MOROHOLOGICAL AND BIOCHEMICAL CHARECTERIZATION OF TOMATO GENOTYPES FOR YIELD AND QUALITY ATTRIBUTES

(*Solanum lycopersicum* L.)

RAJ KUMAR

Thesis

Master of Science in Horticulture

(VEGETABLE SCIENCE)

DEPARTMENT OF VEGETABLE SCIENCE

COLLEGE OF HORTICULTURE AND FORESTRY

RANI LAKSHMI BAI CENTRAL AGRICULTURAL UNIVERSITY

JHANSI – 284003 (UTTAR PRADESH)

JULY 2022

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Submitted to the

Rani Lakshmi Bai Central Agricultural University,

Jhansi 284003 (U.P.) INDIA

BY

RAJ KUMAR

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

Master of Science in Horticulture

(VEGETABLE SCIENCE)

JULY, 2022

College of Horticulture and Forestry

Rani Lakshmi Bai Central Agricultural University

Jhansi -284003

(Vegetable Science)

CERTIFICATE - I

Certified that Mr. Raj Kumar, Id. No. RLBCAU/H /PG/009 has satisfactorily pursued his course of research for not less than IV semesters and that the thesis entitled "**Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes**" submitted by him to the Rani Lakshmi Bai Central Agricultural University, Jhansi 284003 (U.P.) in partial fulfillment of the requirements for the award of the degree of Master of Science in Horticulture in the subject of Vegetable Science is the result of original research work conducted by him under my supervision and is sufficiently of a high standard to warrant its presentation to the examination.

I also certify that the thesis or part thereof has not been previously submitted by him for a degree/diploma of any University.

Date 19/07/2022

Chairperson

(A.K. Pandey)

College of Horticulture and Forestry

Rani Lakshmi Bai Central Agricultural University

Jhansi – 284003

(Vegetable Science

CERTIFICATE - II

This is to certify that the thesis entitled "**Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes**" submitted by Mr. Raj Kumar ID. No. RLBCAU/H /PG/009 submitted to the Rani Lakshmi Bai Central Agricultural University, Jhansi 284003 (U.P.) for partial fulfillment of the requirements for the award of the degree of Master of Science in Horticulture in the subject of Vegetable Science has been approved by the Student's Advisory Committee after the viva voice examination.

Date 22/09/2022

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ACKNOWLEDGEMENTS

Accomplishment of the thesis is the result of benevolence of Almighty, blessing of my parents, motivation and guidelines of my teachers help of my friends and words of encouragement and gesture of helpfulness from the other members of the society.

Every researcher owes a debt to his teachers. I seize this opportunity to express my profound sense of gratitude to the esteemed chairperson of my advisory committee ***Dr. A. K. Pandey****, Dean, College of Horticulture and Forestry, RLBCAU, for his most valuable and dexterous guidance with his friendly nature, love and affection. I have been amazingly fortunate to have an advisor who gave me the freedom to explore on my own and at the same time the scientific guidance and commendable encouragement shaped my efforts in a successful research work. The blessing, help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark.*

It was the collective intellect of my advisory committee which readily sailed me through the intricacies and perplexities of my research work. Hence, I acknowledge with gratitude and appreciation, for worthy counsel, keen interest in planning and execution of the research, constant monitoring, whole hearted involvement and attention bestowed in every part of the investigation which has greatly facilitated in the accomplishment of the thesis by the member of my advisory committee ***Dr. Gaurav Sharma****, Associate Professor (Horticulture), RLBCAU, Jhansi,* ***Dr. Ashutosh Singh,*** *Assistant Professor, Department of Biotechnology & Crop Improvement and* ***Dr. Rakesh Choudhary****, Scientist, Genetics and Plant Breeding, RLBCAU, Jhansi.*

I have immense pleasure in expressing my whole hearted sense of gratitude to ***Dr. Arvind Kumar****, Hon'ble Vice-Chancellor, RLBCAU, Jhansi,* ***Dr. Anil Kumar****, Director Education,* ***Dr. A.K. Pandey****, Dean, College of Horticulture and Forestry,* ***Dr. A. R. Sharma****, Director Research,* ***Dr. Sati Shankar Singh****, Director Extension Education and* ***Dr. Mukesh Srivastava****, Registrar, RLBCAU, Jhansi*

I express my sincere special thanks to ***Dr. Ashutosh Singh****, Assistant Professor Biotechnology & Crop Improvement, College of Horticulture & Forestry for extending technical help at every stage standing beside me during the course of this study and*

providing all the necessary resources. My thanks are also due to ***Dr. Shravan Kumar Shukla,*** *Assistant Professor, Basic Science, College of Agriculture, RLBCAU Jhansi.*

I express my thanks and affection to the pillars of my life, ever supporting father Shri. ***Vinod Kumar****, loving mother Smt.* ***Shanti Devi****, dear brother* ***Anil Kumar*** *and sister* ***Deep Verma*** *all the members of my family for their unconditional love and all-time support; without them, I would have not been able to accomplish this success. I sincerely thank* ***Dr. Arjun Lal Ola****, Dr****. Maneesh Pandey, Dr. Devesh Tiwari, Dr. Saurabh Tiwari, Dr Ranjit Pal, Dr. Govind Vishwakarma*** *and other faculty members of Department of Vegetable Science, for their kind co-operation and support.*

Words are inadequate to express my heartfelt gratitude to my seniors ***Arjun Singh,Sidesh*** *and* ***Chetan*** *for their prompt assistance and moral support.*

A special recognition should always be given to some special friends such as ***Anamika Kapoor, Mahima Singh, Pooja Tetarwal, Vikas Kumar, Shreenidhi M.B, Neeraj Kumar, Chinmaya Pradhan, Sakshi Jain, Ajeet Kumar, Rajat Singh, Avneesh Rathour, Shivam Singh*** *and* ***Shubham Maurya*** *for their whole hearted help and support who helped me in this incredible journey and made my pleasant stay at campus, RLBCAU, Jhansi*

I am very much grateful to the Rani Lakshmi Bai Central Agricultural University Jhansi for extending financial support in the form of university scholarship in pursuing my post-graduate program.

Lastly, I offer my regards and blessings to all of those who supported me directly or indirectly in any respect during the completion of this research work.

Place: Jhansi

Date: 27/09/2022

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%	Per cent
<	Less than
>	Greater than
ANOVA	Analysis of Variance
cm	Centimetre
CV	Coefficient of Variation
d.f	Degree of freedom
et al.	And co-workers
g	Gram
GA	Genetic Advance
GAM	Genetic Advance as percent of Mean
GCV	Genotypic Co-efficient of Variation
i.e.	That is
Kg	Kilogram
M	Meter
MSL	Mean sea level
MSS	Mean sum of square
PCV	Phenotypic Co-efficient of Variation
Per se	As such with mean
Via	Through
Viz.,	Namely
Mg	Milligram
@	at the rate of
DAT	Days after transplanting
Sem(+)	Standard error of mean
CD	At 5% Critical difference with significance level of 5%
Fig.	Figure
h^2	Heritability
°C	Degree Celsius
/	Per

Chapter 1 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is widely grown solanaceous vegetable crops after potato throughout the world. Tomato occupies prime position among the other vegetable crops and frequently grown in various climatic condition all over the globe. Tomato is a self-pollinated, annual crop, belongs to Solanaceae family (Jenkins, 1948). In most of the countries of the world, tomato is considered as "***poor man's orange***" due to its improved nutritional value (Saleem *et al*., 2013). Tomatoes are relatively low in antioxidant content in comparison to other vegetable crops, but high level of consumption makes it a physiologically relevant source of antioxidant and other nutritive components (Boches *et al.*, 2011). Because of the sufficient quantity of the antioxidants, both fresh and processed tomatoes associated with the higher capacity of relative oxygen species (ROS) and provide strength for the lowering of the several types of cancer in the human body cells (Capanoglu *et al.*, 2010). Tomato is richest source of vitamin A, ascorbic acid, glutathione and mineral nutrients like Ca, P and Fe. Tomato fruits and products are the potent source of lycopene, the level of lycopene increases 500 times in tomato fruits during ripening (Bai and Lindhout, 2007). Last four decades, studies have shown that consumption of tomato helps to prevent number of cardiovascular diseases (Arab and Steck, 2000; Jarquin-Enriquez *et al.*, 2013).

Wild resources, landraces and elite breeding lines of tomato has well known for traditional taste and resistance power against number of biotic and abiotic stresses. Last three decades, wild cultivars and local landraces of tomato are still excellent resources to broaden the genetic variability and for germplasm enhancement with respect to develop potent tomato cultivars for the commercial cultivation (Ganeva *et al.*, 2014). Enhancement of breeding program includes characterization of tomato germplasm related to major as well as minor traits. Morphological characterization is the primitive step with respect to trait diversity associated with specific traits for the conservation and prevention of genetic resources (Osei *et al.*, 2014; Sacco *et al.*, 2015). Furthermore, the agronomic and biochemical characterization supported by molecular diversity analysis has been proven by several tomato breeders in the varietal identification, diversity analysis and future breeding program for the exploitation of desirable traits (Figas *et al*., 2015). The modern elite

breeding lines and advance breeding lines developed through rigorous breeding and crossing have been successfully increasing the phenotypic diversity throughout the entire tomato germplasm (Miller and Tanksley, 1990). However, tomato germplasm and breeding lines derived from narrow genetic base due to lack of sharing of breeding materials results inbreeding depression and has caused resistance breakdown, poor yield potential (Poland *et al*., 2009), deterioration of fruit quality (Glogovac *et al*., 2012), decreased tolerance to abiotic stresses (Keneni *et al*., 2012). Uses of wild relative and local landraces of the tomato have proven effective in the finding novel gene source for the desirable traits and also in the broadening genetic variations (Corrado *et al*., 2014). Therefore, often the use of wild species is considered very difficult and time-consuming. Hence, characterization of locally adapted and acclimatized germplasm is one of the effective ways to find promising gene sources and utilize them for the creation of improved varieties (Sacco *et al*., 2015).

Crop enhancement is also required for not just improved productivity and also better fruit quality, in addition to uniformity of growing techniques for higher yield. Crop improvement requires a good understanding of the amount of genetic diversity present for distinct characters in order to improve plant features both qualitatively and quantitatively. For a successful crop improvement programme, the knowledge of genetic variation among germplasm and its transmission abilities are crucial (Gepts, 2006). The genetic improvement of a crop is dependent on the genetic variability in the population. As a result, genotypic and phenotypic variance can be used to reveal population diversity. Furthermore, the genetic component of a trait is the only part of variation that is passed down from generation to generation. The phenotypic manifestation of plant attributes is influenced by the genetic makeup of the crop and the ecosystem in which it develops. Furthermore, additive (heritable) and non-additive variance, which includes dominance and epitasis, make up the genetic variation of any quantitative characteristic (non-allelic interaction). As a result, relevant indices such as phenotypic and genotypic coefficients of variation, heritability and genetic progress must be utilized to separate heritable and non-heritable components of observed phenotypic variability. In addition, genetic progress can be used to predict the effectiveness of selection.

Like other crops, the diversity attributed by tomato is due to complexity chain of interrelation of different characters. However, the degree of association between traits indicated by correlation coefficient has always been a helpful instrument for the selection of desirable characters in a breeding program. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection can be based for yield improvement. Correlation coefficient is not adequate to anticipate traits interrelationship leading to yield (McGiffen *et al*., 1994).

In general, the genotypic and phenotypic coefficients of variability (GCV and PCV) are used to examine variability. A study of correlation between distinct quantitative features can reveal patterns of association that can be used to develop selection strategies to enhance yield attributes. Germplasm is the physical foundation of species hereditary traits that are passed down from generation to generation, and it is thought to be a reservoir of variability for many characters. The more varied the breeding material, the better the prospects of developing desirable and promising varieties (Fess *et al*., 2011).

In tomato, there is more scope for further improvement due to the high level of genotype and phenotype diversity in the population. The larger diversity in the breeding material insures the more opportunities for selection of desirable types for the entire germplasm lines (Islam and khan, 1991). Estimates of various genetic parameters and the correlation of various traits are crucial for a better understanding of nature and the extent of genetic diversity present in breeding stock. The yield, as we all know, is a complicated character that is influenced by a variety of factors. Knowledge of the interrelationships between these elements is required for indirect selection of genotypes with better fruit yields by emphasizing each of these characteristics appropriately.

Furthermore, correlation studies are extremely important in tomato breeding. Selective plant breeding approaches could offer significant improvements, if significant correlation values between yield and other economic traits are discovered. Increasing the possible and need for tomato crops, it is necessary to discover and develop varieties/genotypes suitable for production in Bundelkhand agro-climatic conditions.

Though much work has been done on tomato crop enhancement elsewhere, there is very little work done in the Bundelkhand region.

Keeping the above facts in the view, the proposed research entitled "**Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes**" has been planned with the following objectives:

1. **To study the phenotypic and genotypic diversity among tomato germplasm.**
2. **To study the nature of association among yield and yield components traits.**
3. **To study the biochemical parameters in tomato genotypes.**

Chapter 2 REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L.) is one of the most important and widely grown Solanaceous vegetables and originated in South America (Paran and Fallik, 2011). Tomato was first brought to Europe from the Andes in the 16th century. Today, tomato is grown all over the world and it is the most economically important vegetable crop. Tomato is consumed as soups, paste, concentrate, juice and ketchup in addition to being consumed as fresh vegetable. It is an excellent source of vital minerals like lycopene, β-carotene and vitamin C all of which are beneficial to human health (Bergougnoux, 2014; Blanca *et al*., 2015).

Keeping in mind the importance of crops in aspect to breeding the essential and available literature related to the many parts of the current investigations has been discussed under the following heads.

2.1 Genetic variability

Variability may be defined as the amount of variation present among the members of a population or species for one or more characters at genotypic levels. Cockerham (1963) mentioned detailed overview of strategies for estimating genetic variance. Phenotypic variability includes both genotypic and environmental variation, it is sometimes referred to as total variations. Genotypic variation, which refers to genetic or inherent variability and is evaluated in terms of genotypic variance and consists additive, dominant, and epistatic components, and it is unaffected by environmental variables. Standard deviation divided by

mean are used to estimates the genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) and extent of variation in population.

Nature and extent of genetic variability present in the population plays a major role in improving the productivity of tomato (Sowjanya and Sridevi, 2019). The success of any crop improvement programme depends upon the nature and magnitude of genetic variability existing in breeding material with which plant breeder is working, choice of parents for hybridization and selection procedure. Genetic variability is essentially the first step of plant breeding for crop improvement which is immediately available for germplasm and is considered as the reservoir of variability for different characters. Phenotypic and genotypic coefficients of variation are useful in detecting amounts of variability present in germplasm (Sunil *et al.*, 2016). Rai *et al*. (2016) conducted an experiment at YSPUHF, Solan by using 56 tomato genotypes and found the high magnitude of phenotypic coefficient of variation than the genotypic coefficient of variation for all the studied traits. The estimation concluded by Singh *et al.* (2018) with respect to higher magnitude phenotypic coefficient of variance than genotypic coefficient of variance, phenotypic coefficient of variance was high for character like number of fruits per plant, number of locules per fruit, average fruit yield per plant, pericarp thickness and while moderate for number of fruits per cluster, average fruit weight, number of primary branches per plant, polar diameter of fruit, plant height and fruit TSS.

Meena *et al*. (2018) observed that phenotypic coefficient of variation (PCV) was higher than their respective genotypic coefficient of variation (GCV). Phenotypic coefficient of variation was higher for fruit yield per plant followed by ridges on fruit, average fruit weight and branches per plant , whereas, it was moderate for fruits per cluster followed by flowers per cluster, locules per fruit and clusters per plant and low was recorded for fruits per plant followed by pericarp thickness and fruit length and it was lowest recorded for days to 50% flowering and highest genotypic coefficient of variation was observed for fruit yield per plant, ridges on fruit, flowers per cluster and branches per plant.

Ahirwar *et al.* (2013) recorded higher phenotypic co-efficient of variability (PCV) in tomato than the genotypic co-efficient of variability for traits like plant height at 120 days after transplanting, leaves at 120 days after transplanting, branches at 120 days after transplanting,

days to 50% flowering, number of clusters/plant, fruits set (%), fruits/plant, TSS (^{o}Brix), vitamin 'C' (mg.)/100g, fruits weight(g), yield/plant(kg), yield/ ha.(tonnes).

Hussain *et al.* (2021) recorded high PCV, GCV and genetic advance as percent mean for fruits plant per plant, average fruit weight(g), fruit yield per hectare(q), reducing sugar (%), non-reducing sugar (%), total sugars (%), titratable acidity (%) and ascorbic acid content, indicating the additive genetic effect. Phenotypic selection for their improvement could be achieved by simple selection. However Ullah (2015) conducted experiments and observed high genotypic and phenotypic coefficients of variation for fruits per plant, locule number per fruit and fruit yield per plant.

Haydar *et al.* (2007) observed the maximum genotypic variation for fruit weight followed by number of flowers in three clusters/plant and number of fruits in three clusters/plant while the same was minimum for number of leaves at flowering. Phenotypic variation was also maximum for fruit weight and minimum for number of leaves at flowering. GCV and PCV were to be maximum for fruit weight while it was minimum for number of leaves at flowering.

Cholin and Raghavendra (2021) recorded higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV) for majority of the characters studied, indicating influence of the environment on the trait expression. Highest values were recorded for PCV than that of GCV indicating the sensitive of tomato germplasm and cultivars to environmental fluctuations and climatic condition. Thus, selection based on phenotypic performance would not be effective to bring about considerable genetic improvement.

Kherwa *et al.* (2020) recorded high GCV and PCV for total soluble solids, titratable acidity, ascorbic acid content, lycopene content, total carotenoids content, total phenolics content and total antioxidant capacity and found the most of the characters indicating higher magnitude of variability for these characters while total antioxidant capacity showed the highest genotypic and phenotypic variance whereas TSS showed the lowest genotypic and phenotypic variance.

Hazim *et al.* (2016) recorded highest values of genotypic co-efficient of variance (GCV) and phenotypic co-efficient of variance (PCV) for plant height (cm), number of flower cluster/plant, weight of single fruit(g), number of fruits/plant, number of uniform fruits/plant

and weight of fruits/plant(g) and the lowest value of (GCV) and (PCV) were for days to flowering, number of branches/plant and number of deform fruits/plant.

Saleem *et al.* (2013) recorded greater phenotypic coefficient of variation (PCOV) than genotypic coefficient of the variation (GCOV) for days to maturity, plant height (cm), number of fruits per plant, fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg).

Shashikanth *et al*. (2010) observed higher genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PVC) for characters like number of branches per plant, number of fruits per plant, fruit yield per plant and number of locules per fruit indicating higher magnitude of variability for these traits. Kumar *et al.* (2013) also reported the genotypic coefficient of variability (GCV) was high for number of fruits per plant, followed by fruit weight, yield per plant and plant height. Moderate GCV occurred for number of fruits per cluster, fruit length, fruit diameter, pericarp thickness, number of locules per fruit, stem end scar size and number of seed per fruit. The GVC was low for days to first harvest, harvest duration, hundred seed weight and total soluble solids.

Ahmad *et al.* (2016) estimated the high difference between, GCV and PCV for the traits: flowers/cluster, fruits/cluster and fruit weight and relatively low difference for GCV and PCV value in the traits: fruit diameter, fruit length and fruits/plant and highest value of GCV and PCV noted for traits like: yield/plant and the lowest values of GCV and PCV noted for fruit-length.

Kaushik *et al.* (2011) reported higher magnitude of genotypic and phenotypic coefficient of variation for number of leaves, fruit length (cm) and fruit yield.

Kouam *et al.* (2018) conducted an experiment and recorded phenotypic and genotypic coefficients of variation for the quantitative traits viz., collar diameter (mm), primary branches per plant, plant height (cm), single fruit weight (g), fruit diameter (cm), pericarp thickness (cm), 50% flowering (days), 50% fruiting (days), late blight (%), viral diseases (%), alternaria leaf spot (%), fruit/plant, fruit yield (kg/plant). The highest values of these coefficients were

recorded for disease characteristics, yield attributes and the number of primary branches per plant while the lowest values were noted for time to 50% maturity and time to 50% fruiting.

Anuradha *et al.* (2020) reported that, plant height, days to 50 percent flowering, number of fruits per plant, yield per hectare, ascorbic acid, showed very high phenotypic and genotypic variances and number of primary branches per plant, fruit yield per plant, total soluble solids, lycopene content revealed low phenotypic and genotypic variances.

