EVALUATION OF F_2 POPULATIONS OF TOMATO THROUGH ASSESSMENT OF HERITABILITY AND CHARACTER ASSOCIATIONS

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Evaluation of F_2 Populations of Tomato Through Assessment of Heritability and Character Associations

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CERTIFICATE

This is to certify that thesis entitled, **" Evaluation of F_2 populations of tomato through assessment of heritability and character associations "** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING**, embodies the result of a piece of bona fide research work carried out by SHIRAZUM MUNIRA BINU, Registration No. 15-06717 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated:
Place: Dhaka, Bangladesh

(Prof. Dr. Jamilur Rahman)
Supervisor

Dedicated to my Supervisor, Co-supervisor and Beloved Parents

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The Author

Evaluation of F_2 populations of tomato through assessment of heritability and character associations

Shirazum Munira Binu

Abstract

The present study was investigated to find degree of genetic variability, heritability, and genetic advance of the yield and its contributing attributes among F_2 populations of tomato. The research study was conducted in a randomized complete block design (RCBD) with three replications during the rabi season 2020-2021 at the Sher-e-Bangla Agricultural University, Dhaka. The F_2 populations were characterized for morphological traits e.g. days to first flowering, days to fruiting, plant height, branches per plant, cluster per plant, fruits per plant, and yield per plant. Analysis of variance regarding morphological attributes showed highly significant differences ($P\leq 0.01$) among tomato F_2 populations. Minimum days to first flowering and days to first fruiting were recorded for genotype P_3 (23.33 days and 40.33 days), respectively. Maximum plant height, clusters per plant, fruits per plant, and single fruit weight were observed for C12, C5, C5, and C4 with values of 118.22 cm, 9.89, 38.89, and 100.47 g. Little differences were observed between the phenotypic coefficient of variation and genotypic coefficient of variation for all traits except branches per plant and cluster per plant indicating that most of the traits were minor influenced by environmental factors for their phenotypic expression. All traits had high broad heritability (h^2b), but only branches per plant (42.90) were found moderate heritability. Low genetic advance as a percent of mean (9.62) was recorded for days to first fruiting. Moderate genetic advance was found in fruit diameter (15.59) and plant height (19.21). Low to moderate genetic advance suggests the action of both additive and nonadditive genes and the favourable influence of environment in the expression of the mentioned traits. Yield per plant was positively and significantly associated with plant height (0.417** and 0.317*), branches per plant (0.370** and 0.276*), cluster per plant (0.519** and 0.393**), fruits per plant (0.573** and 0.507**), fruit diameter (0.355** and 0.493**) and single fruit weight (0.586** and 0.447**) at both genotypic and phenotypic level. High positive direct effects on total yield per plant were shown by plant height (6.263) followed by single fruit weight (3.611), number clusters per plant (2.610), fruit length (2.178) and fruits per plant (0.367). Plant height, single fruit weight, cluster per plant having high positive direct effects along with positive significant correlation with yield indicating that these traits can be selected for the improvement of fruit yield. Positive and highly significant heterosis was found in F_2 population for number of fruits per plant in cross C5 (23.68%) and C1 (8.13%) over better parent and cross C5 (79.48%), C6 (60.51%), C1 (56.92%) and C9 (41.03%) over standard parent and for fruit yield per plant cross C8 (45.50%), C5 (45.39%), C12 (33.53%) and C6 (30.42%) over better parent and cross C5 (51.82%), C1 (44.92%), C6 (44.17%), C4 (29.37%) and C3 (29.10%) over the check variety. The crosses C5 (23.68% and 79.48%) for number of fruits per cluster, C8 (50.72%) and C4 (49.46%) for single fruit weight showed significantly high percentage of positive heterosis over better and standard parent, respectively. The cross C1 (-28.91%), C10 (-31.25%), C6 (-20.56%) showed negative heterosis for days to first flowering. Based on the desired morphological traits and heterosis manifestation of the yield attributing traits of the F_2 population, the cross combination C1, C5, C6, C8, could be selected for further improved and advancement of the lines to develop stable inbred lines for future tomato breeding program.

