2.91
EC-635526	31.11	1.09±0.00	-1.56	63.56	1.05±0.02	-0.63	119.53	0.96±0.01	-3.02
EC-654286	31.00	0.71±0.02	-1.39	65.44	1.20±0.01	-0.73	108.59	2.27±0.23	0.92
COHF-T-1	31.00	1.62±0.01	-1.55	61.89	1.12±0.01	-0.77	114.84	1.31±3.57	60.59
COHF-T-2	30.22	1.16±0.01	-1.47	64.00	1.13±0.01	-0.88	115.80	1.48±2.08	34.06
COHF-T-3	28.89	1.15±0.12	-0.18	62.00	1.14±0.06	0.47	118.46	2.06±0.96	14.10
COHF-T-4	28.89	0.70±0.04	-1.06	63.11	1.06±0.00	-1.05	108.22	1.39±1.66	26.61
Solan Lalima (C)	33.89	0.97±0.06	-0.88	65.44	1.13±0.13	2.11	114.82	0.65±1.38	21.52
Grand Mean	31.39	1.00	-	64.17	1.00	-	112.22	1.00	-
S.E (m) ±	0.70	0.27	-	0.99	0.29	-	3.82	1.28	-

* Significant deviation at $P \leq 0.05$

4.8.2.2 Days to first picking

Based on the mean values (Table 4.37), six genotypes were early for days to first picking than the population mean (64.17days). Amongst these desirable genotypes with early picking EC-635526 and COHF-T-4 were stable for all environments with average response ($b_i=1$) and had predictable performance ($S^2_{di} = 0$). Further, genotypes EC-654286, COHF-T-1, COHF-T-2 and

COHF-T-3 with early picking had regression coefficient value more than one ($b_i > 1$) indicating its better response under favourable conditions. EC-687604 had regression coefficient value less than one ($b_i < 1$) which showed that they may respond better under unfavorable environments. Alok and Singh (2009) and Shankar et al. (2017) have also observed stable genotypes for days to first harvest in their studies in variable environmental conditions.

4.8.2.3 Plant height (cm)

Evaluation of the genotypes for stability indicated that five genotypes were found to have plant height higher than the population mean (Table 4.37). Among these desirable genotypes with high plant height only one genotype i.e., EC-635526 had regression coefficient ($b_i = 1$) near to unity indicated that these genotypes well adapted to across all the environments for this trait. Further, COHF-T-1, COHF-T-2 and COHF-T-3 with high plant height had regression coefficient value more than one ($b_i > 1$) indicating their better response under favourable conditions. On the other hand, Solan Lalima had regression coefficient value less than one ($b_i < 1$) hence, may respond better under unfavorable environments. Kalloo et al. (1998), Shankar et al. (2017), Kumar et al. (2018) and Kumar et al. (2019) have also found significant GE interaction for plant height in tomato genotypes.

4.8.2.4 Number of fruit clusters per plant

The evaluation of genotypes for stability parameters (Table 4.38) showed that COHF-T-3 had the highest number of fruits per plant (14.57) followed by four other genotypes those have greater number of fruit clusters per plant than population mean (10.52). The values of regression coefficients ranged from 0.31 to 2.31 indicating variable response of environmental fluctuations. One genotype EC-687423 showed significant deviation from regression line (S^2_{di}) indicating their unpredictable performance and EC-635526 were stable for all environments with average response ($b_i < 1$) and had predictable performance ($S^2_{di} = 0$) whereas, COHF-T-1, COHF-T-2 and COHF-T-2 with ($b_i < 1$) indicated their suitability under favourable environments respectively. Similar results were also reported by Spaldon and Hussan (2017), Shankar et al. (2017) and Selamawit et al. (2017).

4.8.2.5 Number of fruits per cluster

All the tomato genotypes exhibit significant deviation from linear regression (Table 4.38) except (EC-654286). Genotypes EC-654289, EC-687423, EC-635526, EC-654286 and COHF-T-1 exhibited number of fruits per cluster more than the population mean (6.54). The value of

regression coefficient varies from 0.06 to 2.85 that revealed variance in responses to environmental deviations. Among these genotypes EC-654286 had regression coefficient near to unity which indicated that these genotypes were considered as stable across all environments. Whereas, EC-654289, EC-687423 and EC-635526 had regression coefficient greater than 1 ($b_i > 1$) indicated that they were specifically adapted to favourable environments. COHF-T-1 were highly responsive to unfavourable environments as evident from b_i value less than one ($b_i < 1$). Significant variation due to $G \times E$ interactions for various characters have also been reported in tomato by Panthee et al. (2012), Jyothi et al. (2012), Sonam et al. (2017) and Shankar et al. (2017).

4.8.2.6 Number of fruits per plant

Data in Table 4.38 showed that linear regression was non-significant for all the genotypes except check variety. Genotypes EC-687423, EC-635526, COHF-T-1, COHF-T-1 and COHF-T-2 had mean values greater than population mean. Genotype COHF-T-1 exhibited regression coefficients near to unity which indicated that this genotype can perform uniformly equal in all the environments. Genotypes EC-635526, COHF-T-1 and COHF-T-2 were responsive to favourable environments because b_i value was greater than 1. Whereas, genotype EC-687423 was responsive to unfavorable environments because the value of regression coefficient was less than one. The results are in close conformity with the findings of Shobha et al. (2006), Shankar et al. (2017) and Kumar et al. (2018).

Table 4.38 Individual regression analysis and estimates of stability parameters for number of fruit clusters per plant, number of fruits per cluster and number of fruits per plant

Genotypes	Number of fruit clusters per plant			Number of fruits per cluster			Number of fruits per plant		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	7.33	0.60±0.16	0.32	6.66	2.85±24.04	0.60*	26.15	0.64±0.45	7.00
EC-687604	8.42	0.54±0.77*	1.68	5.73	1.26±16.26	0.40*	30.59	0.44±0.48	7.46
EC-687423	11.21	0.61±0.33*	1.28	7.19	2.79±42.89	1.08*	45.92	0.65±0.05	0.45
EC-635526	11.06	1.18±0.10	-0.04	7.13	1.43±100.75	2.54*	38.49	1.54±0.01	-0.18
EC-654286	8.64	0.31±0.14	0.26	8.25	1.09±0.01	0.03	34.21	0.86±0.03	0.22
COHF-T-1	12.59	1.95±0.46	0.99	8.96	0.06±31.32	0.79*	48.57	0.62±0.36	5.50
COHF-T-2	13.77	1.22±0.84*	1.83	4.85	1.43±0.75*	0.01	43.08	1.92±0.38	5.91
COHF-T-3	14.57	2.31±0.05	0.07	5.84	0.30±80.58	2.03*	39.61	1.53±0.01	-0.09
COHF-T-4	8.30	0.91±0.01	-0.03	4.36	0.72±13.48	0.33*	25.06	1.31±0.34	5.14
Solan Lalima (C)	9.28	0.37±0.07	0.13	5.51	2.72±5.28	0.13	28.90	0.51±0.36	21.62*
Grand Mean	10.52	1.00	-	6.45	1.00	-	36.06	1.00	-
S.E (m) ±	0.59	0.55	-	0.63	5.63	-	1.54	0.59	-

* Significant deviation at $P \leq 0.05$

4.8.2.7 Average fruit weight (g)

Stability analysis for average fruit weight (Table 4.39) revealed that the six genotypes including check namely EC-654289, EC-687604, EC-687423, COHF-T-2, COHF-T-4 and Solan Lalima had better average fruit weight than population mean (64.55g) and the performance of all genotypes was predictable and stable based on non-significant deviation from the regression coefficient. Amongst the stable genotypes, COHF-T-2 and EC-687423 were categorized as average responsive on account of their unit regression coefficient and therefore, were suitable for all the environments. In contrary, EC-654289 and COHF-T-4 with significant deviation from unity for parameters of responsiveness ($b_i > 1$) were stable for favorable environments while EC-687604 and Solan Lalima with $b_i < 1$ were suitable with better performance under unfavorable/stress conditions. The results coincide with that of Shankar et al. (2017), Kumar et al. (2018) and Kumar et al. (2019).

4.8.2.8 Fruit length (mm)

The assessment of stability parameters (Table 4.39) revealed that seven genotypes recorded large fruit length in comparison to population mean (48.94 mm). Except EC-687604 and EC-687423, rest of the genotypes were found predictable and stable having non-significant deviation from linear regression ($S^2_{di} = 0$) indicating that their performance can be predicted with reasonable accuracy. Among the genotypes with predictable performance COHF-T-4 were stable with average response ($b_i = 1$) and suitable for all environments. On the other hand, EC-635526, COHF-T-2, COHF-T-3 and Solan Lalima recorded above average response ($b_i > 1$), may be suitable under favourably environments and EC-687423 with $b_i < 1$ were suitable with better performance under unfavorable/stress conditions. Similar results were obtained in tomato for fruit length in tomato by Pandey et al. (2000), Tiwari and Lal (2014) and Shankar et al. (2017).