Reddy *et al.* (2013) recorded higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV) for number of clusters per plant, number of fruits per plant, fruit weight, fruit yield, acidity and shelf life and high PCV and moderate GCV observed for number of primary branches per plant, ascorbic acid and TSS.

Shankar *et al.* (2013) obtained high estimates of PCV and GCV for plant height, number of fruits per cluster, average fruit weight, yield per plant, titrable acidity, ascorbic acid and lycopene and moderate PCV and GCV values for number of primary branches, fruit length, fruit width, number of locules per fruit, pericarp thickness and shelf life, low PCV and GCV for days to 50% flowering.

Kumar and Reddy (2016) observed high GCV and PCV for fruit volume, average fruit weight, yield per plant, number of branches at 60 days after transplanting, polar diameter, pericarp thickness, number of locules per fruit, number of fruits per plant, number of seeds per fruit, thousand seed weight, lycopene content, β-carotene content, ascorbic acid content, TSS: Acid ratio and suggested these characters having higher range of variation. Hence, have better scope of improvement through selection.

Prajapati *et al.* (2015) recorded highest genotypic coefficients of variations (GCV) and phenotypic coefficient of variation (PCV) for average fruit weight, number of seeds/fruit whereas the lowest were recorded for days to 50% fruit setting. Higher GCV and PVC were recorded for most of the characters indicating higher magnitude of variability for these characters and high genotypic variance for most of the characters indicating scope for genetic improvement. Kumari *et al.* (2021) conducted an experiments, using twenty genotypes and found higher magnitude of GCV and PCV for acidity, TLCV incidence, locules/ fruit and

shelf life and observed highest range of variability for plant height, followed by fruit/plant, days to first flowering, days to 50% flowering, average fruit weight, ToLCV incidence, ToLCV severity, ascorbic acid, branches/plant, flower/cluster, flower cluster/plant, fruit set/cluster, fruit yield/ plant, locules/fruit, pericarp thickness, fruit shape index, TSS, lycopene and shelf life.

Ghosh *et al.* (2010) conducted an experiment and studied 12 characters and found the phenotypic variance and phenotypic coefficient of variation was higher than genotypic variance and genotypic coefficient of variation, for most of the yield contributing characters studied except days to first flowering, fruit length and fruit diameter.

Narayan *et al*. (2020) observed high estimate of GCV and PCV for the traits namely plant height, number of fruits per plant, average fruit weight and yield per plant, fruit firmness, red colour, yellow colour, chroma, hue angle, ascorbic acid, acidity and total antioxidant activity. Most of the trait under study exhibited very good scope for improvement through selection.

Mohamed *et al.* (2012) observed high genotypic variance for most of the characters indicating more contribution of genetic component for the total variation. Genotypic coefficients of variations (GCV) and phenotypic coefficient of variation (PCV) were highest for fruit weight and whereas the lowest ones were for days to 50% flowering.

Hasan *et al.* (2016) conducted an experiment and observed that number of fruits per plant exhibited high estimates of PCV, GCV followed by individual fruit weight, plant height and number of fruit cluster per plant. The lowest PCV and GCV values were recorded for TSS contents. Anuradha *et al.* (2020) conducted an experiment using 40 genotypes of tomato and recorded significant differences among genotypes for all characters. In this investigation the high genetic variability was observed for the characters viz; number of primary branches per plant, number of fruits per plant, average fruit weight, fruit yield per plant.

Behera *et al.* (2020) estimated phenotypic (PCV) and genotypic (GCV) coefficients of variation for plant height, fruits/plant, fruit girth, fruit pericarp thickness, root volume, total chlorophyll content and total fruit yield/ha. The highest and lowest values of PCV and GCV were for total chlorophyll content and days to 50% flowering, respectively.

Bamaniya *et al.* (2020) observed high phenotypic coefficient of variation and genotypic coefficient of variation for characters such as plant height at 30 days after transplanting followed by fruit yield per plot (kg), fruit yield per plant (g), fruit yield per ha (q), number of flower clusters per plant, number of fruits per picking (115 days after transplanting), number of fruits per picking (90 days after transplanting). High genotypic coefficient of variation was observed for number of flower clusters per plant, fruit yield/ plant and fruit yield/plot, followed by fruit yield/ha and number of flowers per cluster.

Basavaraj *et al*. (2020) conducted an experiment at Karnataka using 30 genotypes and recorded higher GCV and PVC for characters like average fruit weight, number of fruits per plant, number of fruits per cluster, equatorial diameter, yield per plant and number of branches per plant.

Chaudhari *et al.* (2019) recorded high phenotypic and genotypic coefficient of variability values for the traits such as number of fruits per plant and test seed weight, average fruit weight, yield per plant, plant height and number of locules per fruit. Eppakayala *et al.* (2021) recorded high PCV and GCV were for plant height, days to first flowering, days to 50% flowering, number of flowers per cluster, number of fruits per plant, per cent fruit set, number of marketable fruits per plant, days to first harvest, days to last harvest and fruit weight suggested the wider influence of genetic traits in the genotypes.

Dutta *et al.* (2018) observed higher phenotypic coefficient of variations in the tomato germplasm corresponding genotypic coefficient of variations for characters like plants height (cm), primary branches per plant, days to first flowering, flower cluster per plant, flower per cluster, number of fruits per plants, average fruit weight (g), equatorial diameter of fruit (mm), polar diameter of fruit (mm), pericarp thickness (mm), locules number per fruit, TSS content (^{o}Brix), total sugar content (%), reducing sugar content (%), titrable acidity (%), ascorbic acid (mg/100 g fresh), lycopene content (mg/ 100 g fresh), β-carotene content (mg/ 100 g fresh) which indicated that the apparent variation was not only due to genotypes but also due to the influence of environment in the expression of the traits

Maurya *et al.* (2020) carried out an experiment and recorded high values of GCV and PCV for characters viz., number of fruits per plant, number of locules per fruit, average fruit weight,

fruit yield per plant, fruit yield per plot, plant height, number of fruit set per cluster, TSS(^{0}Brix). Moderate GCV and PCV were observed for traits viz., number of flowers per cluster, ascorbic acid. Low GCV and PCV were observed for traits viz., days to first flowering and days to 50% flowering.

Meena and bahadur (2014) estimated higher phenotypic coefficient of variation (PCV) than their respective genotypic coefficient of variation (GCV) for all the traits under study. Phenotypic coefficient of variation was higher for fruit yield per plant followed by ridges on fruit, average fruit weight and branches per plant.

Heritability and Genetic advance

Rai *et al.* (2016) observed high estimates of heritability and genetic gain for number of fruits per plant, average fruit weight, fruit yield per plant, locular wall thickness and lycopene content. Ahirwar *et al*. (2013) reported significant genetic advance for plant height, number of fruits per plant, ascorbic acid and fruit yield per plant (g). Whereas genetic advance as per cent of mean at 5 per cent was noticed high for all the traits except days to flower initiation and days to first harvest.

Ahmad *et al*. (2016) reported highest value of broad sense heritability (Hb) in fruit diameter followed by fruits/plant and fruit length and suggested that additive gene action is involved in the traits and influence of environment was less. Lowest value of heritability was noted for the trait fruits/cluster. Flowers/cluster and fruit weight also showed relatively lower value of heritability. Genetic advance was highest in fruits/plant among all the traits.

Al-Aysh *et al*. (2012) observed high heritability in broad sense for all the characteristics studied except days to first flowering. Genetic advance as percentage of mean was high for plant height, number of primary branches per plant, number of fruits per plant, number of fruits per cluster, average fruit weight and fruit yield per plant.

Singh *et al*. (2018) reported high heritability coupled with genetic gain for number of fruits per plant, average fruit weight, number of locules per fruit and average yield per plant. high

heritability for characters like average fruit weight, plant height, number of fruits per plant, average yield per plant, days to first fruit harvest and number of locules per fruit while moderate heritability for polar diameter of fruit, days to last fruit harvest, fruit TSS and equatorial diameter of fruit. They observed that low values of heritability in fruit pH, number of fruits per cluster, number of primary branches per plant and pericarp thickness.

Somraj *et al.* (2017) estimated the heritability and genetic advance as per cent of the various phenotypic traits directly associated with the major yield attributing traits like 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.

Meena *et al*. (2018) reported the highest heritability for fruit yield per plant followed by ridges on fruit, plant height, TSS, flowers per cluster, pericarp thickness, fruits per plant, fruits per cluster, fruit clusters per plant and branches per plant, whereas, minimum was recorded for vitamin - C. They reported the maximum genetic advance (%) for the traits like fruit yield per plant, ridges on fruit, average fruit weight, flowers per cluster, fruits per cluster, branches per plant, locules per fruit, fruits per plant, pericarp thickness, TSS, whereas, minimum was recorded for days to 50% flowering.

Khuntia *et al.* (2017) recorded highest estimate of heritability coupled with high genetic advance for plant height, number of fruits per cluster, number of fruits per plant, fruit setting percentage, individual fruit weight, number of harvests, yield per plant, fruit firmness, flesh thickness, number of locules per fruit, shelf life, lycopene and β-carotene.

Kumar *et al*. (2017) recorded high heritability coupled with high genetic advance as per cent over mean for yield per plant, fruit pericarp thickness and fruit equatorial diameter. They also suggested that selection for the major traits may be highly effective as these traits are less influenced by environment. Similarly, a joint consideration of heritability, GCV and genetic advance revealed high value for yield per plant, fruit pericarp thickness and leaf length. Similarly, Dixit and Pandey (2017) observed high estimates of GCV, PCV, heritability (broad

sense) along with high genetic advance for number of fruits per plant, early yield per plant and total yield per plant indicating thereby presence of large amount of variability and additive gene action for expression of these traits. Hence, selection for these traits will be effective, however for other traits hybridization followed by selecting desirable transgressive segregants will be better options for genetic improvement of tomato.

Kherwa *et al.* (2019) high heritability coupled with high genetic advance were recorded for all traits except for TSS and suggested that, these traits which exhibited high heritability in broad sense and high expected genetic advance as percent of mean may be considered to be largely governed by additive gene action therefore; it could be effectively improved through selection.

Kaur *et al.* (2019) estimated high values of heritability for average fruit weight, number of fruits per plant, yield per plant, plant height and total soluble solids indicating that these traits were least affected by environmental modification and selection based on above parameters would be reliable. High genetic advance was observed for yield per plant, number of fruits per plant, average fruit weight and plant height. High heritability with low genetic advance was reported for number of fruits per plant.

Mohamed *et al.* (2012) reported highest heritability with an expected genetic advance for plant height followed by number of fruits per plant, number of branches per plant, days to 50 % flowering, number of fruits per cluster and number of flowers per inflorescence, while the lowest heritability was that of fruit yield per plant.

Gopinath and Vethamoni (2017) observed high estimates of heritability with high genetic advance as percent over mean for fruit yield per plant, individual fruit weight, pericarp thickness and number of primary branches per plant.

Singh *et al.* (2015) reported high heritability along with high genetic advance in per cent of mean for all the traits except days to 50 per cent flowering. Fruit yield per plant followed by average fruit weight, number of locules per fruit, number of fruits per plant and plant height were the top five traits which showed high level of genetic advance indicating opportunity for better selection response.

The findings of Saeed *et al.* (2007) obtained highest heritability for number of fruits/plants followed by number of flowers/plants reflecting on the effectiveness of selection in the tomato germplasm with respect to future breeding program for the improvement.

Khanom *et al.* (2008) reported that high heritability estimates coupled with high genetic advance for number of primary branches per plant, number of days to first flowering, plant height, number of bunches per plant, number of fruits per plant, individual fruit weight and number of seeds per fruit indicating wide scope for improvement through selection of these traits.

Prajapati *et al.* (2015) estimated the highest heritability for average fruit weight (99.92), number of secondary branches (99.65%), while the lowest was recorded for the test weight (45.29%). Highest genetic advance as per cent of mean was recorded for average fruit weight (100.59%) and lowest for days to 50% fruit setting (2.89). Maximum heritability and genetic advance were recorded for average fruit weight, number of seeds per fruit respectively.

Kaushik *et al*. (2011) recorded high values of heritability coupled with high genetic advance for number of leaves at 60 days after transplanting and fruit yield. Behera *et al*. (2020) also reported the high degree of heritability total chlorophyll content, total fruit yield, root volume, pericarp thickness, plant height and number of fruits per plant. Genetic advance was highest for total chlorophyll content, number of fruits per plant and total fruit yield. Therefore, total chlorophyll content and number of fruits were the important components and could be utilized for achieving maximum yield.

Anuradha *et al*. (2020) obtained high heritability coupled with high genetic advance as per cent of mean indicating additive gene action for character like plant height, number of primary branches per plant, days to 50% flowering, days to fruit set, number of fruits per plant, average fruit weight, fruit yield per plant, yield per hectare, ascorbic acid content, TSS, β-Carotene and lycopene content which may be exploited for improvement.

Kavyashree *et al.* (2017) recorded 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, dry matter content, pericarp thickness and fruit yield per plant.

Saravanan *et al*. (2019) observed high PCV, GCV and genetic advance for yield per plant, number of fruits per plant and number of locules per fruit indicating the additive genetic effect. These traits may be utilized in selection for improvement.

Chadha and Walia (2016) obtained high heritability along with high genetic advance for traits *viz.*, total fruits per plant, and marketable fruits per plant and marketable yield per plant. The finding concluded with high to moderate heritability coupled with high to moderate genetic advance indicated preponderance of several additive gene actions which implied that these traits could be improved by pure line selection. Whereas, recombination breeding will prove effective in improving the traits viz., days to first harvest, pericarp thickness, duration of fruit harvest and total soluble solids.

Kumar and Reddy (2016) reported the high heritability along with high genetic advance as per cent of mean for the yield attributing traits like plant height, fruit length, fruit width, average fruit weight, fruit yield per plant, pericarp thickness, total soluble solids, titrable acidity, ascorbic acid content, total sugars, reducing sugars and lycopene content. Hence, capitalizing these traits in selection could be effective for desired genetic improvement.

Sajjan (2016) observed high heritability combined with high genetic advance for average fruit weight (g), number of branches per plant, number of fruits per plant, plant height(cm), fruit yield per plant (kg), total soluble solid, number of locules/fruit and pericarp thickness (mm).

Kumar *et al.* (2014) reported high heritability along with high genetic advance for all the traits except days to 50 per cent flowering. Fruit yield per plant followed by average fruit weight, number of locules per fruit, number of fruits per plant and plant height were the top five traits which showed high level of genetic advance indicating opportunity for better selection response.

Hasan *et al.* (2016) achieved high heritability along with high genetic advance for the traits *viz.*, individual fruit weight, fruits per plant and plant height. These traits can be improved through simple or progeny selection methods.

Bhandari *et al.* (2017) stated that the trait fruit yield (kg)/plant recorded the maximum heritability followed by number of fruits/clusters. Important yield traits like average fruit weight, number of fruits/plant, number of seeds/fruit and fruit yield (kg)/plant revealed high heritability coupled with high genetic advance as percentage of mean.

Correlation studies

Rajoli *et al*. (2017) reported in correlation study that the parameters *viz.,* plant height, number of branches per plant, number of fruits, average fruit weight, fruit length and fruit width have strong association with yield. Therefore, to increase the yield in tomato selection for above mentioned traits can be carried out. And the plant height at first harvesting was positively and significantly associated with fruit yield per plant followed by number of branches per plant, number of fruits per plant, fruit width and average fruit weight. It also had positive and significant correlation with fruit length whereas, number of branches at first harvesting had significant positive association with fruit yield per plant followed by number of fruits per plant, fruit width, and average fruit weight.

Sushma *et al*. (2020) noticed in correlation coefficient studies a 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. Kumari and Dogra (2021) reported that fruit yield per plant, days to marketable maturity, plant height, fruits per cluster, average fruit weight, pericarp thickness and harvest duration have positive and significant correlation with fruit yield per plant.

Mahapatra *et al*. (2013) observed positively significant association fruit yield with other yield attributing traits like plant height, number of primary branches per plant, number of flower clusters per plant, number of fruits per plant, fruit length, fruit width, pericarp thickness, number of locules per fruit, average fruit weight and fruit yield per plant. They also reported that increase in plant height, were corresponding to number of primary branches per plant, days to 50% flowering as well as number of flower clusters per plant.

Anuradha *et al*. (2018) reported the highly significant correlation for the traits like fruit yield per plant, fruit weight and yield per hectare and also for the biochemical characters β-carotene and lycopene.

Shashikanth *et al.* (2012) reported that fruit yield had a positive and highly significant association with number of fruits per plant and number of branches per plant. Strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield.

Prashanth *et al*. (2008) observed inverse relationship between growth and earliness characters but strong association between growth and yield characters. Total yield per plant was positively and significantly associated with early yield per plant, equatorial diameter of the fruit, fruit volume, average fruit weight, polar diameter of the fruit, number of fruits per plant, per cent fruit set, stem girth at 90 days after transplanting, number of locules per fruit, plant height at 60 days after transplanting, pericarp thickness and number of seeds per fruit. Total yield per plant was negatively and significantly associated with number of flowers per cluster and number of fruits per cluster.

Reddy *et al.* (2013) observed that fruit yield per plant was positively and significantly correlated with number of fruits per plant and fruit width. However, fruit yield per plant was negatively and significantly correlated with days to last fruit harvest and shelf life.

Kumar *et al.* (2014) reported that fruit yield per plant had highly significant with positive association on the major agronomic traits like number of fruits per plant, number of primary branches per plant, plant height, pericarp thickness, average fruit weight and fruit diameter. While, days to 50 per cent flowering showed negative and significant association with yield per plant.

Gopinath *et al.* (2017) estimated the correlation and reported that yield had positive significant association with plant height, number of flowers per cluster, percent fruit set, fruit length, fruit diameter, individual fruit weight and number of fruits per plant. Islam *et al*. (2010) observed that yield per plant was found to be highly significant and positively correlated with flowers

per plant, fruits per plant, fruit length, fruit diameter and individual fruit weight which indicated that yield could be increased by combining these traits.

Khapte *et al.* (2014) reported the correlation analysis in tomato revealed that per cent fruit set, number of primary branches, number of fruits per plant, average fruit weight, total soluble solids, fruit length, fruit firmness, number of flower trusses per plant and pericarp thickness were positively and significantly associated with yield per plant.

Das *et al.* (2017) concluded with the traits like number of flower clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant had positive significant correlation with fruit yield per plant and number of flower clusters per plant, number of fruits per cluster, number of flowers per cluster, number of fruits per plant, fruit yield, polar diameter, equatorial diameter, TSS, ascorbic acid and germination percentage of seed had positive significant correlation with seed yield per plant. Sharma *et al.* (2019) reported the significant positive association of higher yield with the traits viz., number of marketable fruits/plants, plant height, intermodal length and average fruit weight.

Mishra and Nandi (2018) concluded in association studies that in tomato ascorbic acid content was positively correlated with days to first flowering, days to 50% flowering, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, length of fruits, pericarp thickness of fruit, number of locules per fruit and TSS of fruit. However, ascorbic acid content per fruit was negatively correlated with diameter of fruits, plant height, total number of branches, average fruit weight, yield per plant and acidity content.

Shivani and Dhirendra (2018) observed the fruit yield per plant was having positive significant correlation with days to fifty per cent flowering, fruit density, titratable acid, fruit infected with insect whereas, it is negative significantly correlated with acidic acid, fruit damage with insect and plant infected with disease. However, fruit yield per ha had positive significantly correlated with number of node first flower.

Kaushal *et al.* (2017) reported that yield per hectare displayed positive correlation with number of fruits per plant, pericarp thickness, number of locules per fruit, average fruit weight, ascorbic acid content and yield per plant.

Rasheed *et al*. (2017) conducted an experiment on tomato hybrids and their parents using eight parents and 15 F_1s and he found that branches per plant, height of the plant, clusters per plant, fruits per cluster, flowers per cluster, fruit set per cent, number of cluster and weight of a single fruit showed significant correlation with yield of fruit per plant at genotypic level and highly significant at phenotypic level and these characters could be used as selection criteria for enhancement of yield per plant in tomato.

Venkadeswaran *et al*. (2021) recorded the yield per hectare with positive and significant association at phenotypic level with the traits like number of primary branches per plant at final harvest, number of flowers per cluster, fruit width and weight of seeds per fruit, fruit firmness, total soluble solids and total carotenoids. Hence, these traits may lead to the development of high yielding genotypes of cherry tomato. Sharma *et al*. (2021) found fruit yield had a positive significance correlation associated with traits like average fruit weight, fruit length, number of fruits per plant, plant height at 120 days after transplanting, days to 50% flowering and number of days to first picking. Strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield. Hence, due weightage should be given to these characters while selecting the germplasm in crop improvement

Jogi *et al.* (2018) revealed that yield per plant exhibited significant and positive association with number of branches per plant, fruit width, 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.