LIST OF CONTENTS

LIST OF TABLE

LIST OF PLATE

LIST OF APPENDICES

LIST OF ABBREVIATED TERMS

FULL NAME	ABBREVIATION
Agro-Ecological Zone	AEZ
And others et at	et.al.
Bangladesh Agricultural Research Institute	BARI
Bangladesh Bureau of Statistics	BBS
Centimeter	Cm
Co-efficient of Variation	CV
Days After Transplanting	DAT
Degree Celsius	^{0}C
Degrees of freedom	df.
Etcetera	etc.
Food and Agriculture Organization	FAO
Genetic Advance	GA
Genotypic Co-efficient of Variation	GCV
Genotypic Variance	6^2g
Gram	G
Hectare	Ha
Heritability in broad sense	h^2b
Journal	J.
Kilogram	Kg
Meter	M
Mean Sum of Square	MS
Millimeter	Mm
Muriate of Potash	MP
Number	No.
Percent	%
Phenotypic Co-efficient of Variation	PCV
Phenotypic variance	6^2p
Randomized Complete Block Design	RCBD
Sher-c-Bangla Agricultural University	SAU
Standard Error	SE
Square meter	m^2
Triple Super Phosphate	TSP

CHAPTER I
INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a self-pollinated crop that belongs to the family Solanaceae with chromosome number (2n=2x=24) and native to Central and South America (Vavilov, 1951). Popularly tomato is called as 'Love Apple'. It is considered a nutritional crop because it contains vitamin A and C, minerals, sugar, organic acids, and lycopene (Rana *et al.*, 2014). Total cultivated area and production of tomato was 73,151.55 acres and 442299.6 (M. Tons) in Bangladesh for the fiscal year 2021-2022 (BBS), respectively.

Tomato belongs to large and diverse Solanaceae family also called as nightshade (Bauchet and Causse, 2012). Deeming its importance on world level it is indispensable to develop new varieties and hybrids which could encounter the environmental changes at global level. Like other self-pollinated crops, hybridization, mass and pedigree selection methods are being used to bring novelty in the existing genetic resources of this crop. Selection is the most decisive stage after hybridization where breeders have to select or reject the lines in the segregating generations. Due to environmental effects the superior lines may fail to perform well in any generation, consequently there is risk of screening out of precious genetic material. Therefore, the major problem faced by plant breeders in trying to improve self-pollinated crop is the identification of genotypes having high yield potential in the segregating generations (Singh and Sharma, 2016).

In breeding generations, F_2 through F_6 are the critical stages for selection and evaluation of the segregating lines. The breeders have to evaluate the segregating lines during these stages and selection is made at each successive stage. As the selection for each generation is done in next year, one should also take into consideration the change in environment form one year to next year. Sometime the selected lines or all the population which has performed well in previous year may show low performance in the next year. The accurate selection from F_2 to F_6 stages can be made sure by calculating the means, variance (additive, environmental and phenotypic), heritability and genetic advance. However during year to year selection and evaluation some time unexpected results may be obtained due to change in environmental conditions. Brown and Caligari (2008) noticed that year to year environmental variation is always unpredictable and the highest yielding progeny lines derived from F_2 and F_3 generation may fail some time to produce the highest yield in the segregating populations.

Hybridization is the most common method of creating the variation (Holme *et al.* 2019; Afifah *et al.* 2021; Lopez-Gomollon *et al.* 2022), including in tomato plants as one crop of significant economic prospects (Quinet *et al.* 2019). The effectiveness of hybridization is highly dependent on the genetic background of the parents used in the crossing program. The Further, the genetic distance between the two parents, the higher or wider the diversity of the resulting lineage (Wei and Zhang, 2018). Farid *et al.* (2022) have performed crosses of various tomato parental lines with different genetic backgrounds, especially on the shape of the fruit and its lycopene content.

In the present investigation the research plant material were different F_2 populations of tomato, hence the selection of these lines must be carried out systematically with a good accuracy approach. Single selection with productivity is considered very risky because the yield is polygenic with a complex genetic pattern (Anisa *et al.* 2022). This indicates that multi-character selection needs to be carried out systematically in the F_2 tomato populations (Medico *et al.* 2020).

Selection is the most decisive stage after hybridization where breeders have to select or reject the lines in the segregating generations. Therefore, the major problem faced by plant breeders in trying to improve self-pollinated crop is the identification of genotypes having high yield potential in the segregating generations. In breeding generations, F_2 through F_6 are the critical stages for selection and evaluation of the segregate. The breeders must evaluate the segregating lines during these stages and selection is made at each successive stage. (Mehboob *et al.*, 2018).