4.8.2.9 Fruit width (mm)

The evaluation of genotypes for stability parameters (Table 4.39) showed that COHF-T-2 (55.67) followed by three other genotypes had maximum fruit width in comparison to population mean (52.00 mm). Regression coefficient (b_i) ranged from 0.49 to 2.91 indicating differences in responses to environmental changes. EC-654286 had significant deviation from regression line indicating its unpredictable performance. COHF-T-2 and EC-687604 were

Table 4.39 Individual regression analysis and estimates of stability parameters Average fruit weight (g), fruit length (mm), fruit width (mm) and fruit shape index

Genotypes	Average fruit weight (g)			Fruit Length (mm)			Fruit Width (mm)			Fruit Shape Index		
	Mean (x)	b _i	S ² _{di}	Mean (x)	b _i	S ² _{di}	Mean (x)	b _i	S ² _{di}	Mean (x)	b _i	S ² _{di}
EC-654289	66.79	1.96±0.84	12.23	42.62	1.15±7.50	0.65	48.15	1.44±2.634	5.02	0.89	3.21±0.54*	0.00
EC-687604	68.79	0.39±0.89	12.90	48.95	1.780±3.73*	3.07	54.20	1.11±0.10	1.66	0.90	1.16±0.06	0.00
EC-687423	71.15	0.94±0.40	5.57	54.49	0.51±5.74	4.98	50.52	2.03±1.38	2.45	1.08	1.13±0.13	0.00
EC-635526	54.88	0.60±1.93	28.63*	51.60	2.66±3.82	3.16	52.09	2.91±1.80	3.31	0.99	2.92±1.04	0.00
EC-654286	56.28	1.26±1.06	15.47	46.09	1.21±0.15*	0.33	51.09	1.10±0.45*	0.56	0.90	3.21±0.54*	0.00
COHF-T-1	61.36	1.85±0.17	2.01	40.51	1.62±3.20	2.57	51.68	2.53±8.81	1.065*	0.79	2.18±1.62	0.01
COHF-T-2	65.74	0.99±0.05	0.17	53.68	1.53±2.29	1.71	55.67	0.80±0.15	0.08	0.97	0.37±0.28	0.00
COHF-T-3	61.85	1.06±0.20	2.40	49.05	1.79±4.59	3.89	51.77	1.05±0.86	0.04	0.95	0.57±0.02	0.00
COHF-T-4	70.37	2.10±0.36	4.85	53.52	1.81±0.84	0.33	54.39	0.49±4.46	8.74	0.98	2.40±0.04	0.00
Solan Lalima (C)	68.32	0.84±1.98	29.43*	48.91	2.24±0.43	0.43	50.46	0.94±0.06	0.25	0.97	1.10±0.13	0.00
Grand Mean	64.55	1.00	-	48.94	1.00	-	52.00	1.00	-	0.94	1.00	-
S.E (m) ±	2.49	0.89	-	1.25	1.81	-	1.51	1.49	-	0.03	4.84	-

* Significant deviation at P≤0.05

stable with average response ($b_i = 1$) had predictable performance and were stable with wider adaptability on account of their regression coefficient equal to unity suitable for all environments. On the other hand, EC-635526 recorded above average response ($b_i > 1$), may be suitable under favourable environments and COHF-T-4 with ($b_i < 1$) were suitable with better performance under unfavorable/stress conditions. Similar results were obtained in tomato for fruit width by Shobha et al. (2006), Selamawit et al. (2017) and Shankar et al. (2017).

4.8.2.10 Fruit shape index

The evaluation of genotypes for stability parameters revealed that six genotypes had higher fruit shape index than population mean (Table 4.39). EC-687423 followed by COHF-T-3 and Solan Lalima recorded mean value above the overall mean (0.94) along with regression value nearer to unity and non significant deviation from regression indicating stability of this hybrid across the environments. Based on the parameter of responsiveness (b_i), EC-635526, EC-654286 and COHF-T-4 with significant deviation from regression coefficient ($b_i > 1$) indicated their suitability for favourable environments and COHF-T-2 with ($b_i < 1$) were suitable with better performance under unfavorable environments. Sharma et al. (2006), Prasanna et al. (2007) and AI-Ayush (2014) had also observed similar findings for fruit shape index.

4.8.2.11 Pericarp thickness (mm)

The examining of stability parameters for pericarp thickness revealed that five genotypes EC-687604, EC635526, EC-654286, COHF-T-3 and COHF-T-4 were found to have significantly more pericarp thickness than the population mean (5.32 mm) (Table 4.40). Based on stability parameters all genotypes were predictable and stable with non-significant deviation from the linear regression ($S^2_{di} = 0$) except EC-6867604. Amongst these genotypes, EC-635526 was stable with unit regression coefficient and may be suitable for all environments. On the other hand, EC-654286 and COHF-T-3 ($b_i > 1$) indicating dynamic stability with deviation in performance over environments i.e., increased sensitivity to environmental changes which causes plants adapted to optimal environment and COHF-T-4 with ($b_i < 1$) were suitable with better performance under unfavorable/stress conditions. These results are in accordance with Kalloo et al. (1998), Prasanna et al. (2007), Shankar et al. (2017), Sonam et al. (2016), Kumar et al. (2018) and Kumar et al. (2019).

4.8.2.12 Fruit firmness (g/cm³)

The assessment of stability parameters (Table 4.40) revealed that five genotypes recorded more fruit firmness in comparison to population mean (979.13 g/cm³). Except COHF-T-2, rest of the genotypes were found predictable and stable having non-significant deviation from linear regression ($S^2_{di}=0$) indicating that their performance can be predicted with reasonable accuracy. EC-687604, EC-635526, EC-654286, COHF-T-1, COHF-T-3 and COHF-T-4 were highly responsive ($b_i > 1$) indicating dynamic stability with deviation in performance over environments. Significant variance due to genotype and environments for various characters has also been reported in tomato by Upadhyay et al. (2005) and Panthee et al. (2012).

4.8.2.13 Number of locules per fruit

The assessment of stability parameters (Table 4.40) revealed that five genotypes recorded more number of locules per fruit in comparison to population mean (3.25). Among these genotypes with predictable performance EC-687423 were stable with average response ($b_i=1$) and suitable for all environments. COHF-T-2, EC-654289, COHF-T-3 and Solan Lalima showed significant deviation from regression line (S^2_{di}) indicating their unpredictable performance. On the other hand, COHF-T-1 recorded above average response ($b_i > 1$), were suitable with better performance under favorable conditions and EC-687604 with $b_i < 1$ were suitable with better performance under unfavorable/stress conditions. Stability of genotypes for number of locules per fruit in tomato have also been observed by Kumar et al. (2001), Sonam et al. (2017) and Kumari et al. (2020).

Table 4.40 Individual regression analysis and estimates of stability parameters for pericarp thickness (mm), fruit firmness (g/cm³) and number of locules

Genotypes	Pericarp Thickness(mm)			Fruit Firmness(g/cm ³)			Number of locules		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	5.16	1.15±0.39	0.01	914.69	1.40±3.50	5.78	4.33	2.07±15.36	0.27*
EC-687604	5.43	1.03±0.02	0.36*	1035.98	2.09±3.22	-5.85	4.53	-2.91±2.46*	0.04
EC-687423	5.10	1.39±0.21	0.00	841.36	2.54±8.66	217.63	3.60	0.93±0.08	0.07
EC-635526	5.75	1.01±0.31	0.01	1168.04	2.48±154.14	6171.74*	2.53	2.80±2.86	0.05
EC-654286	6.20	2.64±1.04	0.04	1184.28	1.76±1.01	-96.32	2.40	1.10±1.73	0.03
COHF-T-1	4.25	1.34±0.15	0.00	745.65	2.06±2.01	-55.34	4.00	2.04±0.41	0.00
COHF-T-2	4.28	1.83±1.08	0.05	729.00	2.59±0.02*	-136.56	3.53	1.01±0.14	0.16*
COHF-T-3	5.43	2.23±0.08	0.00	1115.82	1.59±2.28	-44.20	2.47	1.94±6.69	0.11*
COHF-T-4	6.81	0.61±0.69*	0.12	1214.53	3.51±126.62	5045.11*	2.47	1.96±6.71	0.11*
Solan Lalima (C)	4.80	1.28±1.56	0.07	841.96	0.65±3.69	13.66	2.60	-1.13±12.31	0.21*
Grand Mean	5.32	1.00	-	979.13	1.00	-	3.25	1.00	-
S.E (m) ±	0.19	1.23	-	24.99	5.52	-	0.23	2.49	-

* Significant deviation at $P \leq 0.05$

4.8.2.14 Total soluble solids (°Brix)

The evaluation of genotypes for stability (Table 4.41) showed that three genotypes had more total soluble solids than population mean (3.72 °B). Majority of the genotypes except EC-654286 had non-significant deviation from the linear regression ($S^2_{di}=0$) and therefore, they had predictable and stable performance for total soluble solids (°B). Among them COHF-T-1 and COHF-T-2 ($b_i>1$) indicating dynamic stability with deviation in performance over environments i.e., increased sensitivity to environmental changes which causes plants adapted to optimal environment and EC-687423 with ($b_i<1$) was suitable with better performance under unfavorable/stress conditions. Present findings are in accordance with the reports of Kumar et al. (2001), Shankar et al., (2017), Sonam et al. (2017), Kumar et al. (2018), and Kumar et al. (2019).

4.8.2.15 Titratable Acidity (%)

The perusal data analyzed given in Table 4.41 indicated that five genotypes had greater levels of titratable acidity in comparison to the population means (0.33 %). COHF-T-1 were stable with average response ($b_i=1$) had predictable performance and was stable with wider adaptability on account of their regression coefficient equal to unity suitable for all environments. On the other hand, EC-654289, EC-654286, COHF-T-4 and Solan Lalima ($b_i>1$) indicating dynamic stability with deviation in performance over environments i.e., increased sensitivity to environmental changes which causes plants adaptation to optimal environment. The present results are in line with Shobha et al. (2006), Sonam et al. (2016) and Kumar et al. (2019) in tomato.