Kousar *et al.* (2021) reported that plant height had highly positive correlation with number of branches, clusters per plant, fruit weight and number of lobes in a fruit. A highly positive correlation was observed for number of branches per plant with fruit clusters per plant, fruits per cluster, fruit weight, fruit shape and number of lobes. Fruit clusters per plant had a positive correlation with fruits per cluster, fruit weight, fruit shape, fruit length and number of lobes.

A highly significant correlation was observed for number of fruits per cluster with fruit yield per plant, fruit weight, fruit shape and number of lobes. Fruit yield per plant showed highly significant and positive correlation with fruit weight and number of lobes. Correlation of fruit weight with fruit length was positive and highly significant while fruit weight, fruit shape and number of lobes expressed significant association.

Path Coefficient analysis

Path coefficient analysis method was devised by Dewey and Lu (1959) which helps in partitioning the correlation coefficient under direct and indirect effects which permit a critical examination of the relative importance of each trait. In order to understand such effects of different independent characters or in combination with other characters on yield, the estimates of direct and indirect effects were computed through path coefficient analysis in the present investigation. The path-coefficient analysis is a powerful method in analyzing the scheme of causal relationship between yield and its component traits. Here, the correlations are partitioned into direct and indirect effects to know the precise direct and indirect cause of associations (Thapa *et al.*, 2016). Singh *et al.* (2018) in path coefficient analysis found average fruit weight exhibited very 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.

Kumar *et al.* (2014) carried out path coefficient analysis at phenotypic as well as genotypic levels and it indicated high positive direct effects on number of fruits per plant, pericarp thickness and fruit diameter on fruit yield per plant. This indicates that direct selection for number of fruits per plant, pericarp thickness and diameter of fruit in desired direction would be very effective for yield improvement

Sushma *et al.* (2020) in path coefficient analysis observed that the traits like average fruit weight and number of fruits per plant had positive correlation with yield as well as they have direct effect on yield. Hence these traits can be used for selection in for improvement in yield.

Anuradha *et al*. (2018) revealed that path analysis of the traits like number of fruits per plant and average fruit weight exhibited positive direct effects on fruit yield and these traits also recorded positive correlation with yield. This suggested that direct selection based on these

traits will be rewarding for crop yield improvement. The findings of Prashanth *et al*. (2008) similarly indicated that path analysis for the yield and average fruit weight had high direct positive effects on total yield. Hence, direct selection for early yield and average fruit weight is suggested for yield improvement.

Shashikanth *et al.* (2012) observed in path coefficient analysis that the major yield attributing traits in the tomato like number of flowers per cluster and number of branches per plant had the highest positive direct effect on fruit yield both at genotypic and phenotypic levels and most the fruit related traits contributed of fruit yield mainly through number of branches. Hence, it would be essential to lay stress on these characters in selection programmes aiming at increasing the yield.

Maurya *et al.* (2020) reported that path coefficient analysis indicated highest positive direct effect on the yield, days to 50% flowering followed by fruit width, total soluble solids and average fruit weight. Furthermore, the phenotypic path coefficient analysis revealed that maximum positive direct effect on fruit yield (q/ha) contributes maximal fruit weight followed by number of fruits per plant, number of primary branches per plant, plant height and total soluble solids. However, negative direct effect towards fruit yield per plant was reported by fruit length and pericarp thickness. Genotypic path coefficient analysis revealed that maximum positive direct effect towards fruit yield (q/ha) was contributed by average fruit weight followed by number of fruits per plant, number of seeds per fruit, number of primary branches per plant, plant height and days to first flowering. However, negative direct effect towards fruit yield per plant was contributed by fruit width, fruit length, and pericarp thickness.

Islam *et al.* (2010) reported that fruits per plant had direct positive effect on yield per plant followed by individual fruit weight. On the other hand, the highest negative direct effect on yield per plant showed by days to first flowering followed by fruit length. 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 selection based on these characters.

Kumar *et al.* (2014) reported that number of fruits per plant, pericarp thickness and fruit diameter were identified as most important traits which contributed considerable positive direct effect on fruit yield per plant. The negative direct effects on fruit yield per plant were exhibited by total soluble solids and number of locules per fruit. Substantial positive indirect effects on fruit yield per plant were exerted by number of primary branches per plant, plant height and total soluble solids via number of fruits per plant.

Walia *et al.* (2018) carried out Path coefficient analysis and reported that in the tomato germplasm and cultivars fruits per plant had the maximum positive direct contribution towards marketable yield per plant followed by average fruit weight. Thus, it suggested that direct selection based on these traits would be helpful for developing the high yielding varieties.

Renuka *et al.* (2017) observed that genotypic path coefficient analysis for fruit yield per plant was directly and positively influenced by number of fruits per plant, locules per fruit, pericarp thickness, number of primary branches, indicating that these are the real independent characters and have maximum contribution towards increase in fruit yield. Hence this character may be simultaneously selected to develop the high yielding varieties.

Nevani and Sridevi (2021) estimated the path analysis and revealed that number of fruits per clusters and average fruit weight had positive direct effects on fruit yield while these traits recorded positive correlation with yield.

Rathod *et al*. (2016) concluded that path coefficient analysis indicated highest positive direct effect of number of fruits per plant on fruit yield per plant followed by average fruit weight. Hence, direct selection for these traits is possible for improving fruit yield per plant.

Rawat *et al.* (2017) found that the number of fruits per plant had highest positive direct effect on fruit yield followed by average fruit weight. Buhroy *et al.* (2017) analyzed path analysis revealed number of clusters per plant exerted very high direct effect upon yield per plant followed by individual fruit weight and root fresh weight.

Rajoli *et al.* (2017) reported that path analysis revealed number of fruits per plant followed by plant height, average fruit weight, number of branches per plant, pericarp thickness, fruit length, number of locules per fruit and ascorbic acid had direct positive effect on yield per

plant while other parameters like fruit width followed by fruit firmness, total soluble solids, days to first anthesis and pH showed direct negative effect.

Reddy *et al.* (2013) concluded through path coefficient analysis that effective relationship on the phenotypic traits like plant height, number of fruits per plant, fruit length, fruit width and ascorbic acid had high positive direct effects on fruit yield per plant. The finding indicated that direct selection for these traits will be beneficial for improving of fruit yield per plant.

Hasan *et al.* (2016) estimated that path coefficient analysis on the individual fruit weight, days to first flowering, number of fruit cluster, number of fruits per plant, days to first harvest and ascorbic acid had direct positive effect on yield per plot.

Kumar *et al.* (2021) observed in path coefficient analysis the major yield attributing traits of tomato like fruit per plant, fruit width, plant height, fruit length, days to maturity showed maximum positive direct effect on yield and days to flowering showed minimum positive direct on yield. Number of branches per plant, number of locules per fruit showed negative direct effect on yield. Number of locules per fruit show maximum negative direct effect on yield and number of branches per plant showed minimum negative direct effect on yield.

Akhter *et al.* (2021) reported that path coefficient analysis showed direct positive effect of days to first flowering, clusters per plant, fruits per plant and yield per plant on yield per hectare. findings of Sushma *et al*. (2020) showed that path coefficient analysis in tomato for the characters like number of fruits per plant, average fruit weight, fruit width, ascorbic acid, total soluble solids and lycopene content had high positive direct effects on fruit yield per plant would more helpful in identification and selection programme of high yielding genotypes in tomato.

Kumari *et al*. (2021) reported the maximum positive direct effect towards fruit yield per plant was contributed by average fruit height, followed by days to 50 % flowering, number of fruits per cluster and harvest duration. The other characters which showed positive direct effect were number of fruits per plant, total soluble solids, days to marketable maturity, pericarp thickness, fruit shape index and ascorbic acid. Plant height and number of locules per fruit had negative direct effect on fruit yield per plant. Days to physiological maturity and pericarp thickness

have been recorded maximum with positive indirect effect on the average fruit weight and fruit yield. Moreover, the harvest duration exerted maximum positive indirect effect via days to 50 % flowering, number of fruits per plant exerted maximum positive indirect effect via number of fruits per cluster and days to 50 % flowering recorded maximum positive indirect effect via harvest duration.

Mahapatra *et al.* (2013) concluded that the number of primary branches per plant, number of flower clusters per plant, number of fruits per plant, fruit length, fruit width, pericarp thickness, average fruit weight and number of seeds per fruit exhibited positive direct effects towards yield and these traits also recorded positive significant correlation with yield. This suggested that direct selection based on these traits will be rewarded for crop improvement. Similarly, Reddy *et al.* (2013) also revealed that the 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 Jansirani *et al.* (2014) reported that the path analysis revealed that average fruit weight had the high positive direct effect on yield per plant followed by number of fruits per plant.

Gopinath and Vethamoni *et al.* (2017) found that the number of fruits per cluster and number of fruits per plant exerted highest positive direct effect on fruit yield per plant. Direct selection may be executed considering these traits as the main selection criteria to reduce indirect effect of other characters during development of high yielding tomato variety. Similarly, Kaushal *et al.* (2017) reported the positive effect on fruit yield per hectare was exerted by traits like yield per plant, number of flowers per inflorescence, number of locules per fruit, ascorbic acid content, percentage acidity, fruit diameter, plant height and total soluble solids. The findings suggested that average fruit weight, number of fruits per plant, number of locules per fruit and percentage acidity should be considered as important characters for improvement of tomato through selection.

Mishra and Nandi (2018) carried path analysis studies and concluded traits like number of fruits per plant, number of locules per fruit and number of flowers per cluster had high positive direct effects on ascorbic acid content per fruit. Therefore, direct selection for these traits is done for improving ascorbic acid content of fruit. Sharma *et al.* (2019) concluded in path coefficient analysis that number of marketable fruits/plants had the maximum direct contribution towards marketable yield/plant followed by average fruit weight and fruit shape index. These traits may be given more emphasis for direct selection of high yielding tomato genotypes in future breeding programmes.

Chapter 3 MATERIALS AND METHODS

The present investigation entitled **"Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes"** was carried out at Research Farm (Block B-7-b) and Laboratory of the Department of Vegetable Science, Rani Lakshmi Bai Central Agricultural University, Jhansi during *rabi* season of the year 2021-2022 Experiment comprises 24 tomato genotypes including released varieties, working germplasm, elite breeding lines and commercial tomato hybrids. Experiment was conducted in randomized block design in 3 replications with proper agronomical practices. The details of the experimental procedures, materials and method, observations and statistical methods or techniques adopted during the course of the investigation are presented in this chapter.

3. Details of experiments

3.1 Location of the experimental site and climate

The Present experiment was conducted at Research Farm (Block B-7-b) and Laboratory of the Department of Vegetable Science, Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh. All the physical facilities including farm machinery, irrigation facility was sufficiently available in research farm to conduct the experiment successfully. Jhansi comes under Bundelkhand Agro climatic Zone (6) of Uttar Pradesh and located at latitude of 25. 27° N latitude and longitude of 78.037° E longitude and is about 271 meters from mean sea level. The average annual rainfall of the district is 884.6 mm and 90 per cent is received during monsoon season. (Sandhu *et al.*, 2016)

3.2 Climate and weather conditions

The climate of the Jhansi is semi-arid and subtropical, with hot and dry winds in the summer, warm humid weather in the monsoon period and cold dry weather in the

winter. Summer temperatures range from 40 to 45°C, while winter temperatures drop to below freezing with frost. Winter and summer are both severe. The average annual rainfall in this area is 850 mm to 1000 mm, with around 90% of it happening between July and September. A little over 60% of the area is cultivated, but compared to other parts of Uttar Pradesh, the sub-zone has less developed irrigation facilities. The soil erosion is high and land productivity is low. The climatic condition during the experimental period was optimum for healthy plant growth.

3.3 Experimental details

The particulars of the present experiment are given below (Table 3.1)

Table 3.1 Experiment details:

1.	**Name of the experiment**	"Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes"
2.	**Crop**	Tomato (*Solanum lycopersicum* L.)
3.	**No. of genotypes**	24
4.	**Location**	Research Farm, RLBCAU, Jhansi,
5.	**Season and year**	*Rabi*, 2021-22
6.	**Experimental design**	Randomized Block Design (RBD)
7.	**Replications**	3
8.	**Spacing**	60×60 cm
9.	**Plot size**	3 m x 2.4 m = 7.2 m
10.	**Package of practices**	Recommended package of practices

3.4 Experimental material

The experimental materials utilized in this investigation comprise 24 diverse genotypes of tomato collected from different sources across the country including

public institutes and private seed companies. A list of the genotypes used in this study is given in table (3.2).

3.5 Raising of crop nursery

Seeds of all the 24 genotypes were treated with Capton (2g/kg of seed) prior to sowing. The seedlings were raised in outdoor nursery beds. In the last week of October, 2021 seeds were sown. To encourage germination, the beds were kept moist and beds were covered with grass mulches. Soon after seedlings emerged, proper care was taken for growth of healthy seedlings. Seedlings became ready for transplanting in the last week of November, 2021.

3.6 Cultural practices

The subsequent cultural practices were followed in the experimental field throughout the crop duration as per the recommended package of practices.

3.6.1 Field preparation

The experimental field was ploughed repeatedly to achieve a fine tilth, and the recommended dose, about 20 tonne farmyard manure, 100kg N, 70kg P_2O_5 and 60kg K_2O/ha applied. Farm yard manure, as well as full doses of phosphorus and potassium, and one-third dose of nitrogen, was applied at the time of field preparations. The remaining nitrogen was supplied in two split doses, one at the time of earthling up (20 days after transplanting) and the other 45 days later. The entire field was divided into small experimental blocks and ridges and furrows were made at a distance of 60 cm.

3.6.2 Transplanting of seedlings

On November 23rd, 2022, the seedlings were transplanted in the main field in a randomized block design with three replications. Seedlings were transplanted during the evening period on sides at the base of ridges at a spacing of 60 cm apart and subsequently light irrigation was given.

Table 3.2 List of tomato genotypes used in the study and their source:

S.no.	Genotypes	Features	Source
T1	Kashi Aman	The fruits are round firm with a pericarp thickness of 0.52-0.57cm. Average fruit weight ranges from 80-110 g with an average locules number of 3-4.Average yield 50-60 tonnes/ha. Resistant to ToLCV.	ICAR-IIVR, Varanasi
T2	Kashi Adarsh	The fruits are round and very firm with a pericarp thickness of 6 mm. Average fruit weight ranges from 80-115 g with 3-4 locules. Average yield potential of 60 tonnes/ha.	
T3	Kashi Amrit	Fruits are round, attractive red and fleshy with an average weight of 108 g. Average yield of 620 q/ha.	
T4	Kashi Anupam	Determinate, fruits large, flatish round attractive red with 5-6 locules, medium maturity (75-80 days after transplanting); yield 500-600 q/ha.	
T5	Kashi Vishesh	Determinate, dark green, fruits red, spherical, size medium to large, weight of 80 g, first harvest at 70-75 days after transplanting; yield 400-450 q/ha.	
T6	Kashi Hemant	Determinate growth habit, fruits attractive red and round, weight varies from 80 to 85 g; yield 400-420 q/ha.	

T7	H-88-78-2	It has an indeterminate growth habit and shows moderately resistant to disease reaction due to its slow growth habit.	ICAR-IIVR, Varanasi
T8	Pusa Ruby	Early maturing, fruits a have yellow stem end, slightly furrowed with uniform ripening. Average yield is 32.5 t/ha. It is suitable for table as well as processing purpose.	IARI, New Delhi
T9	Pusa Uphar	Plants are indeterminate, prolific bearer, upright fruits in bunches with 4-6 fruits per bunch, Average yield 370 q/ha.	
T10	Pusa Sadabahar	Determinate, thermo insensitive, fruit set takes place almost round the year, both hot and cold set, Maturity in 60 days. Average yield 350 q/ha.	
T11	Pusa Gaurav	Dwarf stature, bushy with moderate foliage cover. Fruits are smooth, borne in clusters, higher TSS (6%), It has average yield potential of 330-350 q/ha.	
T12	Pusa 120	Semi determinate, spreading, late maturing with dark green foliage. Fruits are flattish round, attractive, less acidic, less seeded, Average yield 300- 320 q/ha.	
T13	Arka Vikash	Fruits are medium large (80-90 g), oblate with light green shoulder, Average yield 35 t/ha. Adopted to both rainfed and irrigated conditions.	IIHR, Bangalore

T14	TGP 93(Lakshmi)	This is a tomato hybrid with determinate growth habit. Fruits are flat and round, good adaptable and moderately resistant to ToLCV	Nunhems India Pvt. Ltd
T15	TGP 94 (WS1508)	Round fruit, average fruit weight 60- 90 g, determinate growth habit.	US Agriseeds
T16	RTS 30	Selection from H-88-78-5.	RLBCAU
T17	TGP 5 (HMC - 610218)	Hybrid Darsh	Clause India Pvt Ltd
T18	Punjab Chhuhara	Plants are dwarf, bushy, determinate and uniform red colour at maturity. This variety is suitable for long transportation.	PAU, Ludhiana
T19	EC 620 424	Tomato accession, germplasm line	NBPGR, New Delhi
T20	EC 620 444	Tomato accession, germplasm line	
T21	EC 620 545	Tomato accession, germplasm line	
T22	Arka Samrat	Fruits oblate to high round, large (90-110g), Deep red, firm fruits, suitable for fresh market. Yields 80-85 t/ha. in 140 days.	IIHR, Bangalore
T23	TGP 95 (HeemSohna)	High yielding, fruit firm, good keeping quality	Syngenta Ltd
T24	TGP 91 (WS 42)	Tomato Hybrid (WS- 42)	Welcome Crop Science Pvt. Ltd

Figure 3.1 Layout of Experimental Plot

R1		R2		R3
R1T1	3M	R2T3		R3T24
R1T2		R2T6		R3T23
R1T3	1 M	R2T9		R3T22
R1T4		R2T12		R3T21
R1T5		R2T15		R3T20
R1T6		R2T18		R3T19
R1T7		R2T21		R3T18
R1T8		R2T24		R3T17
R1T9		R2T1		R3T16
R1T10		R2T5		R3T15
R1T11		R2T7		R3T14
R1T12		R2T10		R3T13
R1T13		R2T11		R3T12
R1T14		R2T13		R3T11
R1T15		R2T16		R3T10
R1T16		R2T17		R3T9
R1T17		R2T19		R3T8
R1T18		R2T22		R3T7
R1T19		R2T23		R3T6
R1T20		R2T2		R3T5
R1T21		R2T4		R3T4
R1T22		R2T8		R3T3
R1T23		R2T14		R3T2
R1T24		R220		R3T1

3.7 Recorded observations

Morphological Characterization of genotypes: A random selection of five plants was made in each block, and the plants were tagged. The following observations were recorded using these tagged plants.

3.7.1. Plant height (cm): Plant height at different stages of plant growth (30, 60 and 90 days after transplanting) were taken with meter scale from the basal point of the plant to the tip of the plant.

3.7.2. Days to flower initiation: The days taken to flower initiation were recorded for each genotype. The number of days was counted from the date of transplanting to the date of flowering initiation.

3.7.3. Number of flowers per cluster: On the five randomly tagged plants of each genotype, the number of flowers per cluster was counted and the mean was calculated.

3.7.4. Days to fruit maturity: The total number of days taken from the date of planting to the fruit maturity was counted on randomly selected five plants for each harvest and average was worked out.

3.7.5. Number of fruits per cluster: To calculate the average number of fruits per cluster for each germplasm, the number of fruits in each cluster of five plants was counted.

3.7.6. Number of fruits per plant: The total numbers of fruits harvested at the marketable stage of each picking were counted from five randomly selected plants and average numbers of fruits per plant was worked out.

3.7.7 Fruit weight per cluster (g): Fruit weight per cluster at maturity stage was measured and the average was calculated.

3.7.8. Ten Fruit weight (g): The 10 fruits of standard size were chosen to observe for weight from each genotype of all three replication.

3.7.9. Fruit length (cm): The five randomly selected fruits of marketable size were halved vertically; the fruit length was measured with the help of scale from stalk end to blossom end and the value was noted and average was worked out.

3.7.10. Fruit diameter (cm): The five randomly selected fruits of marketable size were halved horizontally and the fruit diameter was measured with the help of scale from one end to another end and the value was noted down and averaged.

3.7.11. Pericarp thickness (mm): Pericarp thickness of fruit was measured from randomly selected and tagged five fruits in each genotype in the equatorial section of fruit by using vernier callipers and then the average was calculated.