The genetic variability is the valuable raw material of vegetable breeding industry on which acts to evolve superior genotypes. The higher amount of variation present for a character in the breeding materials, the greater is the scope for its improvement through selection. In tomato, yield is the cumulative effect of many component characters individually contributing towards yield. The knowledge of association of fruit yield with its component traits helps in success in a breeding program (Singh *et al.*, 2002). However, genetic variation is the true heritable variation which is not influenced by the environmental effects. Phenotypic and genotypic coefficients of variation measure the amount of variability present in a population (Ismaeel *et al.*, 2019). Phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability and genetic advance reveal that selection for fruits per plant, fruit weight, would be effective for improvement of fruit yield. (Manna and Paul 2012).

Heritability is the level of genotypic variance to the aggregate phenotypic variance, which contains both genetic and environmental variance. Genetic advance is the enhancement in the

mean phenotypic estimation of the chosen plants over the parental populace. Genetic advance gives evidence of expected gain resulting from the determination of higher individuals. Evaluation of heritability alongside a genetic advance blend is more valuable in predicting the increase beneath choice than heritability alone (Iqbal *et al.*, 2018). Selection for the traits having high heritability coupled with genetic advance is likely to accumulate more additive genes leading to further improvement of their performance. The characters showed high heritability along with moderate or low genetic advance which can be improved by intermating between superior genotypes of segregating populations (Patel *et al.*, 2015).

Heterosis or hybrid vigour is manifested as an improved performance of F_1 hybrids generated through crossing of two genetically diverse parents. Heterosis breeding provides an efficient means to break the yield barrier in most of the crops including tomato. Knowledge of the extent of heterosis for yield and its various component characters is a prerequisite to bringing improvement through heterosis breeding. Heterosis in tomato was first observed by Hedrick and Booth (1968) for higher yield and more fruits. Since then, heterosis for yield, its components, and quality traits were extensively studied. Choudhary *et al.* (1965) emphasized the extensive utilization of heterosis to step up tomato production.

There is pressing need to increase the productivity to the increasing demand. Despite the a huge economic importance of tomato, growers often produce a good quality tomato with high productivity due to lack of early and high yielding variety, also due to various biotic factors viz., pest and disease, abiotic factors, viz., rainfall, temperature, relative humidity, and light intensity, and other crop factors viz., flowers and fruits dropping etc. Therefore, the present research work undertaken to study tomato segregating F_2 populations for the identification of superior individual segregating tomato plants, which will be finally helped in development of potential advance breeding tomato lines in future. The lines could be used to breed new varieties having the desired traits e.g. high yielding, earliness, higher quality, and productivity with resistant or tolerance to biotic and abiotic stress in future.

Yield is an ultimate goal to improve and it is a complex character; therefore, it is necessary to judge the genetic variability of characters concerning different characters which helps in planning a successful breeding program to develop suitable variety. For the genetic improvement of the tomato crop, the basic requirement is to utilize or create genetic variability.

Therefore, present investigations were undertaken to study the evaluation of genetic variability, character associations and heterosis in F_2 populations of tomato with the following objectives:

01. To estimate genetic variability among the F2 populations of tomato

02. To assess the correlation and path coefficient among the yield and yield attributes.

03. To calculate the heterosis in the F_2 populations of tomato.

CHAPTER II

REVIEW OF LITERATURE

Tomato is an introduced crop in Bangladesh. It has a diploid genome with 12 pairs of chromosomes (2n=24). Tomato is a crop species that is elaborated in many studies of breeding, genetics, and genomics in plants. Various resources are currently available for its research, which could lead to an increase in tomato biology evaluation (Barone *et al.,* 2008). Many investigations have been carried out using various genes to investigate its genetic variability (Carelli *et al.*, 2006, Asamizu and Ezura, 2009, Martinez *et al.*, 2006). Apart from the fact that just a few cultivars have achieved genetic uniformity, the high degree of genetic uniformity in tomato cultivars is impacted not only by domestication away from the centre of origin but also by the significant genetic improvement that resulted in uniformity.