Table 4.41 Individual regression analysis and estimates of stability parameters for TSS (°B), Titratable Acidity (%) and TSS: Acid Ratio.

	TSS (°B)			Titratable Acidity (%)			TSS: Acid Ratio		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	3.32	2.26±203.78	0.01	0.34	2.04±0.18	0.00	9.78	1.38±0.22	0.47
EC-687604	3.08	1.18±90.57	0.00	0.40	0.11±0.06*	0.00	7.70	-0.81±0.00*	-0.05
EC-687423	4.82	0.36±107.61	0.00	0.23	2.55±0.14	0.00	21.64	1.08±0.022	0.01
EC-635526	4.25	1.89±60.90	0.00	0.26	1.37±0.48	0.00	16.52	1.71±0.017	-0.01
EC-654286	3.18	1.55±0.33*	0.00	0.40	1.90±4.51	0.00	8.13	0.96±1.13	2.66*
COHF-T-1	3.38	2.00±123.98	0.00	0.36	0.58±0.35*	0.00	9.29	-0.33±0.05*	0.08
COHF-T-2	4.93	2.82±8.15	0.00	0.23	1.57±0.38	0.00	22.25	1.70±1.91	4.54*
COHF-T-3	3.50	0.74±36.91	0.01	0.33	0.53±1.39	0.00	10.71	-0.66±0.51	1.18
COHF-T-4	3.13	1.92±530.41	0.02	0.41	1.73±4.91	0.00	7.76	0.64±0.73	1.69*
Solan Lalima (C)	3.58	1.32±11.10	0.00	0.32	2.06±0.28	0.00	11.16	1.33±0.22	0.49
Grand Mean	3.72	1.00	-	0.33	1.00	-	9.78	1.00	-
S.E (m) ±	0.06	12.26	-	0.02	1.13	-	7.70	0.70	-

* Significant deviation at $P\leq 0.05$

4.8.2.16 TSS: Acid ratio (%)

The assessment of stability parameters (Table 4.42) revealed that five genotypes recorded more TSS: Acid ratio in comparison to population mean (9.78). Among the genotypes with predictable performance three genotypes viz. EC-687423 followed by EC-687423 and Solan Lalima were stable with average response ($b_i=1$) and suitable for all environments. EC-687604 and COHF-T-1 showed significant deviation from regression line (S^2_{di}) indicating their unpredictable performance. On the other hand, EC-635526 and COHF-T-2 recorded above average response ($b_i>1$) whereas, COHF-T-3 with $b_i<1$ may be suitable under favourable environments and vice-versa. These results are in conformity with Ortiz et al. (2006) and Thapliyal (2008).

4.8.2.17 Ascorbic acid content (mg/100g)

Based on the mean values (Table 4.42) six genotypes along with check had a greater level of ascorbic acid in comparison to the population mean with non-significant deviation from linear regression ($S^2_{di}=0$) indicating stable and predictable performance except EC-687423, EC-654286 and COHF-T-3. Majority of them also showed unit regression coefficient ($b_i=1$) indicating their aptness for all the environments except EC-687423, EC-635526 and EC-654286 showed their suitability under favorable conditions while COHF-T-2 did the same under unfavorable environmental conditions. The results are in agreement of Zahedi et al. (2012), Spaldon et al. (2017), Sonam et al. (2017), Kumar et al. (2018) and Kumari et al. (2020).

Table 4.42 Individual regression analysis and estimates of stability parameters for ascorbic acid (mg/100g), lycopene Content (mg/100g) and number of seeds per fruit.

Genotypes	Ascorbic Acid (mg/100g)			Lycopene Content (mg/100g)			Number of seeds per fruit		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	22.79	1.32±85.60	6.16*	4.88	2.66±3.02	0.17	102.92	2.23±2.57	105.16*
EC-687604	26.43	-1.80±35.38	2.45	4.65	0.31±3.74	0.21*	125.71	-1.35±0.39	12.57
EC-687423	19.58	-2.55±5.35*	0.23	5.11	-0.24±0.43	0.02	122.47	1.45±2.44*	99.60
EC-635526	32.46	2.31±24.87	1.67	7.42	1.02±0.71	0.15	143.66	2.44±1.70	68.24
EC-654286	25.60	-2.86±7.70*	0.41	4.98	0.21±0.24	0.01	121.33	-0.27±2.70	110.30*
COHF-T-1	18.72	1.81±24.70	1.66	6.64	1.44±0.59	0.77*	138.07	0.75±0.24	6.60
COHF-T-2	17.75	0.45±30.48	2.09	7.16	1.64±0.21	1.66*	137.87	1.73±0.52	18.25
COHF-T-3	26.65	0.88±0.35*	0.01	4.34	0.10±0.05	-0.00	144.02	1.98±0.33	10.22
COHF-T-4	27.39	1.38±0.39	1.72	4.18	1.29±14.40	0.81	107.49	2.45±3.87	159.90*
Solan Lalima (C)	25.38	1.81±17.53	1.13	5.50	1.26±2.41	0.13	106.55	-1.42±0.71	26.30
Grand Mean	24.28	1.00	-	5.49	1.00	-	125.01	1.00	-
S.E (m) ±	0.98	5.09	-	0.45	2.64	-	5.72	1.24	-

* Significant deviation at $P \leq 0.05$

4.8.2.18 Lycopene content (mg/100g)

Considering high performance than population mean, four genotypes EC-635526, COHF-T-1, COHF-T-2 and Solan Lalima were found to have significantly more lycopene content than the population mean (5.49 mg/100g) (Table 4.42). Amongst the stable genotypes, EC-635526 and COHF-T-1 were categorized as average responsive on account of their unit regression coefficient and therefore, were suitable for all the environments. In contrary, COHF-T-2 and Solan Lalima with significant deviation from unity for parameters of responsiveness ($b_i > 1$) were stable for favorable environments. The present results are getting support from the findings of Jyothi et al. (2012), Sonam et al. (2017) and Kumar et al. (2019).

4.8.2.19 Number of seeds per fruit

The perusal of the Table 4.42 revealed that five genotypes namely COHF-T-3, EC-687604, COHF-T-1, COHF-T-2 and EC-687604 had higher number of seeds per fruit than population mean *i.e.*, 125.01. EC-687423 significantly recorded maximum seeds per fruit than rest of the genotype. All genotype showed non-significant deviation from regression line indicating their expectable performance and hence were stable. Amongst these genotypes EC-635526, COHF-T-2 and COHF-T-3 were highly responsive ($b_i > 1$) representing dynamic stability with deviation in performance over environments *i.e.*, suitable for favorable environments whereas, EC-687604 with $b_i < 1$ may be suitable under favourable environments. The present results are in line with findings of Bhalala and Acharya (2019) observed stability for number of seeds per fruit in tomato.

4.8.2.20 Thousand seed weight (g)

Stability analysis of genotypes for thousand seed weight showed that mean of three genotypes is greater than population mean (4.37 g) and based on regression coefficient analysis two genotypes COHF-T-2 and COHF-T-4 showed average response $b_i = 1$ indicating where aptness for all the environments (Table 4.43). Genotypes EC-635526 and COHF-T-1 had regression coefficient value more than one which showed that they may respond better under favourable environments whereas, COHF-T-3 had regression coefficient value less than one which showed that they may respond better under unfavorable environments. Spaldon et al. (2017), Bhalala and Acharya (2019) and Kumari et al. (2020) observed stability for thousand seed weight in tomato.

4.8.2.21 Harvest duration (days)

Perusal of stability parameters (Table 4.43) showed that COHF-T-2 had the highest harvest duration (37.89). The assessment of the genotypes for stability revealed that seven genotypes had harvest duration more than population mean (33.16 days). Among these desirable genotypes with largest harvest duration three genotypes (EC-635526, EC-654286 and COHF-T-4) were stable for all environments with average response ($b_i=1$) and ($S^2_{di}=0$). Genotypes, EC-687423 and COHF-T-2 had regression coefficient value more than one which showed that they may respond better under favourable environments whereas, EC-687423, COHF-T-2 and Solan Lalima had regression coefficient value less than one which showed that they may respond better under unfavorable environments. Similar results were reported by Joshi (2004), Thapliyal (2008) and Shankar et al. (2017).