3.7.12. Number of Locules per fruit: The number of locules per fruit was counted from the five individual fruits. Fruits were halved transversely and number of locules present in each fruit, was counted and average was worked out.

3.7.13. Yield per plant (kg): Fruit yield per plant of the selected and tagged plants of each genotype was taken from total pickings during the entire harvesting season and summed.

Qualitative Parameters

3.7.14. TSS (^{0} B)

Well-developed red ripe fruits were selected and the juice was extracted from the selected fruits. A drop of juice was placed over the prism presented in the hand refractometer under room temperature conditions (24^0C). For TSS analysis, an 'Erma Hand Refract meter' having a reading range of 0 to 32^0Brix was used. TSS was recorded for the five fruits for each genotype separately and total soluble solids content of fruit was calculated and average was worked out.

3.7.15 Vitamin C content (mg/100 g)

Method: Titration analysis

Procedure

1. Extract of the sample (10 -50 g depending on the sample)
2. Add the 4% oxalic acid to it, makeup volume 100 ml
3. Centrifuge for 30 minutes
4. Pipette out 5 ml of supernatant
5. Add the 10 ml of 4% oxalic acid
6. Titrating against dye (v2 ml)

Calculations

0.5 mg /V1ml X V2ml/5ml X 100ML /Wt. of sample X 100

3.7.16 Acidity (%): Acidity was calculated by following the titration method. Tomato juice was extracted from red ripe fruits and the extracted juice was titrated against N/10 NaOH using phenolphthalein as an indicator.

Reagents used:

NaOH 0.1 N: 4g of NaOH was dissolved in distilled water and final volume was made up to one litre. Phenolphthalein indicator (%) was prepared in 80% ethyl alcohol.

Procedure

Preparation of juice sample: The freshly harvested red-ripened fruits were used for juice extraction and the juice was extracted by cutting of tomato. Extracted juice sample was added with five grams of activated charcoal, and then it was filtered using the muslin cloth. A 25 ml of prepared juice was taken in a conical flask and the volume was made up to 250 ml by adding distilled water.

Titration of juice sample: Five ml of extracted fruit juice was pippeted in 250 ml conical flask. It was added with 75 ml boiling water and 5 drops of phenolphthalein indicator. NaOH was taken in the burette and added slowly to the sample until the final drop gave a pink colour lasting for a minute or longer and readings were noted. Acidity was expressed in per cent and citric acid was estimated using the following formula:

$$\text{Titrable acidity (mg/ 100ml juice)} = \frac{\text{Volume of NaOH x N}}{\text{Volume of Juice Sample}} \text{ X } 100$$

N = Normality of NaOH, i.e., 1/10N

Percent citric acid = T.A. x 0.06404

3.5 Statistical Analysis

The experimental data collected in respect of 18characters on 24 tomato genotypes during 2021-22 was compiled by taking the mean values of selected plants in each plot and subjected for following statistical analysis. For analysis of data, statistical methods selected are given below:

3.5.1Analysis of variance

The Analysis of variance (ANOVA) of the observations recorded on different characteristics was carried out as per the standard procedure is given by Panse and Sukhatme (1985). The significance was tested by referring to the values of F table (Fisher and Yates, 1963).

The following model was adopted for the analysis of variance of various characters

$Yij = \mu+gi+rj+eij$

Where, Yij = Phenotypic observation of ith genotypes and jth replication

μ = General mean

gi = Effect of ith genotype

rj = Effect of jth replication

eij = Random error associated with ith genotypes and jth replication

Table:3.3 ANOVA for RBD

Sl. No	Source of Variation	d.f.	SS	MSS	F Value
1	Replication	(r-1)	SSR	MSSR	MSSR/MSSE
2	Genotypes	(t-1)	SSG	MSSG	MSSG/MSSE
3	Error	(r-1)(t-1)	SSE	MSSE	
4	Total	(tr-1)			

3.5.2 The standard error of mean (SEM)

Standard error of mean was calculated with the help of error mean sum of square from the analysis of variance table given as under:

Standard error mean = (MSSE/r)1/2

S.E. = Standard error

MSSE = Error mean sum of squares

R = Number of replication

3.5.3 Critical difference (CD)

For every character, the critical difference as the difference of any two mean values in order to compare the treatment means was calculated using the following formula and tabulated “t”value at error degree of freedom and at 5 or 1% level of significance

S.E. (d) ± = (2MSSE/r) 1/2

CD at 5 or1% = (2MSSE/r) 1/2 ×t

Where,'t' is the tabulated value at error degree of freedom and at 5 and 1% level of significance

Estimation of mean and range

3.5.4 Mean: The mean value of each character was estimated by dividing the sum total by the corresponding number of observations.

$$\textbf{Mean (x)} = \frac{\sum \boldsymbol{x}}{\boldsymbol{N}}$$

Where, ∑x = sum of all observation for each character in each replication

N = number of observations

3.5.5 Range: It was taken as the difference between the highest and lowest mean value for each character.

Range = [Xn–X1]

Where Xn = highest mean value of the character

X1 = lowest mean value of the character

3.5.6 Estimation of genetic parameter

Burton and Devane (1953) gave the method for computing both genotypic and phenotypic coefficients of variability for all the characters.

3.5.6.1 Estimation of variance components

The Genotypic and phenotypic variance were calculated by following standard procedures given below:

1. Phenotypic variance

$$\sigma 2\ (p) = \sigma 2\ (g) + MSSE$$

2. Genotypic variance

$$\sigma 2\ (g) = \frac{MSSV - MSS}{r}$$

Where,

σ 2 (p) = Phenotypic variance

σ 2 (g) = Genotypic variance

MSSV = Mean sum of square of treatment/accessions (adjusted)

MSSE = Mean sum of the square due to error

r = number of blocks

The test of significance was carried out using the 'F' table value of Fisher and Yates (1963).

3.5.6.2 Coefficient of variation

The phenotypic (PCV) and genotypic coefficient of variation (PCV) were calculated following the standard procedure proposed by Burton and Devane (1953) which are given below:

a) Phenotypic coefficient of variation (PCV):

$$PCV\ (\%) = \frac{\sqrt{\text{phenotypic variance (Vp)}}}{\text{The general mean of a population (GM)}} \times 100$$

b) Genotypic coefficient of variation (GCV):

$$\textbf{GCV (\%)} = \frac{\sqrt{\textbf{Genotypic variance (Vg)}}}{\textbf{The general mean of a population (GM)}} \textbf{ X 100}$$

The categories for genotypic (GCV) and phenotypic coefficients of variation (PCV) given by Sivasubramanian and Menon (1973) as low (0-10%), moderate (10-20%), and high (20% and above) were adopted in the present investigation also.

3.5.6.3 Heritability in the broad sense (h^2 (b))

Heritability in a broad sense was calculated by using the formula suggested by Allard, (1960).

$$\textbf{Heritability } (\mathbf{h^2\%}) = \frac{\text{Genotypic variance (Vg)}}{\text{Phenotypic variance (Vp)}} \text{ X 100}$$

Heritability in the broad sense (h2 (b)) was estimated as the ratio of genotypic variance to phenotypic variance (Allard, 1960).

Where, p2 σ and g2 σ are the phenotypic and genotypic variances of the character, respectively

The estimates of broad sense heritability (h 2 (b)) were also classified into three categories as suggested by Robinson *et al.* (1949).

3.5.6.4 Genetic advance

Improvement in the mean genotypic value of selected plants over the parental population is known as genetic advance. It is the measure of genetic gain under selection.

Genetic advance = h 2 (b) ×σp× K

Where, h 2 (b) = heritability in broad sense,

σp = phenotypic standard deviation and

K=selection differential at5% selection intensity

The value of K (at 5% selection intensity) = 2.06 was adopted following Allard (1960). Genetic advance expressed as percent of population mean was also calculated as per formula mentioned below:

$$\textbf{Genetic advance as \% of mean} = \frac{\text{Genetic advance}}{\text{General mean population (Gm)}} \times 100$$

Genetic advance as percent mean was also classified into 3 categories viz., low (0- 10%), moderate (10-20%), and high (20% and above) as suggested by Johnson *et al*. (1955).

3.5.6.5 Correlation Studies

The correlation coefficients among all possible character combinations at phenotypic (rp) and genotypic (rg) level were estimated by employing the formulae given byAl-Jibourie*et al*. (1958).

$$\text{Genotypic correlation} = \frac{Cov_{xy}(G)}{Vx(G) \times Vy(G)}$$

$$\text{Phenotypic correlation} = \frac{Cov_{xy}(P)}{Vx(P) \times Vy(P)}$$

Where, Covxy (G) = Genotypic coefficient of variance between “x”and “y”

Covxy (P) = Phenotypic coefficient of variance between “x”and “y”

Vx (G) = Genotypic variance of character “x”

Vx (P) = Phenotypic variance of character “x”

Vy (G) = Genotypic variance of character “y”

Vy (P) = Phenotypic variance of character “y”

The significance of correlation was tested by comparing estimated “r” values with the tabulated value at 5 and 1% level of significance.

3.5.6.6 Path Coefficient Analysis

It is a simple standardized partial coefficient method to detect the direct and indirect effects of the independent variable on a dependent variable. It permits the separation of correlation into components of direct and indirect effects.

The method of path coefficient was developed by Wright (1921) and modified by Dewey and Lu (1959). The following set of simultaneous equations were formed and used for the estimation of direct and indirect effects.

Path coefficients were obtained by simultaneous equations which express basic relationship between correlation and path coefficient.

r1y=P1y+P2yr12+P3yr13+..... P(n-1)yr1(n-1)

r2y=P2y+P1yr21+P3yr23+..... P(n-1)yr2(n-1)

r3y=P3y+P2yr32+P1yr31+..... P(n-1)yr3(n-1)(n-1)r(n-1)

y=P (n-1)y+P(n-2)yr(n-1) (n-3)yr(n-1) (n-3)+….....+P(n-(n-1))yr1(n-1)

Where,

y = dependent variable i.e. yield per plant

r = Genotypic or phenotypic correlation coefficients between a pair of character n

n= Total number of characters under study

Apart from these variations, unexplained residual variation is also there which is an account of residual factor is calculated by the following formula.

Residual effect:

Residual effect (R) = 1 – (a2 ⊞ b2 + c2 + ….. + i2 + 2abr12 + 2acr13 +…...)

The statistical analysis was carried out for each observed character under study using MS-Excel and OPSTA

Chapter 4 EXPERIMENTAL RESULTS

The present investigation entitled "**Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes**" was carried out at the Department of Vegetable Science, RLBCAU, Jhansi. The twenty-four tomato germplasm were collected from the different tomato research centres and State Agricultural Universities of India and grown during *Rabi-2021* at research farm. After the experimentation for various characters, the data were compiled and analysed accordingly to the design of the experiment (Randomized Block Design).

The results obtained after the analysis of the data are briefly described under the following sub-heads:

4.1 Analysis of variance

4.2 Mean performance and range

4.3 Components of variation and estimates of genetic parameters

4.4 Correlation coefficient analysis

4.5 Path coefficient analysis

4.1 Analysis of variance

The analysis of variance indicated the significantly higher amount of variability among entire tomato germplasm. The significance of treatment variances of various characters was tested and compared to their respective error variances. It was found that genotypes differed significantly for the entire characters studied *viz.*, plant height at 30, 60 and 90 days after transplanting, days to flower initiation (days), days to fruit maturity(days), number of flowers/cluster, number of fruit per cluster, number of fruit per plant, fruit weight per cluster (g), ten fruit weight (g), yield per plant (kg), number of locules per fruit, pericarp thickness (mm), fruit length (cm), fruit diameter (cm), total soluble solids (^{o}brix), ascorbic acid content (mg/100 g fresh weight), acidity (%), indicating that a wide range of variability exist in the material for all the characters. The test of significance for the characters investigated during experimentation has been presented in Table (4.1).

The investigation of variability by earlier tomato researchers, *viz.,* Singh *et al*. (2021),

Kumar *et al*. (2018), Joshi and Sridevi (2018) found a significantly high variability among all the characters studied. Sinha *et al*. (2019) also showed considerable differences among the genotypes for all the traits except titratable acidity. Sushma *et al*. (2020) found high variability for average fruit weight, plant height, and number of fruits per plant. It may be inferred that the traits investigated in the assessed material have more scope for improvement. Similarly, based on fruit yield per plant, the genotypes Punjab Chuhara, EC 620545 and Arka Samrat appeared to have more scope for obtaining higher yield as compared to other genotypes. As a result, the material evaluated had a lot of potential for genetic improvement through selection and combination breeding for higher yield and quality parameter.

Table 4.1 Analysis of variance (mean sum of square) for yield and quality parameters in different tomato genotypes

Sl. No.	Characters	Replication	Genotypes	Error
		df 2	df 23	Df 46
1	Plant height at 30 DAT (cm)	2.902	38.06**	3.441
2	Plant height at 60 DAT (cm)	9.08	131.65**	11.103
3	Plant height at 90 DAT (cm)	0.08	442.11**	0.5
4	Days to flower initiation(days)	2.01	48.32**	0.62
5	Days to fruit maturity(days)	11.15	628.09**	11.31
6	Number of flowers/clusters	1.19689	2.1851**	0.42
7	Number of locules per fruit	0.4017	1.9573**	0.17
8	Pericarp thickness (mm)	0.2651	7.921**	0.16
9	Number of fruits per cluster	0.16031	1.5928**	0.15
10	Number of fruits per plant	7.908	427.29**	11.29
11	Fruit weight per cluster (g)	0.15042	1.9543**	0.21
12	Ten fruit weight(g)	54.77	1834.49**	19.54
13	Yield/ plant (kg)	0.06436	3.66**	0.08
14	Fruit length (cm)	0.0071	0.68**	0.04
15	Fruit diameter(cm)	0.19803	1.01**	0.04
16	Total soluble solids (^{o}Brix)	0.00042	1.54**	0.00
17	Ascorbic acid content (mg/100 g fresh weight)	0.6481	28.47**	0.47
18	Acidity (%)	0.0002703	0.031**	0.004

******Significant at 1%,DAT-Days after transplanting.

4.2 Mean performance and range

The mean performances were calculated using observations for each genotype in three replications for fruit yield and its component traits. The observations were recorded on five randomly tagged plants from each entry and averaged. The mean performance and grand mean of 24 tomato genotypes for various attributes are presented in Table 4.8 Plant height, days to flower initiation, and days to fruit maturity are the early traits among the 18 characters considered. Fruit characters include fruit length and fruit diameter,

number of locules per fruit and pericarp thickness. Total soluble solids, ascorbic acid content and acidity are quality parameters analyzed. The following are the details of the characters that were recorded during the research.

4.2.1 Plant height at 30 days after transplanting (cm)

The plant height was measured in cm from ground level to the tip of plants and averaged over five plants. The plant height at 30 DAT ranged from 18.26 to 48.03 cm and differed significantly, with average of 28.16 cm (Table 4.2). Maximum plant height was observed for HeemSohna (48.03 cm) followed by WS 42 (43.73 cm). However, the minimum plant height was recorded in genotype Arka Vikas (18.26cm).(Fig.4.1)

4.2.1 Plant height at 60 days after transplanting (cm)

The plant height at 60 days after transplanting differed significantly among the genotypes and was recorded maximum in the genotype WS 42 (64.26 cm) followed by Heem Sohna (61.06cm) and Arka Samrat (60.86 cm). Whereas, the minimum plant height was recorded in Arka Vikas (32.8cm) with the average plant height of 44.80 cm (Table 4.2).(Fig.4.1)

4.2.3 Plant height at 90 days after transplanting (cm)

There was a significant difference for plant height at 90 days after transplanting in the genotypes and the range of plant height varied from 49.6 to 106.46 cm, with average plant height of 77.86 cm. The maximum plant height was recorded in genotype EC 620 424 (106.46 cm) and the minimum plant height in Pusa Sadabahar (49.6cm).

(Table 4.2) (Fig.4.1)

Table 4.2 Mean performance of different tomato genotypes for plant height at 30, 60 and 90 days after transplanting

Genotypes	Plant height (cm) at 30 DAT	Plant height (cm) at 60 DAT	Plant height (cm) at 90 DAT
Kashi Aman	32.33	53.66	85.66
Kashi Aadarsh	27.73	46.26	84.6
Kashi Amrit	26.06	35.03	67.06
Kashi Anupam	22.6	34.26	64.6
Kashi Vishesh	29.26	46.53	74.46
Kashi Hemant	25.13	45.86	76.53
Pusa Ruby	25.46	45.13	98.86
Pusa Uphar	21.33	36.16	58.39
Pusa Sadabahar	22.26	35.53	49.6
Pusa Gaurav	20.46	36.93	72.64
Pusa 120	22.26	37.8	79.93
Arka Vikas	18.26	32.8	67.2
TGP 93	30.46	46.33	75.53
TGP 94	36.13	52.93	76.06
RTS-30	26.86	48.26	87.13
TGP-5	23.53	40.8	76.33
Punjab Chuhara	26.06	43.33	77.06
EC 620424	27.93	46.53	106.46
EC 620444	29.06	42.6	80
EC 620545	25.8	40.6	72.8
H-88-78-2	26	41.73	77.5
Arka Samrat	39.2	60.86	82.2
Heem Sohna	48.03	61.06	96.86
WS 42	43.73	64.26	80.86
General Mean	28.16	44.80	77.86
SE(m)	1.10	2.82	0.53
(CD) at 5%	4.04	6.86	1.05
CV	6.2	5.63	0.6

4.2.4 Days to flower initiation

Days to flower initiation were recorded to determine the earliness among the genotypes which was found to be statistically significant. The average number of days taken to flower initiation was 41.96 days (Table 4.3), with a range from 38.66 to 47.66 days. The minimum number of days taken for flower initiation was recorded in TGP 93 (38.66 days), whereas, the maximum number of days was taken by the genotype Kashi Anupam (47.66 days) followed by EC 620545 (Fig.4.2).