In this chapter, some of the most imperative and convenient works and research findings incorporated on this topic that has been done at home and abroad under the following headings:

2.1. Nomenclature, origin, and distribution

Tomato (*Solanum lycopersicum* L.) is a multiple-harvesting edible fruit that is an autogenous species with a narrow genetic base. Its stature is around one to three meters in tall, with semi woody stem which usually scrambles over neighbouring plants.

Tomatoes were introduced into Europe from the Americas. After that, it became known to botanists about the middle of the sixteenth century. After that, the scientific naming of tomatoes, including wild species, is linked to the theory of diversity in *Solanum Iycopersicum,* which is a cultivated species. According to Pietro Andrea Matthioli (1544), tomatoes were introduced for the first time with the common name "Pomi d'oro" (Golden Apples) in the first edition (written in Italian) of his 'Commentary' upon the work of the 1st century Greek botanist Discords of Anazarbos. In the Latin edition, Matthioli (1554) referred to tomatoes as "Mala aurea" (the Latin equivalent of Golden Apple). Matthioli greatly enriched the tomato description with Italian traditional knowledge. He uses plants previously not known in Europe, and many editions of Matthioli's work were translated into different languages throughout Europe (Watson, 1989).

Before standardized scientific naming different names in different languages were used to name tomatoes at the time. Pre-Linnaean botanists usually used polynomial, or phrase, names, consisting of several words and described the plant itself and distinguishing it from all others. They did not employ today's genus and species concepts but did seek to name plants in a way that reflected their affinities. Interestingly, early botanists found a close relationship between tomatoes with the genus *Solanum*, and after that, they referred to them as *S. pomiferum* (Luckwill, 1943). Tournefort (1694) was the person who naming first the cultivated tomatoes Lycopersicon ("wolf peach" in Greek). Tournefort placed forms with large multilocular fruits in the set of plants he called Lycopersicon, but kept the plants with bilocular fruits as *Solanum.* Linnaeus (1753) which began to consistently use Latin binomials in Species Plantarum, as polynomials were becoming too complicated. It also was difficult to memorize. He classified tomatoes in the genus Solanum and described *S. Iycopersicum* (the cultivated tomato) and *S. peruvianum*. The very next year Miller (1754) followed Tournefort (1694) and he formally described the genus *Lycopersicon*. Miller did not approve of Linnaeus's binomial system, and until 1768 he continued to use polynomial phrase names for all plants (Miller, 1768). Miller's circumscription of the genus Lycopersicon also included the vegetable potatoes as "*Lycopersicon* radice tuberose, esculentum" which was supported by the argument that "This Plant was always ranged in the Genus of Solanum, or Nightshade, and is now brought under that Title by Dr. Linnaeus; but as Lycopersicon has now been established as a distinct Genus, on account of the Fruit being divided into several Cells, by intermediate Partitions, and as the Fruit of this Plant [the potato] exactly agrees with the Characters of the other species of this Genus, I have inserted it here."

Later, Miller (1768) began to use Linnaeus' binomial system. He also published descriptions under Lycopersicon for several species, among them *L. esculentum, L. peruvianum, L. Pimpinellifolium,* and *L. tuberosum* (potatoes). In the posthumously published edition of the gardener's and botanist's dictionary the editor, Thomas Martyn, followed Linnaeus. They merged Lycopersicon back into Solanum. Following Miller's early work, a number of classical and modern authors recognized tomatoes under Lycopersicon, but other taxonomists included tomatoes in Solanum.

The tomato was given the nickname "wolf peach" because it was spherical and juicy, and wolf because it was mistakenly thought to be toxic (Fillipone, 2014). The English term "tomato" is derived from the Spanish word tomate, which is derived from the Nahuatl (Aztec) word tomato,

which means "swelling fruit." It was published for the first time in 1595. Tomatoes, which are members of the deadly nightshade family, were mistakenly assumed to be poisonous by Europeans who were suspicious of their bright, shining fruit (although the leaves are poisonous). Native varieties were small, like cherry tomatoes, and yellow rather than red (Filippone, 2014).