Table 4.43 Individual regression analysis and estimates of stability parameters thousand seed weight, harvest duration and yield per plant (kg)

Genotypes	Thousand Seed Weight			Harvest Duration			Yield per plant (kg)		
	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}	Mean (x)	b_i	S^2_{di}
EC-654289	4.05	2.24±2.84	0.01	25.44	4.45±7.34	9.47	1.57	0.91±0.46	0.04
EC-687604	4.16	0.42±9.13	0.03	24.78	2.44±5.31	6.57	2.02	0.21±0.16	0.01
EC-687423	4.14	2.55±1.14	0.00	36.89	-3.30±3.82	4.44*	2.12	1.06±0.07	0.01
EC-635526	5.16	2.24±1.73	0.00	35.11	1.65±0.46	0.35	1.90	1.36±0.11	0.01
EC-654286	4.07	0.27±5.64	0.02	33.78	1.61±0.08	0.89	1.92	0.97±0.13	0.01
COHF-T-1	4.42	1.89±19.20	0.06	35.33	2.29±6.13	7.74	2.09	0.80±0.15	0.01
COHF-T-2	4.33	1.26±0.32	0.10*	37.89	-0.43±3.61	4.15	2.01	1.74±0.46	0.05
COHF-T-3	5.11	0.26±10.16	0.03	37.44	-2.14±7.01	8.99	2.04	0.88±0.08	0.01
COHF-T-4	4.14	1.33±4.22	0.01	30.89	1.55±0.48	0.72	2.08	1.24±0.16	0.01
Solan Lalima (C)	4.15	0.15±8.25	0.03	34.00	-0.13±8.09	10.54	1.67	0.84±1.14	0.12*
Grand Mean	4.37	1.00	-	33.16	1.00	-	1.94	1.00	-
S.E (m) ±	0.13	3.04	-	1.75	2.08	-	0.12	0.54	-

* Significant deviation at $P \leq 0.05$

4.8.2.22 Yield per plant (kg)

The simultaneous examination of stability parameters for individual genotypes (Table 4.43) revealed that EC-687604, EC-687423, COHF-T-1, COHF-T-2, COHF-T-3 and COHF-T-4 significantly produced higher yield than other genotypes and also population mean (1.94 kg). The comparison of these genotypes for linear regression indicated non-significant deviation from regression line for all the genotypes pointing out the absence of non-linear components of $G \times E$ interaction and hence, their performance can be precisely predicted of the top ranked genotypes, EC-635526, COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4 and Solan Lalima showed its

suitability across the environments ($b_i=1$) while EC-687604 categorized as sensitive to environmental changes and can be adapted to favourable environmental conditions ($b_i>1$). Similar results were also reported by Joshi (2004), Prasanna et al. (2007), Alok and Singh (2009), Jyothi et al. (2012), Shankar et al. (2017), Kumar et al. (2018) and Kumar et al. (2019) for this trait.

4.9 Genotype + (Genotype $\times$ Environment)

GGE biplot analysis is one of the acceptable approach for evaluating environment representation, genotype stability and the effect of GE on genotype efficiency (Yan et al. 2000, Karimizadeh et al. (2013) Asilo et al. (2019) and Singh et al. 2019). GGE biplot analysis provides an easy and complete solution to genotype by environment data analysis, which has been a hurdle for geneticists, plant breeders and agronomists (Fan et al. 2007, Yihunie and Gesesse 2018). Data not only solves short term applied queries but also provide insights on long-term fundamental aspects (Yan and Tinker 2006). GGE biplot analysis surpasses univariate approaches in breaking G $\times$ E components into specific interactions between genotype and environmental components (Flores et al. 1998). GGE biplot had some graphical mapping functions such as mapping of genotype performance in a specific environment, mapping of relative adaptability of a genotype into various environments, mapping of comparison of two genotypes in different environments, mapping of identifying the best genotypes in every environmental condition, mapping of environmental group for a specific genotype(s), mapping of genotype average performance and stability (Yan and Hunt 2001). It also enables for the assessment of environmental relationships and the re-arrangement of target environments in plant breeding programmes.

The GGE biplot can indicate the best genotype with the highest yield in a quadrant with identical locations (Mega-E), genotype average performance, optimum genotype, stability and ideal location to enhance yield and particular site to increase yield (Fashadfar and Sadegi (2014), Susanto et al. (2015) and Bhandari et al. (2022). Plant breeders have utilized this technique extensively in the variety assessment of wheat (Yan et al. 2000), maize (Fan et al. 2007) and soybean (Yan and Rajcan 2002).

4.9.1 Fruit yield per plant (g)

The environment-vector aspect of the GGE biplot (Fig 4.1a) reviews the interrelationships between the test environments. Environment vectors join the test environments to the biplot origins. The angle formed between the vectors of two adjoining testing environments is related to

their correlation coefficient. The cosine of the angle between two testing environments governs the correlation coefficient (Kroonenberg 1995, Yan 2002, Yan and Tinker 2006 and Parihar et al. 2018). A positive association is depicted by acute angles, a negative correlation by obtuse angles and no correlation by straight angles Yan and Tinker (2006) and Farshadfar et al. (2012). A short vector might suggest that the test environment is dissimilar to other environments. According to the standard deviation (SD)-GGE biplot, explained 86.38% of the total variation of which components 1 and 2 described 56.06 and 32.32%, respectively (Fig 4.1a). The distance between two environments indicates distinct effects on genotypes and as a consequence, the three environments were differentiated into two groups i.e., environments E1 and E3 in first group and E2 in the second group indicating that predictions based on either of these environments would be adequate for evaluating fruit yield per plant (g). All the three environments had positive correlation with each other as they form acute angles.

The length of the vectors from the biplot's concentric circle evaluates the environment's ability to discriminate. Of the three environments, E3 and E2 were the most discriminating (informative). On the other hand, E1 were the least discriminative environments having shortest environmental vectors and should not be used as test environments (Fig 4.1b). E3 were the most representative environments forming a small angle with the Average Environment Axis (AEA) and would be the most helpful test environments for assessing the genotypes for stability and were therefore, selected as most ideal test environments.

Genotypes should be assessed for mean performance and stability across environments within a single mega-environment. An ideal variety would be the one having high mean performance for a particular trait and good environmental stability Mortazavian et al. (2014) and Yan (2015). The AEC (Average Environment Coordinate) abscissa is represented by a single horizontal line with one arrow on it, this line's arrowhead points upward, indicating an increasing yield. The stability of the genotypes is represented by the line that passes through the origin and perpendicular to the AEC moving away from the biplot origin in the axis in either direction indicating increased GE interaction and decreased stability (Akter et al. 2015). High mean performance genotypes with high stability are the best genotypes. These genotypes have the shorter AEC vector and are close to the origin. The genotypes G3 (EC-687423) followed by G6 (COHF-T-1), G8 (COHF-T-3), G4 (EC-635526) and G9 (COHF-T-4) showed high fruit yield (Fig. 4.1c) while G8 (COHF-T-3) and G9 (COHF-T-4) placed extremely close to the AEC abscissa demonstrating its extreme stability followed by G6 (COHF-T-1). The rest of the genotypes were placed on the opposite side of the biplot indicating poor performance for yield.

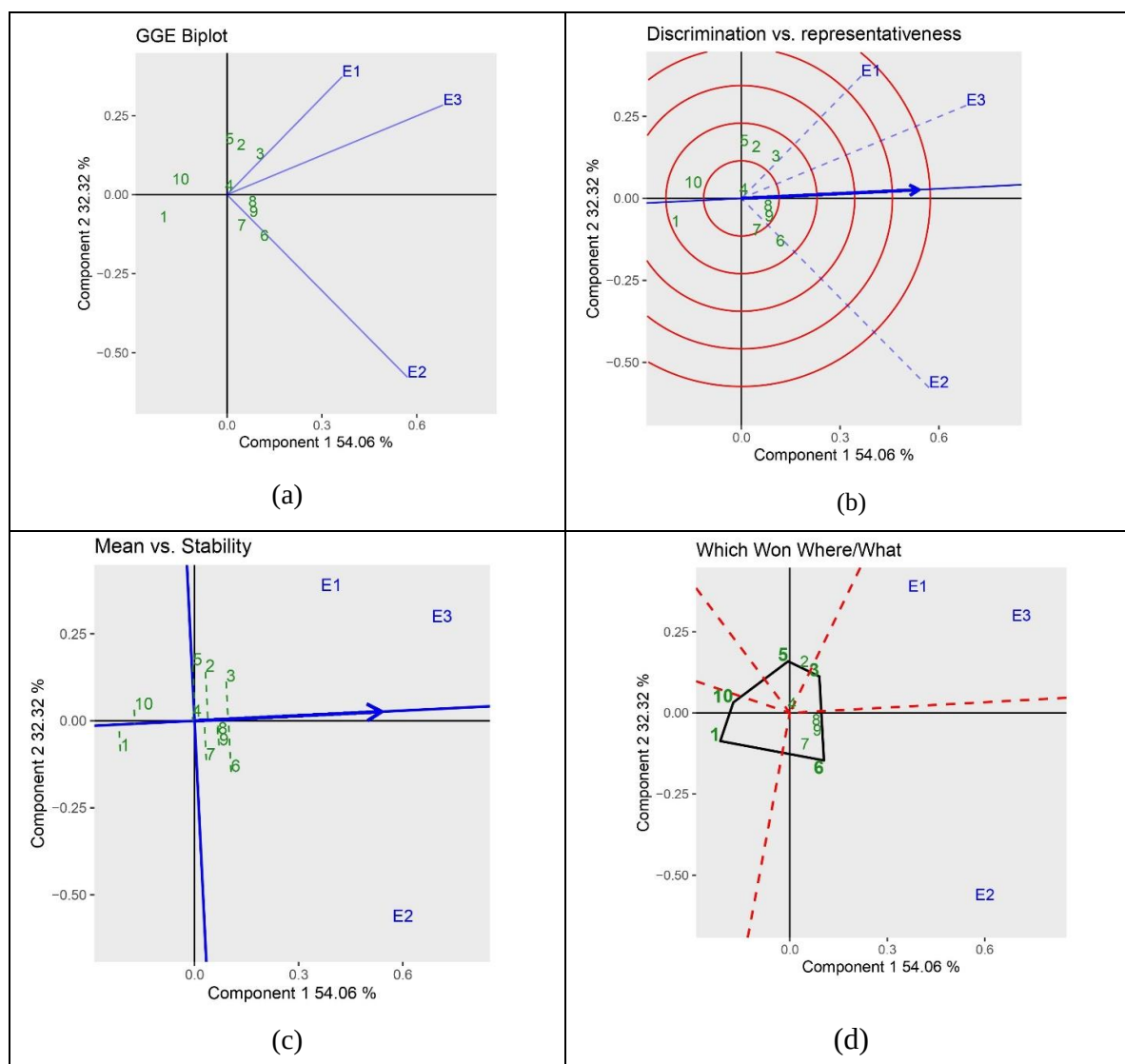


Fig 4.1 G+GE biplots for yield per plant

- An environment vector view biplot generated by using G+GE model with.
- Discrimitiveness vs. representativeness biplot generated using G+GE model.
- Means vs Stability biplot generated using G+GE model. The single arrowed horizontal line represents the AEC abscissa and the direction of AEC abscissa arrowhead indicates increasing yield. The vertical projections on the AEC abscissa indicates stability (greater the projection, higher is the instability)
- A “which won where” biplot generated by using G+GE model.
 - The letters “E” represent the environments UHF Nauni (E1), COHF Neri (E2) and RHR&TS Bajaura (E3).
 - 10 genotypes are specified as digits. 1: EC-654289, 2: EC-687604, 3: EC-687423, 4: EC-635526, 5: EC-654286, 6: COHF-T-1, 7: COHF-T-2, 8: COHF-T-3, 9: COHF-T-4 and 10: Solan Lalima.