4.2.5 Days to fruit Maturity

Early maturing fruits can ensure quick economic return by fetching high price on early harvest and may escape market gluts and give high returns. Significant differences were recorded among the observed values with respect to days to maturity. The average days taken to first harvest was 83.38 days, with a range of 72.33 to 97.66 days (Table 4.3). The minimum days taken to first harvest was noted in genotype EC 620545 (72.33 days) followed by EC620444 (75 days) and RTS -30 (75.66 days) and maximum days was recorded in genotypes EC 620424 (97.66 days). (Fig.4.2)

4.2.6 Number of flowers/cluster

Mean performance for number the number of flowers per cluster showed significant difference among the genotypes, whereas the values varied from 5.06 to 6.86 (Table 4.4). The overall mean for this character was 6.00. The genotype Punjab Chuhara (6.86) recorded maximum number of flowers per cluster followed by Pusa Sadabahar (6.80), RTS - 30 (6.60) whereas TGP-94 showed the lowest number of flowers per cluster (5.06). (Fig 4.3)

4.2.7 Number of fruits per cluster

Significant variation was observed among the genotypes investigated for number of fruits per cluster (Table 4.4). The number of fruits per cluster ranged from 4.4 to 6.93, with a mean value of 5.71. The maximum number of fruits per cluster was recorded in genotype Pusa Gaurav (6.93) followed by WS-42(6.60) and Kashi Hemant (6.6) and Pusa Sadabahar (6.26), whereas, minimum value was recorded in genotype Kashi Vishesh (4.4).(Fig.4.3)

Table 4.3 Mean performance of different tomato genotypes for days to flowering and days to Maturity

Genotypes	Days to flower initiation	Days to fruit Maturity
Kashi Aman	40.00	79.66
Kashi Aadarsh	44.33	89.33
Kashi Amrit	42.00	79.66
Kashi Anupam	47.66	77.00
Kashi Vishesh	46.33	81.33
Kashi Hemant	42.00	84.00
Pusa Ruby	40.00	79.33
Pusa Uphar	39.33	91.33
Pusa Sadabahar	39.66	97.66
Pusa Gaurav	43.33	94.66
Pusa 120	39.00	84.00
Arka Vikas	39.66	81.66
TGP 93	38.66	88.33
TGP 94	39.00	79.00
RTS-30	40.66	75.66
TGP-5	44.00	83.66
Punjab Chuhara	43.00	79.00
EC 620424	42.33	97.66
EC 620444	41.66	75.00
EC 620545	47.33	72.33
H-88-78-2	44.00	79.33
Arka Samrat	39.66	89.33
Heem Sohna	41.00	76.00
WS 42	40.00	83.00
General Mean	41.96	83.38
S E(m)	0.63	1.88
(CD)at 5%	2.64	6.57
CV	2.53	5.00

4.2.8 Number of fruits per plant

The total number of fruits per plant is one of the most important yield components determining the total yield per plant which indicates that they are directly proportional to each other. Among the different tomato genotypes, for number of fruits per plant the value varies significantly from 36.93 to 113.93 with general mean of81.24 (Table 4.4). The highest number of fruits per plant was recorded in genotype Pusa Ruby (113.93). However, the genotype TGP 93 showed the minimum number of fruits per plant (36.93). (Fig.4.3)

4.2.9 Fruit Weight/ cluster

Significant variation was observed among the genotypes investigated for fruit weight per cluster. Among the different tomato genotypes, for fruit weight per cluster, the value varies significantly from 188.73 g to 304.86 g with general mean 240 g .The highest value was recorded in Pusa Sadabahar (304.86 g) followed by WS 42 (296.53 g) and Punjab Chuhara (293.2 g) and minimum value was noted in EC 420424 (188.73).Table (4.5)(Fig.4.1)

4.2.10 Ten Fruit Weight

The ten fruit weight is one of the most important yield components which determining the total yield per plant which indicates that they are directly proportional to each other. Among the different tomato genotypes, for ten frit weight the value varies significantly from (544.33 g) to (849.66 g) with average 710 g. the maximum value was in Kashi Aman (849.66 g) followed by Kashi Amrit (835 g), RTS -30 and WS 42 (826.33 g) whereas minimum value was expressed by H-88-78-2 (544.33 g). (Table 4.5)(Fig.4)

4.2.11 Yield per plant (kg)

One of the most important traits receiving more attention in breeding programmes is yield per plant. It is important trait to design a genotype having potential to excel commercially otherwise, even if the genotype is exceptional performer for other features, it will be of not much commercial use. From the observed values the yield per plant differed significantly for genotypes and the values ranged from 1.40 to 3.98 kg/plant. The general mean of genotypes observed was 2.56 kg/plant (Table 4.5). The genotypes Punjab Chuhara (3.98 kg/plant) and EC 620444 (3.64 kg/plant) were observed to have higher yield per plant, while the minimum was recorded in genotype Arka Vikas (1.40 kg/plant). (Fig.5)

Table 4.4 Mean performance of different tomato genotypes for Number of flowers/cluster and Number of fruits per cluster and number of fruits per plant

Genotypes	No. of flowers/cluster	No. of fruits per cluster	No. of fruit per plant
Kashi Aman	6.13	4.73	47.83
Kashi Adarsh	5.93	5.16	79.8
Kashi Amrit	5.66	5.6	78.26
Kashi Anupam	5.73	5.46	80.26
Kashi Vishesh	5.13	4.4	90.66
Kashi Hemant	5.8	6.6	98.26
Pusa Ruby	5.86	5.8	113.93
Pusa Uphar	6.33	5.66	65.33
Pusa Sadabahar	6.80	6.26	80.4
Pusa Gaurav	6.66	6.93	99.6
Pusa 120	5.6	6.13	78.93
Arka Vikas	5.26	4.93	53.13
TGP 93	5.86	5.2	36.93
TGP 94	5.06	6.23	48.26
RTS-30	6.6	6.33	83.4
TGP-5	6.4	5.26	93.4
Punjab Chuhara	6.86	6	91.93
EC 620424	5.13	4.66	87.06
EC 620444	6.6	6.2	91.53
EC 620545	5.93	5.53	72.73
H-88-78-2	5.93	6.2	80.53
Arka Samrat	6.53	6.06	94.26
Heem Sohna	6.33	5.2	104.9
WS 42	5.94	6.6	110
General Mean	6.00	5.71	81.24
S E(m)	0.42	0.32	2.13
(CD) at 5%	1.23	0.82	6.46
CV	10.25	8.83	12.12

Table 4.5: Mean performance of different tomato genotypes for Fruit Weight/ cluster, Ten Fruit Weight (g) and Yield/plant (Kg).

Genotypes	Fruit Weight/ cluster(g)	Ten Fruit Weight (g)	Yield/plant (Kg)
Kashi Aman	226.3	849.66	2.22
Kashi Aadarsh	276.6	733.00	2.15
Kashi Amrit	241.2	835.00	2.28
Kashi Anupam	257.9	693.00	1.77
Kashi Vishesh	260.86	769.66	2.68
Kashi Hemant	274.1	823.00	2.3
Pusa Ruby	227.00	783.00	3.12
Pusa Uphar	235.86	589.00	2.63
Pusa Sadabahar	304.86	602.66	2.05
Pusa Gaurav	209.4	759.66	1.98
Pusa 120	222.66	574.33	1.99
ArkaVikas	236.93	613.00	1.40
TGP 93	242.13	594.33	1.44
TGP 94	196.46	780.66	2.43
RTS-30	196.22	826.33	3.19
TGP-5	208.20	770.60	3.25
Punjab Chuhara	293.20	658.00	3.98
EC 620424	188.73	721.66	3.14
EC 620444	196.86	629.33	3.64
EC 620545	275.96	740.00	2.36
H-88-78-2	229.00	544.33	1.96
Arka Samrat	252.20	736.66	3.42
Heem Sohna	200.00	770.33	2.66
WS 42	296.53	826.33	3.26
General Mean	240.11	716.06	2.56
S E(m)	0.53	6.81	0.31
(CD)at5%	0.68	11.21	0.42
CV	1.92	9.44	12.11

4.2.12 Number of locules per fruit

Number of locules per fruit of tomato varied significantly among the genotypes. It ranged from 2 to 6, with a mean value of 3.53 (Table 4.6). The maximum number of locules was recorded in the genotype Kashi Aadarsh (6) followed by EC 620 545 (5.33) and minimum no. of locules per fruit was observed in RTS – 30 (2)(Fig.4.6).

4.2.13 Pericarp thickness (mm)

Pericarp thickness per fruit ranged from 1.86 to 3.76 mm, with a mean value of 2.78 mm (Table 4.6). The maximum pericarp thickness was observed in the genotype Arka Samrat (3.76 mm) followed by Kashi Aman (3.65), and Kashi Vishesh (3.46) respectively, wherever the minimum pericarp thickness were recorded in EC 620444 (1.86 mm). (Fig 4.6)

4.2.14 Fruit length (cm)

Significant differences were observed among the genotypes for fruit length/ polar diameter of the fruit. It ranged from 3.36 to 7.3 cm, with a mean value of 4.32 cm (Table4.6). The maximum fruit length was recorded in genotype Punjab Chuhara (7.3 cm) and minimum in genotype Pusa Ruby (3.36 cm). (Fig.4.6)

4.2.15 Fruit diameter (cm)

The fruit diameter differed significantly with maximum being recorded in genotype Kashi Vishesh (5.4 cm) and the minimum in EC 620 424 (3.3 cm), it ranged from 3.3 to 5.4 cm, with a mean value of 4.36 cm (Table 4.6) (Fig4.6)

Table 4.6: Mean performance of different tomato genotypes for Number of locules/fruit, Pericarp thickness (mm), Fruit length (cm) and Fruit diameter (cm)

Genotypes	Number of locules/ fruit	Pericarp thickness (mm)	Fruit length(cm)	Fruit diameter (cm)
Kashi Aman	3	3.65	4.54	4.7
Kashi Aadarsh	6	2.83	4.09	5.03
Kashi Amrit	3.6	3.38	4.21	4.63
Kashi Anupam	3.6	3.26	4.43	5.27
Kashi Vishesh	4.4	3.46	4.79	5.4
Kashi Hemant	3.6	2.26	4.48	4.58
Pusa Ruby	3.3	2.75	3.37	3.62
Pusa Uphar	4.3	3.63	3.93	4.46
Pusa Sadabahar	2.3	2.9	3.74	3.8
Pusa Gaurav	2.3	2.3	5.56	3.76
Pusa 120	4	2.17	3.79	3.9
Arka Vikas	3.3	2.16	3.81	4.55
TGP 93	3	1.88	3.71	4.2
TGP 94	4	2.63	4.28	4.69
RTS-30	2	2.17	4.03	3.85
TGP-5	4.66	2.73	4.43	5.03
Punjab Chuhara	3.3	3.13	7.3	3.41
EC 620424	4	2.56	3.88	3.33
EC 620444	3.33	1.86	3.47	4
EC 620545	5.33	2.65	3.93	5.07
H-88-78-2	2.33	3.21	4.13	4.4
Arka Samrat	2.33	3.76	4.31	4.63
Heem Sohna	2.66	2.63	3.71	4
WS 42	3.33	2.7	3.82	4.42
General Mean	3.53	2.78	4.32	4.36
S E(m)	0.24	0.34	0.12	0.15
(CD) at 5%	0.78	0.81	0.33	0.36
CV	11.14	8.21	4.16	4.45

4.2.16 Total soluble solids (º Brix)

The TSS has a direct impact on tomato flavour and is a crucial biochemical feature for the processing industry. High TSS improves the quality of fruits and results in higher recovery of processed products. The general mean of TSS content for the fruit at the marketable stage was (3.68^{o}B). (Table 4.7) and the range lies between 3 to 4.6^{o}B. The highest TSS content was recorded in fruits of genotype EC 620424 (4.6^{o}B) followed by Kashi Aman (4.26^{o}B) which were significantly superior over rest of the genotypes, whereas, the least value was observed in fruits of H/88/78/2(3.00 ^{o}B). (Fig.4.7)

4.2.17 Ascorbic acid content (mg/100 g of fresh fruit weight)

Vitamin C (ascorbic acid) has unique antioxidant qualities which boosts the body's immune system against diseases. Ascorbic acid content of fruit was observed to be statistically different and ranged from 11.45to29.39mg/100g, with a mean value of 17.83 mg/100g (Table 4.7). The maximum ascorbic acid content of fruit was recorded with the genotype Kashi Amrit (29.39 mg/100g), while the genotype Punjab Chuhara (11.45 mg/100g) showed the minimum value of ascorbic acid content. The genotypes showed ascorbic acid content greater than mean value were EC 620424, TGP – 93, Pusa Uphar, Kashi Anupam, Kashi Aadarsh, Kashi Aman. (Fig.4.7)

4.2.18 Acidity (%)

The acidity of the fruit also plays a role in the flavouring of tomato products. Citric acid is the most common organic acid present in tomatoes, accounting for the majority of the total titrable acidity. The acidity at marketable stage fruits differed significantly among genotypes and ranged from 0.59 to 0.94 %. The general mean for acidity of fruit was 0.811 % (Table 4.7). The highest acidity was recorded in fruits of Pusa Ruby (0.94 %) followed by TGP - 94 (0.93 %), while it was noticed minimum in fruits of Punjab Chuhara (0.54 %).(Fig.6)

Table 4.7: Mean performance of different tomato genotypes for Total soluble solids, Ascorbic acid content and Acidity

Genotypes	Total soluble solids (ºBrix)	Ascorbic acid content (mg/100 g fresh wt.)	Acidity (%)
Kashi Aman	4.26	19.13	0.87
Kashi Aadarsh	3.56	20.86	0.84
Kashi Amrit	4.46	29.39	0.66
Kashi Anupam	3.6	21.2	0.82
Kashi Vishesh	3.8	15.7	0.90
Kashi Hemant	4.1	22.1	0.83
Pusa Ruby	4.03	17.66	0.94
Pusa Uphar	3.38	20.26	0.63
Pusa Sadabahar	3.43	17.37	0.77
Pusa Gaurav	3.66	12.53	0.77
Pusa 120	3.7	13.30	0.87
Arka Vikas	4.5	15.76	0.824
TGP 93	3.33	18.00	0.85
TGP 94	3.73	16.7	0.93
RTS-30	3.16	25.94	0.71
TGP-5	3.3	20.70	0.85
Punjab Chuhara	3.23	11.45	0.59
EC 620424	4.6	18.33	0.77
EC 620444	3.26	17.83	0.92
EC 620545	3.56	15.52	0.86
H-88-78-2	3.00	16.35	0.87
Arka Samrat	3.36	11.46	0.83
Heem Sohna	3.7	12.34	0.79
WS 42	3.64	13.01	0.75
General Mean	3.68	17.83	0.811
S E(m)	0.5	0.3	0.98
CD at 5%	0.11	0.06	0.32
CV	1.5	5.03	1.99

At the 5% level of significance, the analysis of variance for several characters showed extremely significant differences among genotypes. Ranges based on mean values are also useful for examining the genetic variability of germplasm. In the current study, all parameters showed high range differences except acidity. The widest range was observed for ten fruit weight followed by fruit weight per cluster and number of fruit per plant.

The calculated components of variance for all of the traits revealed a large range of variability. In the tomato, a broad range of variations have been found for many quantitative and qualitative traits.

Similar results are reported by Kumar *et al*. (2018), Pandey *et al*. (2018), Rawat *et al*. (2020), Mohamed *et al.* (2012), Behera *et al*. (2020) for almost all characters studied. Bhandari *et al*. (2017) showed the maximum range for average fruit weight followed by fruit yield (Kg)/plant and total number of fruits/plant. Anuradha *et al.* (2020) recorded high genetic variability for, number of fruits per plant, average fruit weight, fruit yield per plant and yield per hectare. Singh *et al.* (2021) recorded high range of genetic variability for fruit yield per plant, pericarp thickness, average fruit weight, locules per fruit and numbers of fruits per plant

Components of variation and estimates of genetic parameters

The genetic variability in a crop are critical factors in selecting the best genotypes for rapid production and related character improvement, as well as selecting the most promising parents for a successful hybridization programme. The amount of genetic variability present in the available germplasm determines the success of breeding programme. Knowing about the phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) can help to anticipate the amount of variability present in a germplasm that can then be used for an effective breeding programme. Heritability in broad sense reflects the reliability with which a genotype can be detected by its phenotypic expression, which is a measure of great significance to the breeder. Because it does not account for the level of absolute variability, the heritability value seems to have little value by itself. It is necessary to utilize heritability along with genetic advance while going for selection.

The components of variances, CV, and genetic parameters (genotypic variance, phenotypic variance, GCV, PCV, heritability in broad sense and genetic advance as per cent of mean of various characters) studied have been mentioned in Table 4.8. The mean values for the various parameters of present investigation have already been discussed under the subheading mean performance of respective characters. The remaining estimates have been explained below:

The magnitude of phenotypic variances and coefficients of variation were generally higher than their genotypic estimations, showing the influence of the environment on the expression of these traits.

On the perusal of data presented in Table 4.8, it is evident that the highest estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were recorded for Days to fruit maturity (days) (21.56 and 20.12 %), number of locules per fruit (22.44 and 24.10 %), pericarp thickness (mm)(27.24 and 26.81), number of fruits per plant(38.81 and 39.30 %) , ten fruit weight (g)(44.42 and 45.12 %), fruit weight per cluster (g)(38.88 and 39.99 %), yield / plant (kg)(56.78 and 58.25%), moderate PCV and GCV was estimated for plant height at 30 DAT (cm)(11.75 and 13.12%), plant height at 60 DAT (cm)(10.20 and 11.57 %) , plant height at 90 DAT (cm)(13.44 and 13.45%), days to flower initiation (days) (13.39 and 13.69%), number of flowers/cluster (12.02 and 15.05%), number of fruits per cluster (12.19 and 14.34%), total soluble solids (^{o}Brix)

(18.29 and 17.45%), ascorbic acid (mg/100 g fresh weight) (14.98 and 14.27%), acidity (%) (14.38 and 15.95%) the lowest estimates of GCV and PCV was observed for fruit length (cm) (9.45 and 10.66%), fruit diameter (cm) (9.77 and 10.36%) only.

In the present investigation, estimation of heritability (Table 4.8) was found to be high for most of the characters *viz*. Fruit length (cm)(88.23%), fruit diameter (cm)(89.03%), days to flower initiation (days)(97.73%), days to fruit maturity (days) (97.16%), pericarp thickness (mm) (93.26%), number of fruits per plant (94.08%), fruit weight per cluster (g) (98.06%), ten fruit weight (g) (95.57%), yield / plant (kg) (94.6%), total soluble solids (^{o} Brix) (98.34%), Plant height at 90 DAT (cm)(98.84%)ascorbic acid (mg/100 g fresh weight) (96.24%), acidity (%) (94.06%), plant height at 60 DAT (cm) (81.98%), number of locules per fruit (82.33%), plant height at 30 DAT (cm) (78.17%), number of fruits per cluster (74.20%),number of flowers/cluster (57.26%).

Estimates of genetic advance as per cent of mean were recorded high for Yield/plant (kg) (86.53%) followed by ten fruit weight (g) (79.98%), fruit weight per cluster (g) (75.99 %), number of fruits per plant (75.28%), pericarp thickness (mm) (51.11%), number of locules per fruit (39.34%),days to fruit maturity (days) (37.61%), total soluble solids (^{o}Brix) (35.05%), acidity (%) (29.24%), plant height at 90 DAT (cm) (27.83%), ascorbic acid (mg/100 g fresh weight) (27.31%), days to flower initiation (days) (25.98%), number of fruits per cluster (23.93%),plant height at 30 DAT (cm) (20.19%),fruit diameter(cm)(18.99), plant height at 60 DAT (cm) (18.13%), number of flowers/cluster (18.24%), fruit length (cm) (15.54%).

The potential to generate new and improved cultivars with desirable features is provided by the variability present in the experimental materials. Phenotypic variability would be caused by the combination of genotypic variation and environmental effects that could contribute the development of phenotype. However, the phenotypic and genotypic components as range, variance, and coefficient of variation, heritability and genetic advance can be used to measure genetic variation in a germplasm collection.

Furthermore, yield per plant cannot be used as a trait for genotypic selection as heterogeneous trait controlled by polygenes and significantly influenced by environmental several factors. The extent and existence of genetic variability in the breeding material

frequently contribute the yield and yield attributing traits that determines the effectiveness of desired selection.

This environmental impact is mainly due to by heterogeneity in soil fertility status and other uncontrollable factors. The characters showing close link with PCV and GCV shows little differences in their values, indicating that the environment had very little influence on their expression. Present study showed that plant height at 90 DAT has little differences between PCV and GCV values. These findings are in line with the results Sinha *et al.* (2019), Basavaraj *et al*. (2015), Rai *et al*. (2016).

Higher estimates value of PCV and GCV was reported for characters like days to fruit maturity (days), number of locules per fruit, pericarp thickness (mm), number of fruits per plant, ten fruit weight (g), fruit weight per cluster (g) (Table 4.8). Similar findings were reported by Rawat *et al.* (2020), Meena *et al*. (2018), Sinha *et al*. (2019), Chaudhari *et al*. (2019). Mishra and Pandey (2018) reported high PCV and GCV values for fruit yield/ plant, number of fruits/plant and number of fruits/clusters.

The present study showed that there are significant differences among all parameters for all genotypes at a given level of significance, indicating that there is a scope for selection and hybridization in current and future breeding programmes. The earlier workers viz., Singh *et al.* (2021), Rawat *et al.* (2020), Anuradha *et al*. (2020), Haydar *et al.* (2007), Lekshmi and Celine (2017), Maurya *et al.* (2020) have also shown likely results of significant differences among studied genotypes, also phenotypic coefficient of variation was found to be higher than the genotypic coefficient of variation for all 18 parameters, indicating that there is a presence of apparent variation not only due to genotype but also due to favourable environmental conditions Sinha *et al*. (2019).

All parameters showed high broad sense heritability indicating that by exploitation of these traits through combination breeding as well as through selection the effective improvement of a genotype is possible. The similar results were found by earlier workers like Somraj *et al.* (2017), Kumar *et al.* (2020), Kherwa *et al*. (2020), Genetic advance was found higher in yield / plant followed by ten fruit weight, fruit weight per cluster. These findings are in line with the results of Anuradha *et al.* (2020).

However, the estimates of high heritability coupled with high genetic advance was observed for most of the characters except plant height at 30 and 60 DAT, number of

flowers per cluster, diameter of fruit and fruit length indicating that these traits were strongly influenced by additive gene action so that simple selection based on phenotypic performance would be more effective. Mohamed and ali (2018), Pandey *et al*. (2018), Saravanan *et al.* (2019), Bhuiyan *et al*. (2016), Kumar *et al*. (2020), Kherwa *et al*. (2020), Prajapati *et al*. (2015), Bhandari *et al*. (2017), Aralikatti *et al.* (2018), Sajjan (2016), Maurya *et al*. (2020), Chadha and Walia, (2016) revealed similar results for yield per plant and average fruit weight. Khuntia *et al*. (2018) reported similar results for number of fruits per cluster, number of fruits per plant, fruit setting percentage, individual fruit weight, yield for plant, fruit firmness, flesh thickness, number of locules per fruit., Kavyashree *et al.* (2017) also reported likewise for number of fruits per cluster, number of fruits per plant, average fruit weight, pericarp thickness and fruit yield per plant. Dixit and Pandey (2017) also observed similar trend for number of fruits per plant, total yield per plant.