The tomato is a South American and Central American native (Filippone, 2014). Tomatoes are tropical plants that may be found in practically every part of the planet, from the tropics to just below the Arctic Circle. The most likely centre of tomato domestication has been identified as Mexico. Italy and Spain are considered secondary diversification centres (Gentilcore, 2010). The cultivated tomato evolved in the South American region of Peru, Ecuador, and Bolivia (Vavilov, 1951). Spain, Brazil, Iran, Mexico, Greece, Russia, China, the United States, India, Turkey, Egypt, and Italy are all major tomato producers. The tomato is thought to have arrived in India during the British colonial period. It may grow in a variety of environments. One cultivated species and 12 wild cousins have been identified in tomatoes (*Solanum lycopersicum* L.) (Peralta *et al*., 2008). Modern cultivars and hybrids have a little genetic variation (Chen *et al.*, 2009). The cultivated tomato genome is thought to have fewer than 5% of the wild counterparts' genetic diversity (Miller and Tanksley, 1990). Domestication and inbreeding, according to Yi *et al*. (2008), reduced genetic variety significantly.

2.2 Nutritional and medicinal value of tomato

Tomatoes are now eaten spontaneously over all the world. Their consumption is proved to benefit the heart among other organs. Lycopene is one of the most powerful natural antioxidants which is found in tomatoes. In some studies, lycopene in cooked tomatoes has been found to help prevent prostate cancer and has also improved the skin's ability which is able to protect against harmful UV rays (World Cancer Research Fund, 2007). Tomato is termed "the most popular vegetable fruit". It is a fruit of good source of nutrients such as vitamins (vitamin C), and other minerals like calcium, phosphorus, and iron.

Sharon (2009) research revealed that against the risk of colorectal cancers, lycopene provides a protective effect and may help reduce the risk of pancreatic cancer. Tomato products help to decrease the risk of prostate cancer due to high concentration of lycopene, a potent antioxidant (Tzonou *et al*,. 1999), others have failed to show this benefit (Cohen *et al.*, 2000). In recent years, especially in relation to prostate cancer and tomato products have been the focus of

intense investigation (Stacewicz-Sapuntzakis & Bowen, 2005). As Giovannucci *et al.* (1999) reported the epidemiological literature on the relationship between intake of tomatoes and tomato-based products and plasma levels of lycopene and added the risks of various cancers. Tomatoes are a very good source of potassium and a good source of niacin, vitamin B6, and folate. Diets rich in potassium have been shown to lower high blood pressure and it is reported that it can reduce the risk of heart disease (Sanjiv and Rao, 2000). Natural chlorine which is found in tomatoes helps to stimulate the liver. Tomato also helps and assists the liver in removing toxic waste products from the system. Fresh tomato juice can help to regenerate the damaged, destroyed, or surgically removed liver (International Cyber Business Services, 2000).

2.3 Variability

The user key to finding the genetic enhancement of a crop over a proper breeding program and process is to assess the amount and nature of variation of plant traits. Variability is a useful thing that can help the breeder for improving the selection efficiency. Many researchers already study about the variability of various characteristics in tomatoes.

Any crop improvement program's effectiveness is determined by the amount of genetic variability and the degree to which the desired traits is heritable. Both morphological and molecular indicators can be used to determine genetic variability. Previous scholars have underlined the occurrence of genetic heterogeneity in breeding material (Naz *et al.*, 2013; Reddy *et al.*, 2013). Here are some of the prior research reports that have been mentioned.

Bhuiyan *et al.* (2016) conducted studies on genetic variability experiments on 18 genotypes and found that the fruit yield per plant had the greatest range of variation and the highest mean value. Days to maturity, plant height, number of clusters per plant, number of fruits per cluster, number of fruits per plant, and yield per plant all indicated greater environmental influence on their expression.

While working with the genetic variability among the yield-contributing traits and their direct and indirect contributions to yields, Paul *et al.* (2014) discovered significant differences among genotypes and identified better combinations as selection criteria for developing high-yielding tomato genotypes

Naz *et al.* (2013) led a field experiment that was about to study the genetic variation among twenty-five tomato accessions that helped in the reliable varietal selection program for breeding. Two parameters were used to analyse all tomato accessions e.g. morphological and molecular parameters. The height of the plant, fruit colour, and fruit size show variability in this research.

In another case, Reddy *et al.* (2013) used nineteen exotic collections of tomatoes which revealed considerable genetic variability for all the eighteen quantitative characters which was pertaining to growth, earliness, yield, and quality. Fruit weight, plant height, and the number of fruits per plant show the total variation.