The most attractive quality of a GGE biplot is its capacity to display the ‘which won where’ arrangement of a genotype by environment data set. The best method for identifying winning genotypes and visualizing the interaction patterns between genotypes and environments is the polygon view of the GGE biplot (Erdemci 2018) in MET data analysis (Fig. 4.1d). This is useful for evaluating the likely presence of various mega-environments and for identifying genotypes that may be well adapted to certain mega-environments (Yan and Tinker 2006 and Alwala et al. 2010).



EC-687423



COHF-T-1



COHF-T-3



COHF-T-4

Plate 4.1 Some promising genotypes of tomato

The remaining genotypes were positioned inside the polygon that was created by connecting the vertex genotypes with straight lines. Due to their distance from the biplot's origin, these genotypes may perform best or worst in certain or all conditions (Haruna et al. 2017).

The "Which won where" biplot divided the three environments in two sectors while the ten genotypes fell into five sectors (Fig. 4.1d) indicating that the genetic response is the same across different groups of locations being evaluated G3(EC-687423) in E1 and E3, G6 (COHF-T-1) followed by G8 (COHF-T-3), G9 (COHF-T-4) in E2, as they were positioned on the vertices of the polygon indicating their reliability and stability across

Chapter - 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

The present investigation entitled “**Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)**” was carried out during summer season of 2022 at the Experimental Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan.

The genetic material comprising of twenty-five genotypes including check variety Solan Lalima was assessed in Randomized Complete Block Design with three replications. Sowing of seeds in the nursery was done on Feb 2022 and seedlings were transplanted on March 2022 in a plot size of 2m × 2m with 90 × 30 cm spacing accommodating 10 plants per plot. The observations were recorded on characters viz., days to 50 % flowering, days to first picking, plant height (cm), number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight (g), fruit length (mm), fruit width (mm), fruit shape index, pericarp thickness (mm), fruit firmness (g/cm³), number of locules, TSS (°B), titratable acidity (%), TSS: Acid ratio, ascorbic acid (mg/100g), lycopene content (mg/100g), harvest duration, number of seeds per fruit, thousand seed weight, yield per plant (kg) and yield per hectare (q). The data was analyzed to work out mean performance and the inferences were drawn for PCV and GCV, heritability, genetic advance, correlation coefficient, path coefficient and stability analysis. The results of the present investigation have been summarized below:

Variability Studies

5.1.1 Mean performance of the genotypes

Analysis of variance (ANOVA) revealed highly significant differences among all the genotypes for all the parameters indicating the presence of wide range of variability. Based upon the overall mean performances of all the tomato genotypes, EC-687423 (2.19 kg) recorded highest yield per plant followed by COHF-T-1 (2.13 kg) and COHF-T-4 (2.09kg). The genotype COHF-T-1 was also found superior with respect to days to 50 % flowering,

days to first picking, plant height, number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, harvest duration and yield per plant.

Minimum days to 50 % flowering was recorded in COHF-T-1 (26.67 days) followed by COHF-T-3 (27.67 days) and COHF-T-2 (28.33 days), minimum days to first picking were assessed in COHF-T-3 (57.33 days) followed by COHF-T-1 (59.00 days) and COHF-T-2 (59.67 days). However, maximum plant height was recorded in COHF-T-1 (127.37cm) followed by EC-687423 (123.59cm) and COHF-T-3 (123.49cm). Number of fruit clusters per plant was recorded maximum in COHF-T-1 (13.08) followed by COHF-T-3 (12.95) and EC-687423 (12.87), while maximum number of fruits per cluster was observed in COHF-T-1 (6.99) followed by EC-687423 (6.84) and EC-654289 (6.73). Number of fruits per plant was recorded maximum in EC-635526 (38.51) followed by EC-654286 (37.10) and COHF-T-1 (35.18), maximum average fruit weight was observed in EC-687423 (74.02gm) followed by COHF-T-4 (73.05gm) and EC-654289 (70.12 gm). Fruit length was recorded maximum in EC-687423 (57.11mm) followed by COHF-T-2 (56.50mm) and COHF-T-4 (55.40mm) whereas, fruit width was maximum in COHF-T-2 (58.46mm) followed by EC-687604 (58.26mm) and EC-635526 (57.11mm). Fruit shape index was recorded maximum in EC-615039 (1.27) which was statistically at par with EC-687423 (1.14) and EC-692336 (1.14). Pericarp thickness was observed maximum in COHF-T-4 (6.79mm) followed by EC-654286 (6.59mm) and EC-635526 (6.03mm), while fruit firmness was recorded maximum in COHF-T-4 (1274.60 g/cm³) followed by EC-654286 (1203.91 g/cm³) and EC-635526 (1158.88 g/cm³). Number of locules was recorded maximum in EC-687604 (5.03) followed by EC-635529 (4.82) and EC-692350 (4.57). Total soluble solids were recorded maximum for EC-687422 (5.13°B) followed by COHF-T-2 (5.07°B) and EC-631411 (4.88°B) whereas, titratable acidity was recorded maximum for EC-632936 (0.51) followed by EC-631359 (0.50) and EC-698849 (0.48). TSS: Acid ratio was recorded maximum in EC-687422 (20.53) followed by COHF-T-2 (20.30) and EC-687423 (18.51). Ascorbic acid was recorded maximum in EC-692336 (31.65 mg/100g) followed by EC-698849 (30.77 mg/100g) and EC-631359 (30.60 mg/100g), while lycopene content was maximum observed in EC-635526 (7.56 mg/100g) followed by EC-687422 (7.48 mg/100g) and COHF-T-2 (7.43 mg/100g). Number of seeds per fruit was recorded maximum in EC-635526 (153.08) followed by COHF-T-3 (148.63) and COHF-T-1 (148.61) whereas, thousand seed weight was maximum in COHF-T-3 (4.83) followed by EC-635526 (4.78) and COHF-T-2 (4.68). Harvest duration was recorded maximum in COHF-T-3 (40.33days)

which was statistically at par with COHF-T-1 (40.00 days) and COHF-T-2 (38.67days). Yield per plant was recorded maximum for EC-687423 (2.19 kg) followed by COHF-T-1 (2.13 kg) and COHF-T-4 (2.09 kg), whereas yield per hectare was recorded maximum for EC-687423 (458.28 q/ha) followed by COHF-T-1 (430.48 q/ha) and COHF-T-4 (419.51 q/ha). Consequently, after evaluating the performance of these genotypes can be utilized effectively in subsequent breeding strategies.

For all the parameters under study phenotypic coefficients of variation were greater than the genotypic coefficients of variation. It indicated that the genotypic worth of any cultivar is certainly influenced by environment. High phenotypic and genotypic coefficients of variation (PCV and GCV) was observed in TSS: Acid ratio (47.66 %, 47.09 %), yield per hectare (47.63 %, 43.98 %), yield per plant (45.66 %, 43.98 %), number of fruits per plant (45.58 %, 45.10%), number of fruit clusters per plant (37.91 %, 37.87 %) and thousand seed weight (31.94 %, 31.84 %), respectively. Moderate magnitude of PCV and GCV were recorded for number of seeds per fruit (29.40 %, 26.78 %), lycopene content (28.47 %, 28.32 %), harvest duration (26.65 %, 22.43 %), number of fruits per cluster (26.46 %, 26.40 %), number of locules per fruit (24.74 %, 20.43 %), TSS (24.17 %, 23.38 %), titratable acidity (23.33 %, 23.12 %), fruit width (23.13 %, 22.99 %), fruit firmness (22.18 %, 22.06 %), average fruit weight (22.02 %, 21.87 %), pericarp thickness (21.01 %, 20.95 %), plant height (20.94 %, 20.72 %), ascorbic acid (20.09 %, 19.33 %) and fruit length (19.82 %, 19.72 %) respectively whereas, low magnitude of PCV and GCV was recorded for days to 50 per cent flowering (11.89 %, 11.48 %), fruit shape index (10.78 %, 10.41 %) and days to first picking (10.09 %, 9.91 %), respectively. Thus, indicating the role of environmental factors for the expression of these characters.