Table 4.8: Estimation of variability, heritability and expected genetic advance for 18 characters

S. No.	Characters	General Mean	Range	Genotypic variance	Phenotypic variance	Genotypic coefficient variation	Phenotypic coefficient variation	Heritability (Broad sense) in %	Genetic advance as % of mean
1	Plant height at 30DAT (cm)	28.16	18.26 –48.03	12.44	15.16	11.75	13.12	78.17	20.19
2	Plant height at 60 DAT (cm)	64.26	32.8 –64.26	41.32	52.83	10.20	11.57	81.98	18.13
3	Plant height at 90 DAT (cm)	77.86	49.6-106.46	146.70	147.10	13.44	13.45	98.84	27.83
4	Days to flower initiation (days)	41.96	38.66-47.66	17.19	17.98	13.39	13.69	97.73	25.98
5	Days to fruit maturity(days)	83.38	77.33–97.66	207.55	217.89	21.56	20.12	97.16	37.61
6	No. of flowers/cluster	6.00	5.06 -6.86	0.62	1.52	12.02	15.05	57.26	18.24
7	No. of locules/fruit	3.53	2 -6	0.73	0.86	22.44	24.10	82.33	39.34
8	Pericarp thickness (mm)	2.78	1.86 -3.76	2.62	3.01	27.24	26.81	93.26	51.11
9	No. of fruits/cluster	5.71	4.4 –6.93	0.52	0.45	12.19	14.34	74.20	23.93
10	No. of fruits/plant	81.24	36.93–113.93	138.67	149.36	38.81	39.30	94.08	75.28
11	Ten fruit wt.(g)	716.064	544.33 -849.66	656.643	826.08	44.42	45.12	95.57	79.98
12	Fruit wt./cluster (g)	240.11	188.73- 304.86	258.11	355.67	38.88	39.99	98.06	75.99
13	Yield/plant (kg)	2.56	1.40 -3.98	0.80	0.84.97	56.78	58.25	94.6	86.53
14	Fruit length(cm)	4.36	3.32 -5.4	0.27	0.29	9.45	10.66	88.23	15.54
15	Fruit diameter(cm)	5.70	4.41 -6.63	0.31	0.35	9.77	10.36	89.03	18.99
16	TSS(°Brix)	3.68	3 –4.6	0.44	0.40	18.29	17.45	98.34	35.05
17	Ascorbic acid (mg/100gfreshwt.)	17.83	11.45-29.39	9.33	9.76	14.98	14.27	96.24	27.31
18	Acidity (%)	0.81	0.94 -0.59	0.03	0.03	14.38	15.95	94.06	29.24

Correlation among yield components

Traditionally, breeding programmes in tomato have concentrated on generating varieties with superior agronomic performance, mainly yield and fruit quality parameters. Therefore, it is important to know about the type of correlation that exists between the traits and their extent of correlation. Correlation analysis of these traits is an important approach which gives an idea about the relationship among the various traits and determines the component characters on which genetically improved genotypes may be selected for fruit yield. The efficacy of the selecting process is also influenced by the degree of relationship. Depending on the genetic correlation between the traits, selection for one trait may increase or decrease the expression of another one, while phenotypic correlations are estimated directly from values measured in the field and are the result of genetic and environmental causes.

Estimation of correlations at both phenotypic and genotypic levels is tested for their significance at five and one per cent levels against the tabulated value of correlation coefficient. Correlation analysis for fruit yield has given the association of different traits at genotypic and phenotypic level and results have been presented in Table 4.9 and 4.10.

At both the phenotypic and genotypic level, correlation studies on yield per plant recorded a highly significant and positive association with ten fruit weight (0.715 and 0.733**), total soluble solids (0.765 and 0.794**), days to fruit maturity (0.785 and 0.816**), whereas, fruit length (0.577** and 0.629*) shows a highly significant and positive association at phenotypic level, but only significant and positive at the genotypic level. In addition to the traits, plant height at 60 days after transplanting (0.375*), days to flower initiation (0.357*), fruit length (0.577*), fruit weight per cluster (0.331*), and pericarp thickness (0.338*) showed positive significant association with yield/plant at phenotypic level. Hence, it may be inferred that simple recurrent selection could be used to improve tomato yield by incorporating these traits. But, acidity content (-0.358*) shows a negative significant correlation with yield per plant. Correlation between ten fruit weight and number of locules per fruit shows a highly significant negative correlation at the phenotypic level and significant at the genotypic level.

The characters like number of fruits per cluster (-0.351*), acidity (-0.388*), and pericarp thickness (-0.359*) have significant negative correlations, but fruit diameter (-0.521** and -0.585**) shows negative correlations with high significance at phenotypic level and

significant at genotypic level for plant height at 30 days after transplanting. A highly significant and positive correlation was found in plant height at 90 days after transplanting (0.752** and 0.853**) at both levels and number of fruits per plant (0.426**) at phenotypic level. Also, a significant and positive correlation is seen in fruit weight per cluster (0.416*) at phenotypic level.

Plant height at 60 days after transplanting had a significant and positive correlation with plant height at 90 days after transplanting (0.415*), fruit diameter (0.335*) and high significance was noticed for total soluble solids (0.475**) and ten fruit weight (0.532**) at phenotypic levels. Among estimated genotypic correlation, ten fruit weight (0.619**) showed positive significance at genotypic level with plant height at 60 days after transplanting. The correlation shows positive significance between plant height at 90 days after transplanting to number of fruits per plant (0.355*). A highly significant but negative correlation is seen for fruit diameter (-0.478**) and acidity (-0.398*).

Total soluble solids are a major fruit quality character. It had a positive and highly significant association with fruit length (0.560 and 0.635**), days to maturity (0.633 and 0.655**) and pericarp thickness (0.568 and 0.587*) at phenotypic level and significant at genotypic level. Whereas, the ten-fruit weight (0.847 and 0.865**) shows high significance positivity at both levels.

Number of fruits per plant (-0.352*) showed a negative but significant correlation at the phenotypic level and a highly significant negative correlation was seen with the number of locules per fruit (-0.539 and -0.595**) at both levels.

Number of fruits per plant was found to have a highly significant but negative correlation with fruit diameter (-0.640 and -0.695**), pericarp thickness (-0.676 and -0.758**) at both levels. The same was also observed in ascorbic acid content (-0.531*) and ten fruit weight (-0.567**) at phenotypic levels. Fruit weight per cluster (0.593**) and number of locules per fruit (0.463**) had a highly significant positive correlation at the phenotypic level. Characters like days to flower initiation (-0.507*), days to maturity (-0.431*), and fruit weight per cluster (-0.465**) showed a significant but negative correlation with ascorbic acid content. But fruit diameter (0.470**) showed a highly significant positive correlation. However, the ten fruit weight high significant positively correlated with pericarp thickness (0.744**) and fruit length (0.654**) at phenotypic level. Days to flower initiation recorded

high significant positive correlation with days to fruit maturity (0.671 and 0.703**) both phenotypic and genotypically. Also, phenotypically positive significant association was found for fruit length (0.410*).

Positive correlation was seen for fruit length in high significance with days to fruit maturity (0.520** and 0.579*) at both phenotypic and genotypic level, whereas, a highly significant negative correlation was recorded for number of locules per fruit (-0.652 and -0.759**) at both genotypic and phenotypic levels. At the phenotypic level, pericarp thickness was noted as a positive, highly significant correlation with fruit diameter (0.523**) and a significant correlation with days to fruit maturity (0.348*) at the phenotypic level. At both the phenotypic and genotypic levels, the correlation was negative but highly significant with the number of locules per fruit (-0.655 and -0.757**).

The current correlation analysis revealed that the genotypic correlation was higher than the phenotypic correlations, showing that the traits are highly heritable (Table 4.9 and 4.10). The analysis stated that number of fruit per plant, total soluble solids, and days to maturity, whereas, fruit length shows a highly significant and positive association at the phenotypic level.

The results are in agreement with the studies of Singh *et al*. (2004), Singh *et al*. (1990), Meena and Bahadur, (2014), Kumar *et al*. (2013), Sharma and Singh (2012), Phom *et al*. (2015), Jogi *et al*. (2018), Yadav *et al*. (2020), Joshi and Sridevi (2018), Sushma *et al*. (2020), Ritonga *et al*. (2018) for association between yield per plant and single fruit weight. Sushma *et al*. (2020), Singh *et al*. (2004), Kumar *et al.* (2013), for pericarp thickness. Jogi *et al.* (2018), Srinivasulu *et al*. (2020), for fruit length. Sushma *et al*. (2020), Phom *et al.* (2015), for plant height. Abhay and Kori (2008), Ara *et al*. (2009), Sharma *et al.* (2019), Kant and Mani, (2004) reported significant and positive association of yield with fruit/plant and plant height in tomato.

Srinivasulu *et al*. (2020) reported positive and significant correlation of fruit length with days to flower initiation, days to fruit maturity. Whereas, Sushma *et al*. (2020) reported for TSS content and the same is true for fruit diameter (Basfore *et al.,* 2020). Singh *et al*. (2021) noted a significant correlation for TSS content and pericarp thickness, TSS content has also been reported to be positively associated with single fruit weight, days to maturity and pericarp thickness (Sharma *et al.,* 2019). Basfore *et al*. (2020) observed that fruit

length showed significant correlation with pericarp thickness. A similar study by Sharma *et al.* (2019) reports that days to maturity shows significant association with average single fruit weight and pericarp thickness. Sushma *et al.* (2020) reported positive association of fruit length, fruit width, ascorbic acid, total soluble solids with fruit yield per plant. Number of locules per fruit also show correlation with fruit length as reported by Vijaylaxmi *et al.* (2021).Singh *et al*. (2015) noted significant association of average fruit weight with fruit length.

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Table 4.9: Phenotypic correlation coefficient among yield per plant and its component characters in tomato

	PH30	PH60	PH90	NFRPC	TSS	NFRPP	Vit.C	TFW	ACD %	DFI
PH30	1 **									
PH60	0.271	1 **								
PH90	0.752**	0.415 *	1 **							
NFRPC	-0.351*	-0.151	-0.051	1 **						
TSS	0.070	0.475**	0.201	-.0671	1 **					
NFRPP	0.426**	-0.187	0.355 *	0.109	-0.352 *	1 **				
Vit. C	-0.131	0.281	0.061	-0.069	0.001	-0.531 **	1 **			
TFW	-0.077	0.532**	0.0878	0.019	0.847**	-0.567 **	0.171	1 **		
ACD %	-0.388*	-0.264	-0.398 *	-0.131	-0.048	-0.221	0.078	-0.254	1 **	
DFI	-0.216	0.197	-0.099	0.2928	0.2830	0.061	-0.5072 **	0.2305	0.116	1 **
FL	-0.157	0.209	-0.149	-0.113	0.560**	-0.255	-0.271	0.6541**	-0.221	0.410 *
DM	-0.108	0.109	0.110	0.285	0.633**	0.150	-0.431**	0.490**	-0.001	0.671**
FD	-0.521 **	0.335*	-0.478 **	-0.268	0.060	-0.640 **	0.470**	0.360 *	0.160	9.00
NFLPC	-0.050	-0.326	-0.0745	0.1537	-0.1550	0.1971	0.1274	-0.2006	-0.097	-0.2802
FRWPC	0.416 *	0.332	0.362 *	-0.32	0.132	0.593**	-0.465**	-0.090	0.022	0.407 *
NO.LOPF	0.102	0.010	0.135	-9.0-04	-0.539**	0.463**	0.052	-0.600 **	0.312	-0.017
PT	-0.359 *	0.137	-0.261	-0.131	0.568**	-0.676 **	0.168	0.744**	-0.003	0.121
YPP	0.167	0.375 *	0.307	0.113	0.765**	0.131	-0.281	0.715**	-0.358 *	0.357 *

	FL	DM	FD	NFLPC	FRWPC	NO.LO/F	PT	YPP
FL	1 **							
DM	0.520**	1 **						
FD	0.282	-0.225	1 **					
NFLPC	-0.397 *	0.021	-0.194	1 **				
FRWPC	0.268	0.311	-0.220	-0.358 *	1 **			
NO.LO/F	-0.652 **	-0.263	-0.092	0.129	0.279	1 **		
PT	0.591**	0.348 *	0.523**	-0.106	-0.372 *	-0.655 **	1 **	
YPP	0.577**	0.785**	-0.143	-0.014	0.331 *	-0.307	0.338 *	1 **

**Significance at 5 % level *Significance at 1% level

PH30 PH60, PH90 - Plant height at 30,60,90 days after transplanting, DF- Days to flower initiation, DM-Days to fruit maturity, NFLPC- Number of flowers/cluster, FRWPC- Fruit weight per cluster , NO.LO/F- Number of locules per fruit, PT- Pericarp thickness ,NFRPC-Number of fruits per cluster, NFRPP- Number of fruits per plant, TFW- Ten fruit weight, YPP-Yield / plant, FL- Fruit length, FD-Fruit diameter, TSS- Total soluble solids, Vit.C - Ascorbic acid content, ACD %- Acidity (%) .

Table 4.10: Genotypic correlation coefficient among yield per plant and its component characters in tomato

	PH30	PH60	PH90	NFRPC	TSS	NFRPP	Vit.C	TFW	ACD%	DFI
PH30	1**									
PH60	0.351	1 **								
PH90	0.853**	0.461	1 **							
NFRPC	-0.270	-0.298	-0.056	1 **						
TSS	0.069	0.530	0.196	-0.083	1 **					
NFRPP	0.508	-0.198	0.404	0.068	-0.368	1 **				
Vit.C	-0.136	0.257	0.057	-0.116	-0.001	-0.556	1 **			
TFW	-0.071	0.619**	0.087	0.031	0.865 **	-0.566	0.170	1 **		
ACD%	-0.486	-0.238	-0.418	-0.151	-0.046	-0.261	0.100	-0.278	1 **	
DFI	-0.227	0.231	-0.106	0.343	0.293	0.071	-0.522	0.232	0.125	1 **
FL	-0.125	0.186	-0.151	-0.163	0.635 **	-0.268	-0.294	0.708 *	-0.232	0.450
DM	-0.076	0.127	0.110	0.308	0.655**	0.138	-0.440	0.503	-0.021	0.703*
FD	-0.585**	0.380	-0.502	-0.362	0.069	-0.695**	0.519	0.373	0.153	-0.010
NFLPC	-0.204	-0.429	-0.088	0.433	-0.192	0.286	0.221	-0.283	-0.120	-0.412
FRWPC	0.564	0.377	0.384	-0.333	0.134	0.609**	-0.489	-0.086	0.005	0.439
NO.LO/F	0.030	0.102	0.150	0.084	-0.595 *	0.527	0.093	-0.685 *	0.293	0.003
PT	-0.402	0.159	-0.268	-0.182	0.587 *	-0.758**	0.175	0.781**	-0.018	0.123
YPP	0.185	0.467	0.315	0.178	0.794**	0.136	-0.288	0.733**	-0.400	0.368

	FL	DM	FD	NFLPC	FRWPC	NO.LO/F	PT	YPP
FL	1 **							
DM	0.579 *	1 **						
FD	0.285	-0.253	1 **					
NFLPC	-0.540	0.053	-0.345	1 **				
FRWPC	0.219	0.340	-0.279	-0.506	1 **			
NO.LO/F	-0.759 **	-0.311	-0.082	0.188	0.327	1 **		
PT	0.632 *	0.364	0.528	-0.126	-0.405	-0.757 **	1 **	
YPP	0.629 *	0.816**	-0.155	-0.002	0.362	-0.426	0.332	1 **

**Significance at 5 % level *Significance at 1 % level

PH30 PH60, PH90- Plant height at 30,60,90 days after transplanting, DFI- Days to flower initiation, , DM-Days to fruit maturity, NFLPC- Number of flowers/cluster, FRWPC - Fruit weight per cluster, NO.LO/F- Number of locules per fruit, PT- Pericarp thickness, NFRPC - Number of fruits per cluster, NFRPP- Number of fruits per plant, TFW- Ten fruit weight, YPP-Yield / plant, FL- Fruit length, FD-Fruit diameter, TSS- Total soluble solids, Vit. C - Ascorbic acid content, ACD % - Acidity (%).

4.5 Path coefficient analysis

The correlation coefficient studies provide knowledge about the level of significance between various traits, whereas the path coefficient analysis provides more explanation of the relationship. It enables the partitioning of correlation coefficients into direct and indirect impacts of the traits that contribute to the dependent variable.

Many independent characters have an impact on dependent characters like yield per plant, both directly and indirectly. As a result, even if a character's correlation with yield is significant, it may not be evaluated for improvement because its association with yield could be attributable to the trait's indirect impacts on other characters. In such situations, path coefficient analysis is usually preferable to divide the correlation value into direct and indirect effects.

Data presented in Table 4.11 shows the path analysis of the genotypic correlations of yield per plant with its component characters. The direct effects of the characters on their correlation with yield are depicted diagonally in the table, while all other anti-diagonal estimates are their indirect contributions to their correlation with yield per plant via the relevant characters.

Direct effect estimates at the genotypic level

Among eighteen traits, ten characters showed a positive direct effect on yield per plant at the genotypic level. The characters showing a direct positive effect on yield per plant are organised in the following decreasing order: ten fruit weight (1.1705), number of fruits per plant (0.7406), fruit length (0.2411), number of locules per fruit (0.2212), ascorbic acid content (0.0764), acidity (0.0672), plant height at 60 days after transplanting (0.0609), number of flowers/cluster (0.0421),total soluble solids (0.0325) and pericarp thickness (0.0053).

Genotypically, a highly significant and positive direct effect was found between total soluble solids (0.791**), ten fruit weight (0.730**), days to fruit maturity (0.816**) and a significant positive direct effect was seen for fruit length (0.6189*) and yield per plant. The characters that had a direct negative effect on yield per plant were days to maturity (-0.058), plant height at 30 days after transplanting (-0.102), days to flower initiation (-0.106), number of fruits per cluster (-0.139), plant height at 90 days after transplanting (-0.258) and fruit diameter (-0.409).

Indirect effect estimates at the genotypic level

The Path analysis study on quality characters revealed the total soluble solids of fruit were found to have a highly positive indirect effect *via* plant height at 60 days after transplanting (0.0319), number of fruits per cluster (0.0121), ten fruit weight (0.9891),fruit length (0.1491) and pericarp thickness (0.0029). It had a high negative indirect effect via plant height at 30 days after transplanting (-0.0069), plant height at 90 days after transplanting (-0.0509),number of fruits per plant (-0.2698), ascorbic acid content (-0.0002), acidity (-0.0029), days to flower initiation (-0.0321), days to maturity (-0.0381), fruit diameter (-0.0279), number of flowers/cluster (-0.082),fruit weight per cluster (-0.0116) and number of locules per fruit(-0.1289).

The important yield contributing character i.e. ten fruit weight showed its effect on yield and had an indirect high positive effect *via* plant height at 30 days after transplanting (0.0697), plant height at 60 days after transplanting (0.0381), total soluble solids (0.0279), ascorbic acid content (0.0145), fruit length (0.1691), fruit weight per cluster (0.0080), pericarp thickness (0.0051).It had a high negative indirect effect *via* plant height at 90 days after transplanting (-0.0231), number of fruits per cluster (-0.0057), number of fruits per plant (-0.4202), acidity (-0.0192), days to flower initiation (-0.0253), days to maturity (-0.0276), fruit diameter (-0.1541), number of flowers/cluster (-0.0137), number of locules per fruit(-0.1482).

Plant height at 30 days after transplanting (0.0234), plant height at 90 days after transplanting (0.0277), total soluble content(0.0096), number of fruits per plant (0.0487), ten fruit weight (0.2704), acidity percent (0.0079), fruit length (0.1074), fruit diameter (0.0041), number of locules per fruit (0.0006), pericarp thickness (0.0007) had an indirect positive influence on days to flower initiation. Plant height at 60 days after transplanting (-0.0141), number of fruits per cluster (-0.0482), ascorbic acid content (-0.0403), days to flowering (-0.0781), days to maturity (-0.0402), number of flowers/cluster (-0.0172), and fruit weight per cluster had an indirect negative influence on days to flower initiation.