Alam *et al.* (2012) gathered many tomato accessions for comparing the genomic material of the BARI released varieties to that of other commercially available varieties. They also advised that a multivariate and biochemical investigation of genetic affinity among tomato cultivars is required before any development program can be established.

In a field experiment to explore the genetic variation across 30 tomato germplasm lines, Shashikanth *et al.* (2010) found that the range of variance and mean values for plant height, days to 50% blooming, and average fruit weight was all high. He also noticed that most of the characters had a lot of genotypic variances, indicating that the genetic component contributed a lot to the total variation. The evaluation aids breeders in enhancing selection efficiency. Many scholars looked into the variations of various tomato characters. Some of them are shown below.

Morphological trait measurements can provide a simple technique and also quantify genetic variation. It also simultaneously assesses genotypic performance and characters under relevant growing environments (Shuaib *et al.*, 2007). Some of the previous research reports which are related in this case are discussed here.

Mahesha *et al.* (2006), has figured out the significant variability for all the characters under study and marked a wide range of variation for plant height, number of branches per plant, fruit weight, fruit length, fruit diameter, fruit set percentage, fruits per plant, fruit yield per plant. On the basis of phenotypic characteristics like colour, size, taste, etc. a number of germplasms are available in tomatoes.

Singh *et al.* (2006) performed a field experiment on 15 advanced generation breeding lines of tomatoes where they studied the variation for total soluble solids (TSS), pericarp thickness, fruit firmness, acidity, lycopene content, and dry matter content and figured out the significant differences among the genotypes under normal conditions. On the other hand, the differences were not significant under high-temperature conditions. During November than February planting the population mean was higher for all the characters except acid content and TSS. Singh (2005) conducted a field experiment in which he used 30 tomatoes and five genotypes (DT-39, RHR-33-1, ATL-16, DARL-13, and RT-JOB-21) showed a maximum number of primary branches than the control. From BT-117-5-3-1 the maximum number of fruits per plant was obtained. Fruit yield was higher (1.84 kg/plant) in DT-39. Total soluble solids content was higher in fruits in most of the cultivars compared to the control. The acidity percentage in fruits was highest in KS-60. The physiological loss in weight at seven days was highest in NDT-111 and lowest in Plant T-3. ATL-13 showed the highest lycopene content (59.67 mg/100 g).

Agong *et al*. (2001) has shown a large and significant variation in the quantitative traits between the accessions and evaluated the Kenyan tomato germplasm. The average fresh and dry fruit weight varied notably among the accessions.

Most of the landraces gave lower fresh and dry fruit yields than the market cultivars. According to Mohanty and Prusti (2001) Research, a considerable genetic variability among 18 indigenous and exotic tomato cultivars for five economic characteristics (plant height, number of branches per plant, number of fruits per plant, average fruit weight, and yield) in Orissa, India during rabi 1998-99. The fundamental key to achieving the genetic improvement of a crop through a proper breeding programme is to find out and calculate the amount and nature of variation of plant characteristics in the breeding population. The assessment helps the breeder for improving the selection efficiency. Many researchers studied variations of various characters in tomatoes. Some of those studies are presented here.

2.3.1 Days to first flowering

Nalla *et al.* (2014) did a field experiment using 27 tomato genotypes and reported days to 50% flowering (1.14%) contributed very little to variability. Thirteen quantitative characters were

studied in 55 genotypes of tomato by Narolia *et al.* (2012) who found high variability for all the characters studied except the number of branches per plant and days to flowering for which variability was moderate 15 and low, respectively. The stability of five cultivars of tomatoes for growth and earliness was determined in a field experiment by Ravindra *et al.* (2003). Significant genotype × environment interaction was observed for several days to flowering.

Farzaneh *et al.* (2013) showed earliness in a number of days to first flowering while studying combining ability from a 9x9 diallel cross. Whereas Monamodi *et al.*, (2013) had not found any significant differences in days to first flowering among tomato genotypes. Kumari *et al.* (2007) recorded data for total soluble solids, dry matter content, Vitamin C, lycopene, pH, days to flowering, days to maturity, individual fruit weight, fruit length, fruit diameter, the total number of fruits per plant, plant height, early yield, and total yield and found that there were highly significant differences for all the characters among parents except pH, early yield, total yield, and days to flowering.