Among all the parameters studied, high heritability along with high genetic advance as per cent of mean was recorded for TSS: Acid ratio (97.62 %, 95.84 %), number of fruits per plant (97.92 %, 91.94 %), yield per hectare (87.63 %, 85.98 %), yield per plant (92.77 %, 82.27 %), number of fruit clusters per plant (99.81 %, 77.94 %), thousand seed weight (99.37 %, 65.38 %), lycopene content (98.94 %, 58.04 %) and number of fruits per cluster (99.49 %, 54.24 %) indicating that the heritability for these parameters is due to additive gene effects. Thus, improvement can be brought about by selection for these parameters. High heritability coupled with moderate genetic advance was recorded in titratable acidity (98.17 %, 47.19 %), fruit width (98.84 %, 47.09 %), TSS (93.57 %, 46.59 %), fruit firmness (98.89 %, 45.18 %), average fruit weight (98.65 %, 44.75 %), pericarp thickness (99.44 %, 43.03 %), plant height

(97.93 %, 42.33 %), fruit length (99.00 %, 40.42 %) and ascorbic acid (92.52 %, 38.29 %), which may be attributed to additive and non-additive gene effects. High heritability coupled with low genetic advance as per cent mean was observed for days to 50 % flowering (93.19 %, 22.83 %), fruit shape index (93.31 %, 20.71 %) and days to first picking (96.46 %, 20.04 %) which suggests that non-additive gene action plays a significant role in the expression of these traits and their improvement can be achieved through hybridization techniques.

5.1.2 Correlation studies

The genotypic correlation coefficients were generally greater than the phenotypic correlation coefficients. Results revealed that yield per plant was positively and significantly correlated with plant height (0.892 and 0.917), fruit width (0.863 and 0.886), thousand seed weight (0.854 and 0.917), fruit length (0.892 and 0.917), harvest duration (0.892 and 0.917), number of fruits per cluster (0.892 and 0.917), fruit firmness (0.892 and 0.917), average fruit weight (0.892 and 0.874), pericarp thickness (0.640 and 0.661) and lycopene content (0.425 and 0.444) while it had negative and significant association with days to 50% flowering (-0.877 and -0.932), days to first picking (-0.844 and -0.891), number of locules (-0.404 and -0.421) and titratable acidity (-0.369 and -0.384). From the correlation studies, it is concluded that yield per plant was positively and significantly correlated with days to 50% flowering, days to first picking, higher plant height having more number of fruits per plant, maximum fruit length, higher fruit width, pericarp thickness, fruit firmness, number of fruits per cluster and harvest duration.

5.1.3 Path coefficient analysis

Path coefficient analysis at genotypic level indicated that the positive direct effect on yield per plant was observed by TSS: Acid ratio (1.024), fruit firmness (0.678), average fruit weight (0.620), days to first picking (0.580), fruit length (0.454), plant height (0.438), fruit width (0.429), number of seeds per fruit (0.308), fruit shape index (0.293), thousand seed weight (0.221), harvest duration (0.165), titratable acidity (0.136), number of fruits per plant (0.0125) and number of fruits per cluster (0.063) whereas, negative direct effect was recorded for ascorbic acid (-0.022), lycopene content (-0.0705), number of fruit clusters per plant (-0.239), number of locules (-0.280), days to 50 % flowering (-0.359), pericarp thickness (-0.719) and TSS (-0.941) So, selection based on these traits will be effective to enhance yield per plant.

5.1.4 Stability analysis

Experiment:2

The present investigation entitled, “Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)” was undertaken with the aim to identify potential genotypes with high yield and component traits over a wide spectrum of environments. Keeping this in view, the present study was carried out to evaluate elite nine genotypes in comparison to recommended variety, Solan Lalima at three diverse locations during summer 2023 viz., Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP) (E1), Experimental Research Farm, Dr. YSP UHF COHF, Neri, Hamirpur (HP) (E2) and Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP) (E3). The experiment was laid out in Randomized Complete Block Design with three replications at each location to identify stable and high yielding tomato genotypes. Data was recorded on ten randomly taken plants in field conditions on days to 50 % flowering, days to first picking, plant height (cm), number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight (g), fruit length (mm), fruit width (mm), fruit shape index, pericarp thickness (mm), fruit firmness (g/cm^3), number of locules, TSS($^{\circ}\text{B}$), titratable acidity (%), TSS: Acid ratio, ascorbic acid (mg/100g), lycopene content (mg/100g), harvest duration, number of seeds per fruit, thousand seed weight and yield per plant (kg).

The data was analysed following the standard procedures of stability analysis (Eberhart and Russell 1966) to identify the genotypes on the basis of stability parameters such as mean, regression coefficient and deviation from regression coefficient. Also, GGE biplot analysis was carried out to identify ideal test environments and identify winning genotypes suitable for different environments on the basis of graphical visualization. The analysis of variance revealed the presence of sufficient genetic variability for most of the yield and yield contributing traits over the environments indicating variable performance of the genotypes and existence of considerable variability irrespective of the effect of environments for all the characters.

The analysis of variance revealed that the mean sum of squares associated with genotypes exhibited a remarkably significant for most of the characteristics in various environments, except for titratable acidity (%). On the basis of mean performance over locations, genotypes namely, EC-687423, COHF-T-1 and COHF-T-4 were the top ranked

genotypes for fruit yield per plant. Besides, they also showed better performance for days to 50 % flowering, days to first picking, plant height (cm), number of fruit clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight (g), fruit length (mm) and fruit width (mm).

Joint regression analysis revealed the prevalence of variability among genotypes and also environments. When $G \times E$ (linear) was tested against pooled error and mean sum of squares, it was found to be significant for all the traits except days to 50% flowering, days to first picking, plant height (cm), pericarp thickness (mm), fruit firmness (g/cm^3) and number of seeds per fruit. Further, testing against pooled deviation, mean sum of square was significant for the traits viz., days to 50 % flowering, pericarp thickness (mm), titratable acidity (%) and ascorbic acid (mg/100g).

The simultaneous examination of stability parameters for fruit yield per plant showed that EC-687423, COHF-T-1, COHF-T-4, COHF-T-3 and EC-687604 significantly produced higher yield than population mean (1.94 kg). The top ranked genotypes, EC-635526, COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4 and Solan Lalima showed its suitability across the environments ($b_i=1$) while, EC-687604 categorized as sensitive to environmental changes and can be adapted to favourable environmental conditions ($b_i>1$). These high yielding genotypes also showed stability across environments for majority of the traits.

Based on GGE biplot for fruit yield per plant, environment E3 (Bajaura) and E2 (Neri) were the most discriminating (informative) environment and was thus helpful for choosing genotypes that were typically acclimated whereas, on the other hand, E1 (Nauni) were the least discriminative environments having shortest environmental vectors. Mean vs stability biplot revealed that genotypes G3 (EC-687423) followed by G6 (COHF-T-1), G7 (COHF-T-2), G4 (EC-635526) and G8 (COHF-T-3) showed high fruit yield (Fig. 4.1c) with G3 (EC-687423) placed extremely close to the AEC abscissa with almost zero PC_2 scores demonstrating its extreme stability followed by G6 (COHF-T-1). ‘Which won where’ polygon view of GGE biplot model showed that the top high yielding genotype G3 (EC-687423) was the winning genotype that predominated for all the environments being situated on the vertex of the polygon indicating their reliability and stability across all environments on the basis of fruit yield along with desirable performance for majority of the traits.

5.2 CONCLUSIONS:

- Based on overall mean performance of the genotypes, it is concluded that genotypes EC-687423, COHF-T-1 and COHF-T-3 were found superior over the check Solan Lalima for terms of yield per plant. These genotypes were also promising for days to 50% flowering, days to first picking, plant height, number of fruits clusters per plant, number of fruits per cluster, number of fruits per plant, harvest duration and yield per plant. Thus, these genotypes can be recommended in future breeding programme for their superior characters.
- Higher estimates of genotypic (GCV) and phenotypic coefficient of variation(PCV) were observed for TSS: Acid ratio, yield per hectare, yield per plant, number of fruits per plant, number of fruit clusters per plant and thousand seed weight while moderate estimates were found in number of seeds per fruit, lycopene content, harvest duration, number of fruits per cluster, number of locules per fruit, TSS, titratable acidity, fruit width, fruit firmness, average fruit weight, pericarp thickness, plant height, ascorbic acid and fruit length reflecting presence of high and moderate genetic variability among all the genotypes for these traits and offered better scope for improvement.
- High heritability was observed for all the horticultural traits except number of locules, harvest duration and number of seeds per fruit.
- The highest genetic advance as per cent mean was recorded for TSS: Acid ratio, number of fruits per plant, yield per hectare, yield per plant, number of fruit clusters per plant, thousand seed weight, lycopene content, number of fruits per cluster and number of seeds per fruit indicating the presence of additive gene effect which in turn offers good scope for reliable and effective selection.
- Positive and significant correlation of yield per plant was recorded with plant height, fruit width, thousand seed weight, fruit length, harvest duration, number of fruits per cluster, fruit firmness, average fruit weight, pericarp thickness and lycopene content. Hence, selection for these traits would be much effective for yield improvement.
- Path coefficient analysis studies indicated that positive direct effects towards yield per plant were observed through TSS: Acid ratio, fruit firmness, average fruit weight, days to first picking, fruit length, plant height, fruit width, number of seeds per fruit, fruit shape index, thousand seed weight, harvest duration, titratable acidity, number of fruits per plant

and number of fruits per cluster. Therefore, selection for these traits would be more effective for improvement of fruit yield.