Days to fruit maturity was recorded as an indirect positive effect via plant height at 30 days after transplanting (0.0082), plant height at 60 days after transplanting (0.0079), total soluble solids (0.0221), number of fruits per plant (0.1021), days to flower initiation (0.0749), fruit length (0.1401), fruit diameter (0.1039), number of flowers per cluster (0.0023) and pericarp thickness (0.0021)

It had an indirect negative effect via plant height at 90 days after transplanting (-0.0292), number of fruit per cluster (-0.0432), ascorbic acid content (-0.0298), ten fruit weight (-0.0015), acidity percent(-0.0015), fruit weight per cluster (-0.0295) and number of locules per fruit (-0.669)

The path coefficient analysis technique was proposed by Wright (1921), and it was proven by Deway and Lu (1959). The correlation coefficients are classified as direct and indirect effect components through path coefficient analysis. The path coefficient is a normalized partial regression analysis that divides total correlation values into individual causal variables. The direct impacts of the characters on their association with yield per plant are represented diagonally in the path analysis of genotypic correlations of fruit yield per plant with its component traits. All other off-diagonal estimations illustrated the characteristics 'indirect effects on their connection with yield per plant (Table 4.11).

The ten fruit weight, number of fruits per plant, fruit length, number of locules per fruit, ascorbic acid content, acidity, plant height at 60 days after transplanting, number of flowers/cluster, total soluble solids, and pericarp thickness showed positive direct effects. Similar studies done by earlier researchers have also reported in same line like number of fruits per plant exhibited very high positive direct effect on fruit yield per plant by Singh and singh *et al.*(2018), Anuradha *et al.*(2018), Islam *et al.(*2010), Kumar *et al*.(2014), Kumar *et al.*(2018) and Rahman *et al*.(2015), Sushma *et al.*(2020), Nevani and Sridevi (2021) reported number of fruit/clusters had the highest positive direct effects on fruit yield/plant.

Meena and Bahadur (2014), Kumar *et al.* (2013), reported fruit weight had greatest positive direct effect on fruit yield per plant.

Plant height had a positive direct effect on yield per plant as reported by Nagariya *et al*. (2015), Chabbi *et al.* (2018), Haydar *et al*. (2007), Phom *et al*.(2015), Maurya *et al*.(2020), Vijaylaxmi *et al*. (2021), Naveen *et al*. (2017). For ascorbic acid content, Sushma *et al*. (2020) and Vijaylaxmi *et al*. (2021) reported positive direct effect for number of locules per fruit. Naveen *et al*. (2017), Vijaylaxmi *et al*. (2021),Singh *et al*. (2018), Anuradha *et al*. (2018), Bheemireddy *et al*. (2018), Jansirani and Khapte (2014),Konda *et al*. (2017), Jogi *et al*. (2018), Verma and Sarnaik (2000), Singh *et al*.(2015),Chabbi *et al*.(2018) reported direct positive effect for number of fruits per plant.

Again, in case of yield per plant, Maurya *et al*. (2020) and Naveen *et al*. (2017) observed direct positive effect for TSS content and acidity. Srinivasulu *et al*. (2020) and Vijaylaxmi *et al*. (2021) reported direct positive effect for fruit length. Meena and Bahadur, (2014), Haydar *et al*. (2007), Nagariya *et al*. (2015) reported positive direct effect for number of flowers and Jogi *et al.* (2018) observed direct positive effect of yield per plant with pericarp thickness.

Table 4.11: Genotypic path coefficient analysis for Yield per plant and other component characters in tomato

Traits	PH30	PH60	PH90	NFRPC	TSS	NFRPP	Vit.C	TFW	ACD%	DFI
PH30	**-0.1023**	0.0214	-0.2227	0.0379	0.0023	0.3676	-0.0102	-0.0840	-0.0298	0.0243
PH60	-0.0363	**0.0609**	-0.1202	0.0419	0.0174	-0.1591	0.0201	0.7290	-0.0159	-0.0251
PH90	-0.0882	0.0281	**-0.2588**	0.0079	0.0065	0.2732	0.0054	0.1014	-0.0179	0.0104
NFRPC	0.0278	-0.0182	0.0147	**-0.1395**	-0.0027	0.0497	-0.0079	0.0365	-0.0103	-0.0367
TSS	-0.0069	0.0319	-0.0509	0.0121	**0.0325**	-0.2698	-0.0002	0.9891	-0.0029	-0.0321
NFRPP	-0.0525	-0.0128	-0.1053	-0.0096	-0.0121	**0.7406**	-0.0398	-0.6498	-0.0167	-0.0078
Vit.C	0.0141	0.0157	-0.0147	0.0163	0.0000	-0.4221	**0.0764**	0.2011	0.0071	0.0559
TFW	0.0697	0.0381	-0.0231	-0.0057	0.0279	-0.4202	0.0145	**1.1705**	-0.0192	-0.0253
ACD%	0.0502	-0.0145	0.1089	0.0212	-0.0015	-0.2012	0.0088	-0.3301	**0.0672**	-0.0130
DFI	0.0234	-0.0141	0.0277	-0.0482	0.0096	0.0487	-0.0403	0.2704	0.0079	**-0.1067**
FL	0.0129	0.0113	0.0395	0.0229	0.0208	-0.1879	-0.0301	0.8202	-0.0161	-0.0470
DM	0.0082	0.0079	-0.0292	-0.0432	0.0221	0.1021	-0.0298	-0.0015	-0.0015	0.0749
FD	0.0601	0.0232	0.1309	0.0508	0.0023	-0.5354	0.0402	0.4223	0.0106	0.0009
NFLPC	0.0210	-0.0262	0.0230	-0.0608	-0.0063	0.2224	0.0180	-0.3324	-0.0079	0.0439
FRWPC	-0.0585	0.0230	-0.1001	0.0467	0.0044	0.4489	-0.0379	-0.1011	0.0004	-0.0398
No.Lo/F	-0.0031	0.0062	-0.0391	-0.0119	-0.0204	0.3743	0.0072	-0.8021	0.0201	-0.0003
PT	0.0415	0.0097	0.0699	0.0255	0.0192	-0.6012	0.0201	0.9014	-0.0011	-0.0129

	FL	DM	FD	NFLPC	FRWPC	No.L/F	PT	
PH30	-0.0297	0.0044	0.2398	-0.0085	-0.0485	0.0064	-0.0024	**0.185**
PH60	0.0443	-0.0073	-0.1565	-0.0179	-0.0324	0.0220	0.0009	**0.467**
PH90	-0.0361	-0.0063	0.2067	-0.0037	-0.0330	0.0324	-0.0016	**0.315**
NFRPC	-0.0388	-0.0176	0.1490	0.0180	0.0286	0.0183	-0.0011	**0.178**
TSS	0.1491	-0.0381	-0.0279	-0.0082	-0.0116	-0.1289	0.0029	**0.7913****
NFRPP	-0.0639	-0.0079	0.2926	0.0119	-0.0524	0.1140	-0.0043	**0.136**
Vit.C	-0.0702	0.0252	-0.2137	0.0092	0.0422	0.0202	0.0010	**-0.288**
TFW	0.1691	-0.0276	-0.1541	-0.0137	0.0080	-0.1482	0.0051	**0.730****
ACD%	-0.0555	0.0012	-0.0631	-0.0050	-0.0004	0.0633	-0.0001	**-0.400**
DFI	0.1074	-0.0402	0.0041	-0.0172	-0.0377	0.0006	0.0007	**0.368**
FL	**0.2411**	-0.0331	-0.1173	-0.0225	-0.0188	-0.1643	0.0037	**0.6189***
DM	0.1401	**-0.0583**	0.1039	0.0023	-0.0295	-0.0669	0.0021	**0.8166****
FD	0.0679	0.0145	**-0.4099**	-0.0144	0.0240	-0.0178	0.0031	**-0.156**
NFLPC	-0.1289	-0.0030	0.1422	**0.0421**	0.0435	0.0408	-0.0007	**-0.002**
FRWPC	0.0523	-0.0195	0.1148	-0.0211	**-0.0860**	0.0707	-0.0024	**0.362**
No.L/F	-0.1812	0.0178	0.0339	0.0079	-0.0281	**0.2212**	-0.0044	**-0.427**
PT	0.1523	-0.0208	-0.2174	-0.0052	0.0348	-0.1638	**0.0053**	**0.338**

$Residual [,1][1,] -0.0165 **Significance at 5 % level *Significance at 1% level

PH30 PH60, PH90- Plant height at 30,60,90 days after transplanting, DFI- Days to flower initiation, , DM-Days to maturity, NFLPC- Number of flowers/cluster, FRWPC- Fruit weight per cluster, No.Lo/F- Number of locules per fruit, PT- Pericarp thickness,NFRPC-Number of fruits per cluster, NFRPP- Number of fruits per plant, TFW- Ten fruit weight, YPP-Yield / plant, FL- Fruit length, FD-Fruit diameter, TSS- Total soluble solids, Vit.C- Ascorbic acid content, ACD % - Acidity (%).

Plate 4.1 Field view of Experimental Plot

Plate 4.2 Number of locules in different genotypes of tomato

Chapter 5 SUMMARY AND CONCLUSION

Tomato (*Solanum lycopersicum* L.) is an important remunerable vegetable crop of India as well as all over the world which is cultivated for its delicious fruit and other processed product. The goal of the experiment was to know the nature and magnitude of interrelationship existing between yield and its component characters as well as, the association among the component characters themselves, quantify genetic variability and exploring the potential of using it in the development of new recombinant genotypes with the goal of identifying the best genotype for a given environmental conditions. The present investigation, entitled – **"Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes"** was carried out at research farm of Department of Vegetable Science, Rani Lakshmi Bai Central Agricultural University (RLBCAU), Jhansi during *Rabi,* 2021- 2022. The present study was undertaken with the following objectives:

1. To study the phenotypic and genotypic diversity among tomato germplasm
2. To study the nature of association among yield and yield component traits
3. To study the biochemical parameters in tomato genotypes

The nature of variability and genetic parameters like genotypic coefficient of variance, heritability, genetic advance and genetic advance in percentage were estimated. The experimental materials comprising 24 genotypes, including both from public and private sectors, were collected from different parts of the country and experiment was conducted using a randomized block design for evaluation of interrelationships of yield and its attributes through genotypic and phenotypic correlation coefficients. Path analysis was used to determine the direct and indirect contribution of various attributes to the yield. In the present study following character were studied for quantitative traits *viz.*, plant height at 30, 60, 90 days after transplanting, days to flower initiation, days to fruit maturity, number of flowers/clusters, number of fruit per cluster, ten fruit weight, fruit weight per cluster, number of locules per fruit, pericarp thickness, number of fruits per plant, yield / plant, fruit length, fruit diameter, and qualitative traits like TSS content, ascorbic acid content, acidity. The following points summarize and conclude the research findings:

The analysis of variance show extremely significant difference among all 24 tomato genotypes for all the traits and indicating wide range of genetic variability and there are greater chances of improvement in all genotypes for the parameters studied.

1. Findings show quite higher PCV than the GCV, indicating that environmental factors influenced their expression in some sort. The range values of PCV and GCV lied between 10.36 to 58.25% and 9.45 to 56.78%, respectively. The highest value was observed for yield per plant (kg) and the lowest for fruit length (cm).
2. The higher values of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for the Days to fruit maturity (days), number of locules per fruit, pericarp thickness (mm), number of fruits per plant, ten fruit weight (g), fruit weight per cluster (g), yield / plant (kg). The results demonstrated that evident variation is caused not only by genetic factors, but also by environmental influences on the expression of these traits.
3. Moderate PCV and GCV was estimated for plant height at 30 DAT (cm), plant height at 60 DAT (cm), plant height at 90 DAT (cm), days to flower initiation (days) , number of flowers/cluster, number of fruits per cluster, total soluble solids (^{o}Brix), ascorbic acid (mg/100 g fresh weight), acidity (%),The presence of a considerable amount of genetic variation for most of the traits was proved and simultaneous assessments of PCV revealed the effect of the environment on the total variation. Whereas, the lowest estimates of GCV and PCV was observed for fruit length.
4. Except for the number of flowers/clusters, all of the traits have shown high values of broad sense heritability, indicating that they have strong genetic potential and less effect from the environment. The genetic advance as percent of mean were recorded very high for yield / plant followed by ten fruit weight, fruit weight per cluster, number of fruits/plant, pericarp thickness, number of locules per fruit, days to fruit maturity, TSS, acidity, plant height at 90 DAT, ascorbic acid, days to flower initiation, number of fruits per cluster, plant height at 30 DAT. Number of flower per cluster, plant height at 60 DAT, fruit diameter and fruit length were found to have moderate value.
5. The range values of heritability and genetic advance as percent of mean lies between 57.26% to 99.73% and 17.54 to 86.53, respectively. The highest value of heritability was observed for plant height at 90 DAT and the lowest for number of

flowers per cluster. The highest and lowest value of genetic advance as percent of mean is seen for yield per plant and fruit length, respectively.

6. High heritability together with high genetic advance as per cent of mean was observed for most of the characters except plant height at 30 and 60 DAT, number of flowers per cluster, fruit diameter and fruit length. The findings suggested that selection based on phenotypic performance would be more effective for the traits because of additive gene action.
7. Ten fruit weight, total soluble solids, days to maturity expressed positive and significant correlation with yield per plant at both the phenotypic and genotypic level whereas, fruit length shows a highly significant and positive association at phenotypic level, but only significant and positive at the genotypic level, indicating that increasing these component traits sequentially improves economic yield. Meanwhile, plant height, number of fruits per plant, and days to flower initiation all showed a positive but non-significant relationship with yield per plant.
8. The path analysis studies revealed that 10 parameters showed a positive and direct effect on fruit yield per plant. The characters like ten fruit weight, number of fruits per plant, fruit length, number of locules per fruit, ascorbic acid content, acidity, plant height at 60 days after transplanting, number of flowers/clusters, total soluble solids, pericarp thickness showed positive direct effect. Among them ten fruit weight followed by number of fruits per plant had highest direct effects on yield per plant had highest direct effects on yield per plant.
9. On the basis of mean performance and other genetic factors like CV, PCV, GCV, Heritability, Genetic advance, Correlation, direct effect with yield, five genotypes namely Heem Sohna, Arka Samrat, WS 42, TGP-93 and Kashi Hemant were found to be superior performing genotypes in Bundelkhand region.
10. The genotypes EC 620545 (72days), EC 620444 and RTS-30 (75days) and Heem Sohna (76 days) showed earliness in maturity. Whereas, genotypes Pusa Ruby, WS 42 and Heem Sohna recorded highest number of fruits per plant. However, quality wise Kashi Amrit, RTS-30 and Kashi Aadarsh were found to be better performing.

6. BIBLIOGRAPHY

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7. APPENDIX

Table 7.1 Meteorological data from December to April

Days	Temp.(^{0}C)		RH(%)		Wind velocity (km/h)
	Max.	Min.	Max.	Min.	
2nd Dec	24.4	10.5	88	55	3.2
(3-9) Dec.	23.6	9.8	86	59	2.9
(10-16) Dec	25.6	11.8	87	58	3.5
(17-23) Dec	24.5	6.9	86	57	3.1
(24-31) Dec	23.8	5.7	87	60	2.5
(01-07) Jan.	20.7	8.7	90	69	2.8
(08-14) Jan.	19.3	9.3	91	67	2.5
(15-21) Jan.	21.4	6.3	88	60	3.0
(22-28) Jan.	21	7.1	88	56	2.7
(29-04) Feb.	25.7	7.3	88	48	3.8
(05-11) Feb.	24.2	8.1	86	49	3.0
(12-18) Feb.	26.9	10.9	87	46	3.1
(19-25) Feb.	27.5	11.3	81	45	3.6
(26- 04) Mar.	32.1	14.2	83	41	3.7
(05-11) Mar.	32.8	14.3	81	43	3.9
(12-18) Mar.	31.7	14.5	80	39	4.2
(19-25) Mar.	34.2	16.6	80	38	4.1
(26-01) Apr.	38.0	15.8	77	32	4.3

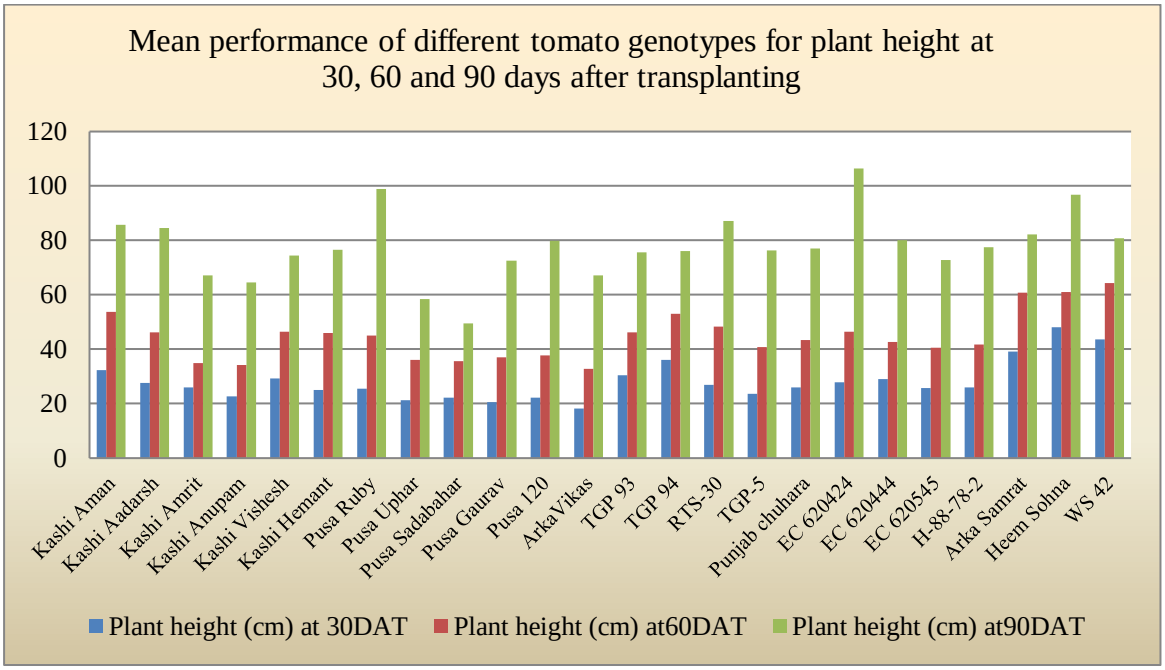

Fig.4.1: Frequency distribution of the plant height among the tomato genotypes

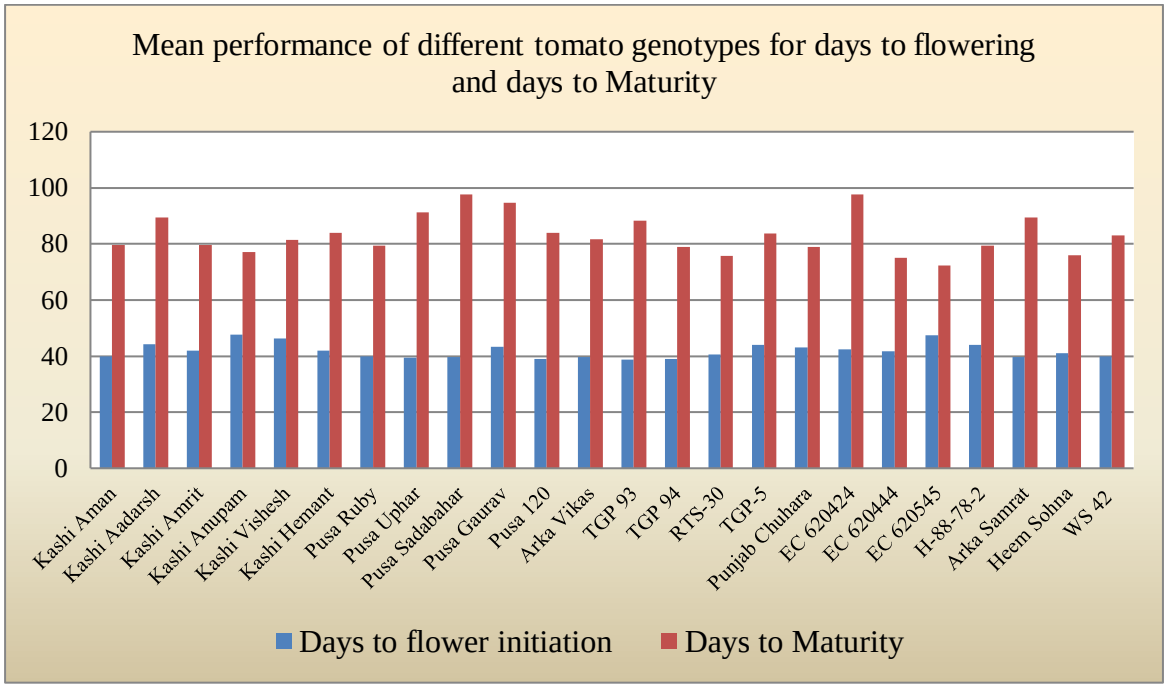

Fig.4. 2: Frequency distribution for the days to flowering and maturity

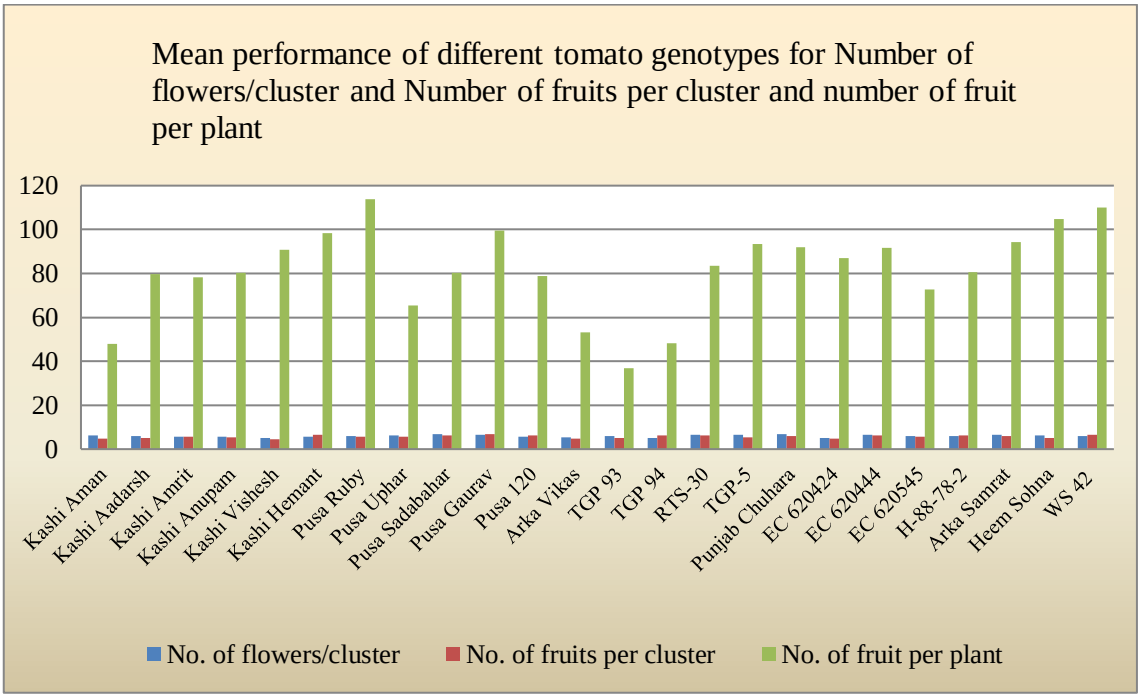

Fig.4.3: Frequency distribution for the for Number of flowers/cluster and Number of fruits per cluster and number of fruits per plant