Matin *et al.* (2001) reported significant differences among the 26 tomato genotypes for days to first flowering ranging between 49.67 and 68.33 days. He also reported that the phenotypic variance was comparatively higher than the genotypic variance indicating high degrees of environmental effect for days to first flowering.

Chadha *et al.* (2001) conducted an experiment to determine the number of combinations demonstrating combining ability for days to blooming and discovered that only 3% of 40 F_1s had the high specific combining ability. In a 9 x 9 half diallel analysis in tomatoes, Baishya *et al.* (2001) found that many of the crosses out of 36 showed acceptable negative heterosis over the superior parent for days to blooming.

According to Dhaliwal *et al.* (2002), extremely substantial variance for 16 GCA and SCA was discovered in combining ability experiments for days to blooming in tomatoes. Cheema *et al.* (2003) found significantly significant differences in General and Specific combining skills in tomato plants (*Solanum lycopersicum* L.)

Singh *et al.* (1997) conducted an experiment on heterosis breeding in tomato. Eight cultivars with diverse values for quantitative characters were crossed in a diallel set. Data on yield and nine component traits were recorded for the 28 F_1 hybrids and parents. Hybrids Punjab Chhuhara × 84-8, HS102 × Pusa Ruby, HS102 × 84-8 and Pusa Ruby × 84-10 showed

significant negative heterosis for days to first flowering over the better parent, indicating their potential for producing an early crop. Hybrid Punjab Chhuhara × 84-8 showed the highest heterosis for fruit yield plant-1 (1200 g).

Biswas and Mallik (1989) observed that a minimum of 66 days was necessary for first flowering for cv. Selection-7 and a maximum of 83 days for cv. Mtuatham in an experiment with 18 promising cultivars of tomato considering local cultivar Patharkutchi as control at Mymensingh reported significant variation for days to first flowering in six cultivars of tomato. The phenotypic variance was comparatively higher than the genotypic variance indicating high degrees of environmental effect for days to first flowering (Aditya, 1995 and Matin, 2001). Geogieva et al. (1969) reported that pre-flowering periods of the varieties ranged from 56 to 76 days.

2.3.2 Plant height (cm)

According to Paul *et al.* (2014), substantial differences between different tomato genotypes were identified in all parameters tested, except for the height of the first leaf appearance at the seedling stage.

Naz *et al.* (2013); has performed an experiment where they used 25 tomato germplasm to characterize morphologically by comparing the height of the plant, leaf length, shape and arrangement, and fruit shape and size. This study revealed that the height of the plant shows the highest variability. Kumari *et al.* (2007); conducted an experiment where the highest genotypic coefficient of variation for plant height was found.

Joshi *et al.* (2004) conducted a field experiment with forty tomato genotypes to evaluate their genetic variability and has found that plant height gave the highest heritability (78.82%). Shravan *et al.* (2004), Prasad and Mathura (1999) and Aditya and Phir (1995) reported significant variations in plant height.

Hannan *et al.* (2007) held an experiment, where they estimated heterosis and character association in 45 single cross hybrids, obtained from 10 parental lines of tomato for yield and yield component traits. The characters studied were plant height, days to first flowering (DFF), number of flowers per cluster (NFPC), number of fruits per plant (NFPP), fruit weight per plant (FWPP), and days to first fruit ripening. They obtained significant differences among genotypes for all the traits and found positive high significant hererosis for FPP (72.9, 75.33

and 20.74), TFWPP (189, 172 and 187), NFPC (48.65, 44.14 and 37.86) over the mid parent, better parent and standard parent heterosis, respectively, and significantly high percentage of positive heterosis for NFPP, TFWPP and NFC. They concluded that five hybrids possessed significant positive useful heterobeltiosis for TFWPP, positively correlated with FPP, NFPC and Plant height. They selected three single cross hybrids for their heterotic performance.

Ravindra *et al.* (2003); have found significant genotype x environment interaction for plant height. Parthasarathy and Aswath (2002), conducted a study with 23 genotypes of tomato and figured out a considerable variability among genotypes for 8 morphological characters. Plant height, fruit number, fruit size were contribute higher variability among them.