- The analysis of variance revealed variable performance of the genotypes and existence of considerable variability irrespective of the effect of environments for all the characters indicating sufficient genetic variability.
- On the basis of mean performance over environments, genotypes namely, EC-687423, COHF-T-1, COHF-T-2, EC-635526 and COHF-T-3 were the top ranked genotypes for fruit yield per plant.
- Joint regression analysis revealed prevalence of variability among genotypes and also environments. Significance of $G \times E$ (linear) was tested against pooled error, mean sum of square and was observed to be significant for all the traits except days to 50% flowering, days to first picking, plant height (cm), pericarp thickness (mm), fruit firmness (g/cm^3) and number of seeds per fruit.
- Based on Eberhart and Russell model, EC-635526 followed by COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4 and Solan Lalima exhibited not only broad adaptability to many environments for majority of the traits but also had high predictable yields for fruit yield per plant.
- Based on GGE biplot for fruit yield per plant, environment E3 (Bajaura) and E2 (Neri) was the most representative and discriminative environment and thus, helpful for choosing genotypes that were specifically acclimated.
- “Which won where” polygon view of GGE biplot model showed that E3 (Bajaura) and E1 (Nauni) was the most responsive environment for genotype G3(EC-687423), G6(COHF-T-1) followed by G8(COHF-T-3), G9(COHF-T-4) in E2 (Neri), as they were positioned on the vertices of the polygon indicating their reliability and stability across all environments for fruit yield per plant.

Table 5.1 Top three promising genotypes for different characters studied in tomato

CHARACTERS	GENOTYPES
Days to 50% flowering	COHF-T-1
	COHF-T-3
	COHF-T-2
Days to first picking	COHF-T-3
	COHF-T-1
	COHF-T-2
Plant Height (cm)	COHF-T-1
	EC-687423
	COHF-T-3
Number of fruit clusters per plant	COHF-T-1
	COHF-T-3
	EC-687423
Number of fruits per cluster	COHF-T-1
	EC-687423
	EC-654289
Number of fruits per plant	EC-635526
	EC-654286
	COHF-T-1
Average fruit weight (g)	EC-687423
	COHF-T-4
	EC-654289
Fruit length (mm)	EC-687423
	COHF-T-2
	COHF-T-4
Fruit width (mm)	COHF-T-2
	EC-687604
	EC-635526
Fruit shape index	EC-615039
	EC-687423
	EC-692336

CHARACTERS	GENOTYPES
Pericarp thickness (mm)	COHF-T-4
	EC-654286
	EC-635526
Fruit firmness (g/cm ³)	COHF-T-4
	EC-654286
	EC-635526
Number of locules	EC-687604
	EC-635529
	EC-692350
TSS (°Brix)	EC-687422
	COHF-T-2
	EC-631411
Titratable acidity (%)	EC-632936
	EC-631359
	EC-698849
TSS: Acid ratio	EC-687422
	COHF-T-2
	EC-687423
Ascorbic acid (mg/100g)	EC-692336
	EC-698849
	EC-631359
Lycopene content (mg/100g)	EC-635526
	EC-687422
	COHF-T-2
Number of seeds per fruit	EC-635526
	COHF-T-3
	COHF-T-1
Thousand seed weight	COHF-T-3
	EC-635526
	COHF-T-2
Harvest duration (days)	COHF-T-3
	COHF-T-1
	COHF-T-2
Yield per plant (kg)	EC-687423
	COHF-T-1
	COHF-T-4
Yield per hectare (q/ha)	EC-687423
	COHF-T-1
	COHF-T-4

Table 5.2: Stable genotypes on the basis of stability parameters

Characters	Well adapted to all environments $b_i=1$	Specifically adapted favourable environments $b_i>1$	Specifically adapted unfavourable environments $b_i<1$
Days to 50 % flowering	EC-687423, EC-35526, COHF-T-2, COHF-T-3	EC-687604, COHF-T-1	EC-654289, EC-654286, COHF-T-4, Solan Lalima
Days to first harvesting	EC-687423, EC-35526, EC-54286, COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4, Solan Lalima	-	EC-654289, EC-687604
Plant height (cm)	COHF-T-1, COHF-T-2, COHF-T-4	EC-54286, COHF-T-3	EC-654289, EC-687604, EC-687423, EC-35526, Solan Lalima
Number of fruit clusters per plant	EC-35526, COHF-T-2, COHF-T-4	EC-54286, COHF-T-1, COHF-T-3	EC-654289, EC-687604, EC-687423, Solan Lalima
Number of fruits per cluster	EC-54286, EC-687604, EC-35526, COHF-T-2	EC-687423, COHF-T-3, COHF-T-4,	EC-654289, COHF-T-1, Solan Lalima
Number of fruits per plant	EC-35526, COHF-T-4	COHF-T-2, COHF-T-3	EC-654289, EC-687604, EC-687423, EC-54286, COHF-T-1, Solan Lalima
Average fruit weight(g)	EC-687423, EC-654286, COHF-T-2, COHF-T-3	EC-654289, COHF-T-1, COHF-T-4	EC-687604, EC-35526, Solan Lalima
Fruit Length(mm)	EC-654289, EC-654286	EC-687604, EC-35526, COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4, Solan Lalima	EC-687423
Fruit Width(mm)	EC-687604, EC-654286, COHF-T-3, Solan Lalima	EC-687423, EC-35526, COHF-T-1	EC-654289, COHF-T-2, COHF-T-4
Fruit Shape Index	EC-687604, Solan Lalima	EC-654289, EC-687423, EC-35526, EC-654286, COHF-T-1, COHF-T-4	COHF-T-2, COHF-T-3
Pericarp Thickness(mm)	EC-654289, EC-687604, EC-687423, COHF-T-1, Solan Lalima	EC-35526, EC-654286, COHF-T-2, COHF-T-3	COHF-T-4
Fruit Firmness(g/cm³)	EC-654289	EC-687604, EC-687423, EC-35526, EC-654286, COHF-T-1, COHF-T-2, COHF-T-3, COHF-T-4	Solan Lalima

Characters	Well adapted to all environments bi=1	Specifically adapted favourable environments bi>1	Specifically adapted unfavourable environments bi<1
Number of locules	EC-654286, COHF-T-2,	EC-654289, EC-35526, COHF-T-1, COHF-T-3, COHF-T-4	EC-687604, EC-687423, Solan Lalima
TSS(°B)	EC-687604, EC-654286, Solan Lalima	EC-654289, EC-35526, COHF-T-1, COHF-T-2, COHF-T-4	EC-687423, COHF-T-3,
Titrateable Acidity (%)	EC-35526	EC-654289, EC-687423, EC-654286, COHF-T-2, COHF-T-4, Solan Lalima	EC-687604, COHF-T-1, COHF-T-3,
TSS:Acid Ratio	EC-654289, EC-687423, EC-654286, Solan Lalima	EC-35526, COHF-T-2	EC-687604, COHF-T-1, COHF-T-3, COHF-T-4
Ascorbic Acid (mg/100g)	EC-654289, COHF-T-3, COHF-T-4	EC-35526, COHF-T-1, Solan Lalima	EC-687604, EC-687423, EC-654286, COHF-T-2
Lycopene Content (mg/100g)	EC-35526, COHF-T-1, COHF-T-4, Solan Lalima	EC-654289, COHF-T-2	EC-687604, EC-687423, EC-654286, COHF-T-3
Number of seeds per fruit	EC-687423	EC-654289, EC-35526, COHF-T-2, COHF-T-3, COHF-T-4	EC-687604, EC-654286, COHF-T-1, Solan Lalima
Thousand Seed Weight	COHF-T-2, COHF-T-4	EC-654289, EC-687423, EC-35526, COHF-T-1	EC-687604, EC-654286, COHF-T-3, Solan Lalima
Harvest Duration	-	EC-654289, EC-687604, EC-35526, EC-654286, COHF-T-1, COHF-T-4	EC-687423, COHF-T-2, COHF-T-3, Solan Lalima
Yield per plant (kg)	EC-654289, EC-687423, EC-35526, EC-654286, COHF-T-1, COHF-T-3, COHF-T-4, Solan Lalima	COHF-T-2	EC-687604,

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APPENDIX-I

Mean monthly meteorological data during the field experiment periods (February to July, 2022) at College of Horticulture and Forestry Neri, Hamirpur.

Months, Year	Maximum (°C)	Minimum (°C)	Mean (°C)	Relative humidity (%)	Rainfall (mm)
February, 2022	20.17	9.98	15.07	62.51	2.26
March, 2022	31.15	18.28	24.72	44.86	0.21
April, 2022	38.06	23.65	30.85	27.19	0.33
May, 2022	39.72	26	32.86	28.92	1.67
June, 2022	38.84	27.59	33.21	41.32	5.52
July, 2022	32.12	25.89	29	79.45	10.38

Source: Meteorological Observatory, Department of Soil Science and Water Management, College of Horticulture and Forestry Neri, Hamirpur, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230 (HP).