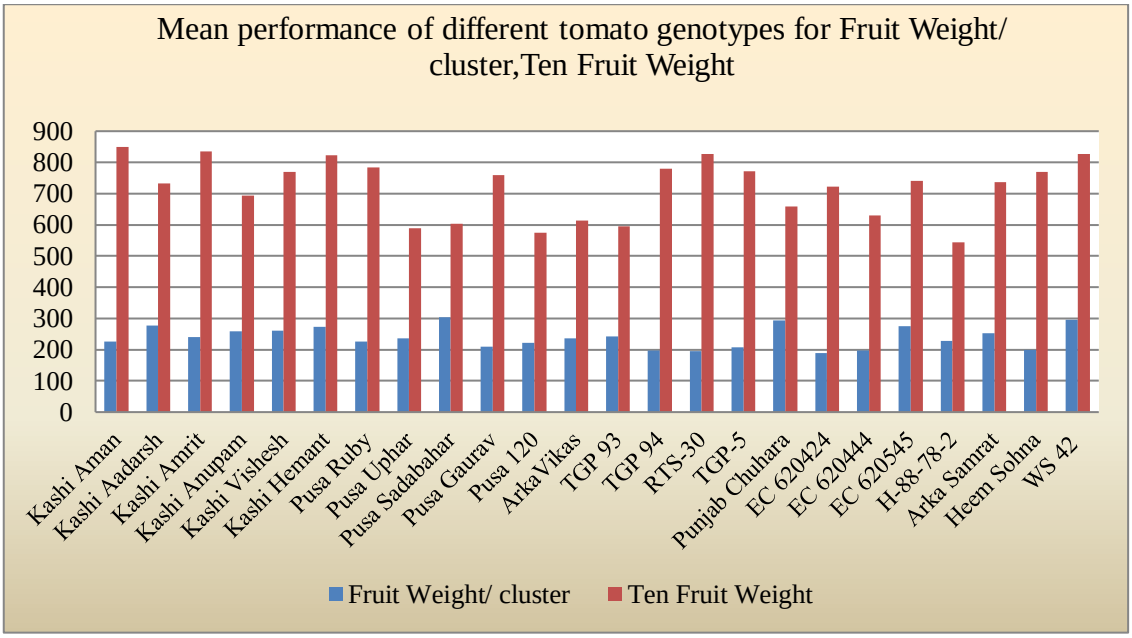

Fig.4.4: Frequency distribution for the fruit weight per cluster and ten fruit weight

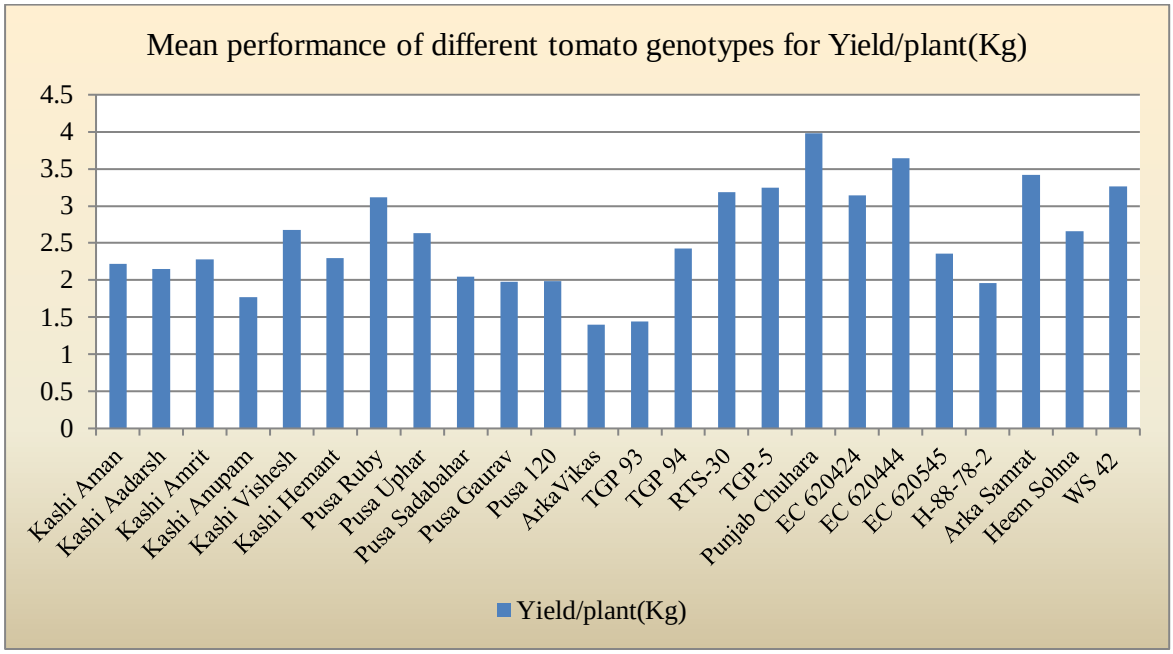

Fig.4.5: Frequency distribution for the mean performance of tomato genotypes for Yield/plant (Kg)

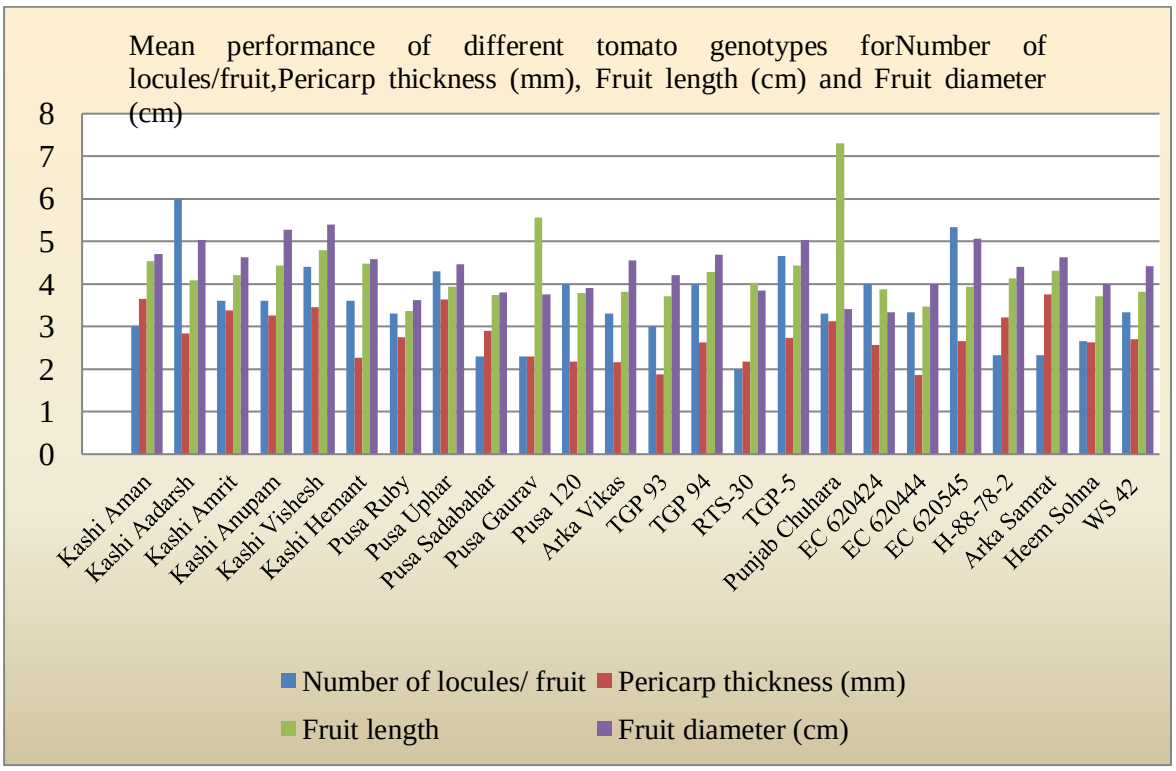

Fig.4.6: Frequency distribution for the locules number, pericarp thickness and fruit diameter

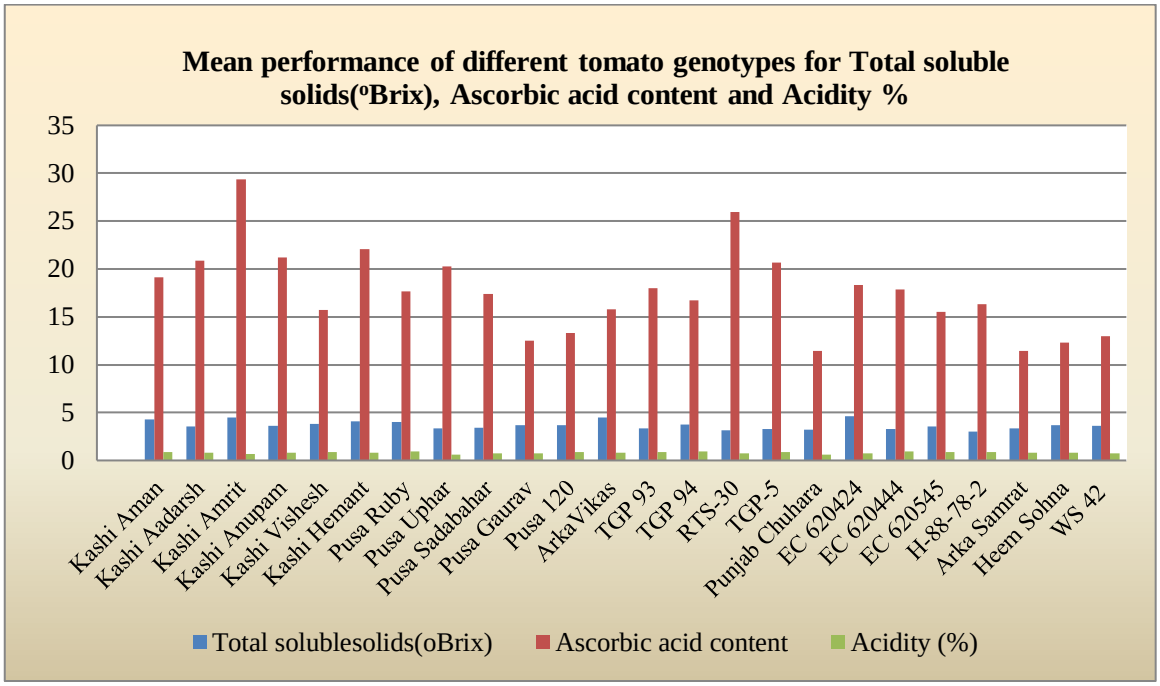

Fig.4.7: Frequency distribution for the TSS, Vitamin C and Acidity

Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes

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ABSTRACT

The present investigation entitled "**Morphological and Biochemical characterization of tomato genotypes for yield and quality attributes**" Was undertaken in Rabi season of the year 2021-22 at Research Farm of Department of Vegetable Science. Rani Lakshmi Bai Central Agricultural University, Jhansi. Twenty four tomato genotypes collected from both public and private sector of various parts of country were analysed for quantitative and qualitative characters viz., plant height at 30, 60 and 90 days after transplanting, days to flower initiation (days), days to fruit maturity (days), number of flowers/cluster, number of fruit per cluster, number of fruit per plant, fruit weight per cluster, ten fruit weight (g), yield per plant (kg), number of locules per fruit, pericarp thickness (mm), fruit length (cm), fruit diameter (cm), total soluble solids (°brix), ascorbic acid content (mg/100 g fresh weight) and acidity (%).

The estimates of GCV and PCV and Genetic advance as percent of mean were found higher for yield per plant followed by number of fruits per plants. While the highest value of heritability was observed for plant height at 90 days after transplanting, the range values of heritability and genetic advance as percent of mean were between 57.26% to 99.73% and 17.54 to 86.53, respectively.

Correlation studies revealed that yield per plant exhibited the highest positive and significant correlation with ten fruit weight, total soluble solids, and days to maturity. Path coefficient analysis revealed that the ten fruit weight followed by number of fruits per plants was having maximum direct positive effect on yield per plant. On the basis of mean performance and other genetic factors like CV, PCV, GCV, heritability, genetic advance, correlation, path analysis, five genotypes namely Heem Sohna, Arka Samrat,WS-42, TGP 93, Kashi Hemant were found to be superior performing genotypes in Bundelkhand region.Whereas, genotypes Pusa Ruby, WS – 42 and Heem Sohna recorded highest number of fruits per plant. However, quality wise Kashi Amrit, RTS -30 and Kashi Aadarsh were found to be better performing.

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टमाटर के आनुवांशिक प्रारूपों के रूपात्मक एवं जैव रासायनिक लक्षणों का उपज और गुणवत्ता पर प्रभाव का अध्ययन

नामः राज कुमार

आई. डी. संख्याःआरएलबीसीएयू/एच/पीजी/009/20

सेमेस्टर और प्रवेश का वर्षः IV और 2021–2022

डिग्रीः M.Sc. (हॉर्ट.)

विभागः सब्जी विज्ञान

प्रमुखः सब्जी विज्ञान

थीसिस शीर्षकः टमाटर के आनुवांशिक प्रारूपों के रूपात्मक एवं जैव रासायनिक लक्षणों का उपज और गुणवत्ता पर प्रभाव का अध्ययन

सलाहकारः डॉ. ए. के. पाण्डेय

सार

रानी लक्ष्मी बाई केन्द्रीय कृषि विश्वविद्यालय, झाँसी सब्जी विज्ञान विभाग के अनुसंधान फार्म में रबी मौसम, वर्ष 2021–22 में "टमाटर के आनुवांशिक प्रारूपों के रूपात्मक एवं जैव रासायनिक लक्षणों का उपज और गुणवत्ता पर प्रभाव का अध्ययन" शीर्षक के अंतर्गत शोधकार्य किया गया। अध्ययन में देश के निजी एवं सरकारी शोध संस्थानों से टमाटर के 24 जीनोटाइप एकत्रित किये गए। जिसमें अनुमोदित प्रजातियाँ, जंगली प्रजातियाँ जनन द्रव्य एवं उन्नत प्रजनक वंशक्रम समायोजित थी। इन सब जीनोटाइप का विश्लेषण रूपात्मक एवं जैव रासायनिक लक्षण जैसे अलग–अलग समय अंतराल पर पौधे की लम्बाई, फूल आने का समय, फूलो की संख्या, फलों की संख्या, दस फलों का वजन, उपज, फलों की लम्बाई, व्यास, कुल घुलनशील ठोस पदार्थ, विटामिन 'सी' और अम्लता प्रतिशत इत्यादि लक्षणों के आधार पर इनके औसत प्रतिशत, जी सी वी और पी सी वी के साथ–साथ आनुवांशिकता, आनुवांशिक अग्रिम प्रतिशत अनुपात का अध्ययन किया गया अध्ययन के फलस्वरूप यह पाया गया की औसत प्रतिशत के रूप में जी सी वी और पी सी वी और आनुवांशिक अग्रिम औसत मान प्रति पौधे उपज और उसके बाद प्रति पौधे फलों की संख्या के लिए अधिक पाया गया, जबकि रोपाई के 90 दिनों के बाद पौधे की ऊँचाई के लिए आनुवांशिकता का उच्चतम मूल्य पाया गया। आनुवांशिकता और आनुवांशिक प्रगति के औसत मान के प्रतिशत के रूप में क्रमशः 57.26 प्रतिशत से 99.73 प्रतिशत और 17.54 से 86.53 प्रतिशत के मध्य पाए गए। सहसंबंध अध्ययनों से पता चला है कि प्रति पौधे उपज में दस फलों के वजन, कुल घुलनशील ठोस पदार्थों और परिपक्वता के दिनों के साथ उच्चतम सकारात्मक और महत्वपूर्ण सहसंबंध प्रदर्शित किया। पथ गुणांक विश्लेषण से पता चला कि दस फलों के वजन के बाद प्रति पौध फलों की संख्या, प्रति पौधे उपज पर अधिकतम प्रत्यक्ष सकारात्मक प्रभाव डाल रही थी। औसत प्रदर्शन और अन्य आनुवांशिक कारकों जैसे जी सी वी, पी सी वी, आनुवांशिकता, आनुवांशिक अग्रिम, सहसंबंध, पथ विश्लेषण के आधार पर, पाँच जीनोटाइप क्रमशः हेम सोहना, अर्का सम्राट, डब्ल्यूएस–42, टीजीपी–93 एवं काशी हेमन्त का बुन्देलखण्ड क्षेत्र में बेहतर प्रदर्शन रहा। जीनोटाइप ईसी 620545, ईसी 620444 और आरटीएस–30 ने फल परिपक्वता के दृष्टि से अगेती थे। यद्यापि गुणवत्ता के आधार पर काशी अमृत, आरटीएस–30 और काशी आदर्श का अच्छा प्रदर्शन रहा।

राज कुमार
राज कुमार

सलाहकार
डॉ. ए. के. पाण्डेय

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Acadamic Qualification

DEGREE	BOARD/ UNIVERSITY	INSTITUTION/ SCHOOL	YEAR OF PASING	PERCENTAGE
M.Sc (Horticulture) Vegetable Science	Rani Laxmi Bai Central Agricultural University	College of Horticulture & Forestry	2022	86.50%
B.Sc (Hons) Horticulture	Banda University Of Agriculture and Technology Banda U.P	College of Horticulture	2020	84.92%
10+2/Pre University/Intermediate	U.P Board Prayagraj	H R D Inter College Biswan Sitapur	2016	77.33%
10th/ High School	U.P Board Prayagraj	H R D Inter College Biswan Sitapur	2014	80.33%

DECLARATION

I do hereby declare that all information given above is true to the best of my knowledge and belief.

Place: Jhansi

Your truly

Raj Kumar

Raj Kumar