APPENDIX-II

Analysis of variance (ANOVA) for various horticultural traits in tomato

Source	Mean sum of squares		
Character	Replications	Genotype	Errors
df	2	24	48
Days to 50% flowering	1.10	46.31 *	1.10
Days to first picking	1.41	144.36*	1.74
Plant height (cm)	7.09	1284.64*	9.01
Number of fruit clusters per plant	0.01	26.04*	0.02
Number of fruits per cluster	0.01	4.88*	0.01
Number of fruits per plant	17.00	492.46*	3.46
Average fruit weight(g)	5.21	563.03*	2.55
Fruit Length(mm)	0.43	215.56*	0.72
Fruit Width(mm)	2.30	304.48*	1.19
Fruit Shape Index	0.00	0.03*	0.00
Pericarp Thickness (mm)	0.00	2.94*	0.01
Fruit Firmness (g/cm ³)	264.28	102806.70*	382.31
Number of locules	0.15	1.82*	0.08
TSS (°B)	0.03	2.09*	0.05
Titrateable Acidity (%)	0.00	0.02*	0.00
TSS: Acid Ratio	0.05	79.56*	0.64
Ascorbic Acid (mg/100g)	1.26	70.24*	1.84
Lycopene Content (mg/100g)	0.01	6.95*	0.03
Number of seeds per fruit	234.32	2517.45*	96.83
Thousand Seed Weight	0.01	3.53*	0.01
Harvest Duration	0.53	142.61*	0.92
Yield per plant (kg)	0.05	1.55*	0.04
Yield per Hectare (q/ha)	3235.72	77646.10*	3489.51

*Significant at $P \leq 0.05$

APPENDIX-III

Mean monthly meteorological data during the field experiment periods (February to July, 2023) at UHF, Nauni Solan (HP).

Months, Year	Maximum (°C)	Minimum (°C)	Mean (°C)	Relative humidity (%)	Rainfall (mm)
February, 2023	23.78	5.56	14.67	39.21	0.26
March, 2023	23.58	8.05	15.82	56.45	4.21
April, 2023	26.63	10.51	18.57	38.57	3.81
May, 2023	27.94	13.21	20.57	48.84	4.91
June, 2023	29.34	17.41	23.37	56.17	5.13
July, 2023	27.54	20.11	23.82	79.87	21.31

Source: Meteorological Observatory, Department of Environmental Science, College of Forestry, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230 (HP).

APPENDIX-IV

Mean monthly meteorological data during the field experiment periods (February to July, 2023) at College of Horticulture and Forestry Neri, Hamirpur.

Months, Year	Maximum (°C)	Minimum (°C)	Mean (°C)	Relative humidity (%)	Rainfall (mm)
February, 2023	24.92	12.32	18.62	46.08	0.52
March, 2023	26.76	15.99	21.38	53.56	2.81
April, 2023	30.80	18.69	24.75	48.00	2.89
May, 2023	34.04	21.44	27.74	46.99	4.45
June, 2023	35.55	25.49	30.52	56.12	4.89
July, 2023	31.67	25.36	28.51	79.39	16.53

Source: Meteorological Observatory, Department of Soil Science and Water Management, College of Horticulture and Forestry Neri, Hamirpur, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230 (HP).

APPENDIX-V

Mean monthly meteorological data during the field experiment periods (February to July, 2023) at RHR&TS, Bajaura, Kullu.

Months, Year	Maximum (°C)	Minimum (°C)	Mean (°C)	Relative humidity (%)	Rainfall (mm)
February, 2023	19.42	2.86	11.14	55.02	0.46
March, 2023	22.76	3.86	13.31	66.83	1.01
April, 2023	24.99	5.71	15.35	62.20	2.54
May, 2023	29.79	8.19	18.99	63.59	3.38
June, 2023	32.66	13.24	22.95	74.45	6.56
July, 2023	37.78	15.21	26.50	86.89	26.61

Source: Meteorological Observatory, Hill Agricultural Research and Extension Centre (HAREC), Bajaura, CSK HPKV Palampur-176062 (HP).

APPENDIX-VI

Analysis of variance for different traits of tomato in the respective environments.

Source		Replication	Treatment	Error
Characters	df	2	9	18
Days to 50 % flowering	E1	9.73	15.84*	3.88
	E2	7.32	12.52*	4.80
	E3	14.43	16.53*	5.88
Days to first picking	E1	14.43	11.50*	4.17
	E2	8.03	11.26*	3.00
	E3	5.03	13.13*	2.40
Plant height (cm)	E1	2.44	137.85*	8.07
	E2	6.01	171.29*	13.06
	E3	7.04	89.70*	7.05
Number of fruit clusters per plant	E1	0.03	11.57*	0.09
	E2	0.02	21.64*	0.13
	E3	0.16	28.78*	0.12
Number of fruits per cluster	E1	0.01	8.86*	0.02
	E2	0.01	5.59*	0.02
	E3	0.07	8.15*	0.03
Number of fruits per plant	E1	0.17	208.45*	0.51
	E2	0.67	228.09*	1.09
	E3	0.34	268.31*	0.99
Average fruit weight(g)	E1	0.50	212.84*	1.12
	E2	0.54	297.18*	2.48
	E3	3.50	184.36*	1.40
Fruit Length(mm)	E1	0.11	81.41*	1.16
	E2	2.56	57.60*	1.96
	E3	5.46	88.95*	1.08
Fruit Width(mm)	E1	0.56	37.57*	0.97
	E2	0.39	17.44*	1.26
	E3	1.04	26.66*	1.09
Fruit Shape Index	E1	0.001	0.02*	0.00
	E2	0.001	0.01*	0.00
	E3	0.001	0.03*	0.00
Pericarp Thickness(mm)	E1	0.02	2.34*	0.02
	E2	0.01	2.12*	0.02
	E3	0.02	2.03*	0.03
Fruit Firmness(g/cm³)	E1	989.88	112830.21*	266.42
	E2	253.93	105527.19*	800.16
	E3	179.80	101600.88*	170.34
Number of locules	E1	0.001	2.94*	0.01
	E2	0.008	1.90*	0.01
	E3	0.010	2.24*	0.01
TSS (°B)	E1	0.010	1.20*	0.01
	E2	0.012	1.57*	0.01
	E3	0.002	1.71*	0.01
Titrateable Acidity (%)	E1	0.001	0.02	0.00
	E2	0.001	0.01	0.00
	E3	0.000	0.02	0.00
TSS:Acid Ratio	E1	0.100	135.59*	0.19
	E2	0.122	55.95*	0.09
	E3	0.001	109.39	0.14

Ascorbic Acid (mg/100g)	E1	0.10	76.67*	0.50
	E2	0.05	58.65*	0.55
	E3	0.14	74.45*	0.43
Lycopene Content (mg/100g)	E1	0.071	3.541*	0.031
	E2	0.004	6.681*	0.011
	E3	0.017	4.102*	0.018
Number of seeds per fruit	E1	10.68	755.82*	7.05
	E2	2.79	1,059.70*	11.60
	E3	1.93	892.74*	14.59
Thousand Seed Weight	E1	0.003	0.676*	0.013
	E2	0.002	0.532*	0.010
	E3	0.002	0.516*	0.008
Harvest Duration	E1	7.30	139.05*	2.71
	E2	12.70	67.42*	2.03
	E3	20.63	38.24*	4.23
Yield per plant (kg)	E1	0.001	0.275*	0.004
	E2	0.011	0.303*	0.009
	E3	0.014	0.413*	0.009

* Significant at $P \leq 0.05\%$ Where, E1=UHF Nauni, E2=COHF Neri and E3= RHR&TS Bajaura

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Title of Thesis : “ Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)”
Name of the Student : Nikhil Thakur
Admission Number : H-2020-88-D
Major Discipline : Vegetable Science
Minor Discipline : Genetics and Plant Breeding
Date of Thesis Submission :
Total pages of the thesis : 162+v
Major Advisor : Dr Deepa Sharma

ABSTRACT

The study titled " Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.)" was conducted during 2022 and 2023. In the first experiment twenty-five genotypes, including check Solan Lalima, were assessed for various horticultural traits at the Vegetable Research Farm, Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur and significant variation among genotypes for all the traits were observed. Genotypes EC-687423, COHF-T-1 and COHF-T-3 exhibited superiority over the check Solan Lalima in terms of yield per plant and other key traits. Heritability and genetic advance were recorded maximum for number of fruits per plant, yield per plant, number of fruit clusters per plant, thousand seed weight and number of fruits per cluster implying that the presence of additive gene effects. Positive and significant correlation of yield per plant was recorded with plant height, fruit width, thousand seed weight, fruit length, harvest duration, number of fruits per cluster, fruit firmness, average fruit weight, pericarp thickness and lycopene content. Path coefficient analysis highlighted traits like fruit firmness, average fruit weight, fruit length, plant height, fruit width, number of seeds per fruit, harvest duration, number of fruits per plant and number of fruits per cluster having direct positive effects on yield per plant, indicating their prioritization for effective selection strategies. On the basis of overall performance of the first experiment ten elite genotypes, including the check were selected for second experiment to analyze stability for growth, yield and quality attributes in tomato at different locations: (i) Experimental Research Farm, Department of Vegetable Science, UHF, Nauni Solan (HP) (ii) Experimental Research Farm, Dr. YSP UHF COHF Neri, Hamirpur (HP) (iii) Experimental Research Farm, Dr. YSP UHF RHR&TS, Bajaura, Kullu (HP) and result revealed that the, genotypes EC-687423 (2.12 kg), COHF-T-1(2.09 kg) and COHF-T-4 (2.08 kg) comes out as best performing for fruit yield per plant across environments. Using the Eberhart and Russell model, these genotypes demonstrated broad adaptability and predictability for fruit yield per plant. The GGE biplot analysis identified environments E3 (Bajaura) and E2 (Neri) as representative and discriminative, aiding in the selection of genotypes acclimated to specific conditions. Notably, genotypes G3(EC-687423) in E1 and E3, G6 (COHF-T-1) followed by G8 (COHF-T-3) and G9 (COHF-T-4) in E2, found to be best performing as they were positioned on the vertices of the polygon indicating their reliability and stability across all environments for fruit yield per plant.

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Date:

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Certificate/Degree	Month & Year	School/College	Board/University	Marks (%)	Division
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