Singh *et al.* (2002); carried out a field experiment where 92 tomato genotypes were used to study genetic variability and reported that the analysis of variance revealed highly significant genetic variation for plant height, number of days to first fruit set, number of fruit clusters per plant, number of fruits per plant, fruit weight per plant and fruit yield. The traits characterized by adequate variability may be considered in a hybridization program for yield improvement in tomato.

Matin and Kuddus (2001), held an experiment where they reported that phenotypic variance was relatively higher than genotypic variance for plant height. They again observed that genotypic co-efficient of variation was lowering than phenotypic co-efficient of variation indicating influence of environment for expression of this character. Ghosh *et al.* (1995); and Nandpuri *et al.* (1974) reported a high degree of variation for plant height.

In another experiment, a narrow range of variations in plant height was observed by Ahmed *et al.* (2016). Dev *et al.* (1994); reported heterosis in tomatoes in a line × tester analysis. Appreciable heterosis was seen for the nine characters studied over their respective better parent. Heterosis over the better parent ranged from 0.05 to 115.7%, the minimum being for plant height and the maximum for number of fruits per plant. They concluded that the best F_1 hybrid was EC156 × Marglove, which gave 83.18 and 29.23% greater yields than the better parent and the control variety, respectively.

Farkas (1993), figured out the problems in heterosis breeding of tomato. In a strain × 5 tester analysis in which the maternal parents had a morphological marker ah and positional sterility gene (ps2, s16). He found high GCA variances for early and total yield, mean fruit weight and

fruit firmness, but not for plant height and width. Estimation of GCA effects indicated that the maternal parent was superior in early and total yield. He also added that GCA and SCA effects were not directly related to the observed performance of hybrids for given characters. Moreover, heterosis effects compensated for a yield decrease in hybrids of the processing type.

Sonone *et al.* (1986) and Prasad and Prasad (1977) also reported in tomato high phenotypic and genotypic co-efficient of variation for plant height were seen. Mallik (1985) stated that than genotypic co-efficient of variations for plant height lower than phenotypic co- efficient of variations in tomato.

2.3.3 Number of branches per plant

Upadhyay *et al.* (2005); evaluated 34 genotypes of tomatoes where they found a range between 2.33-7.0 branches per plant. He stated that the PCV (35.93%) was higher than GCV (24.72%) for this character.

Singh *et al.* (2005); led a field experiment with 30 tomato and five genotypes (DT39, RHR-33-1, ATL-16, DARL-13 and RT-JOB-21) Where higher number of primary branches than the control was shown. The maximum number of fruits per plant was obtained from BT-117-5-3-1. Fruit yield was maximum (1.84 kg/plant) in DT-39. Most of the cultivars showed higher total soluble solids content in their fruits compared to the control. The acidity percentage in fruits was highest in KS-60. The physiological loss in weight at 7 days was highest in NDT-111 and lowest in Plant T-3. ATL-13 showed the highest lycopene content (59.67 mg/100 g).

Singh (2005), Mohanty (2003) observed in their study that GCV was slightly lower than PCV for the number of branches per plant.

Shravan *et al.* (2004) conducted an experiment where 30 tomato genotypes were used to study their genetic variability and reported significant differences for number of primary branches per plant among the genotypes. Ravindra *et al.* (2003) observed remarkable genotype x environment interaction for a number of primary branches.

Singh *et al.* (2002) carried out a field experiment where they worked with 92 tomato genotypes to study genetic variability and concluded that the analysis of variance revealed highly significant genetic variation for plant height, number of days to first fruit set, number of fruit clusters per plant, number of fruits per plant, fruit weight per plant and fruit yield. The traits

characterized by adequate variability may be considered in a hybridization program for yield improvement in tomato.

Singh and Singh (1993), performed an experiment on heterosis breeding in tomato. In a diallel set eight cultivars with diverse values for quantitative characters were crossed. Data on yield and nine component traits were recorded for the 28 F_1 hybrids and parents. Hybrid Punjab Chhuhara × 84-8 showed the highest heterosis for fruit yield per plant (1200 g). Heterosis for this hybrid was also superior for the number of fruits per plant and early yield over the mean parent, and number of branches per plant over the better parent.

2.3.4 Number of clusters per plant

Dufera (2013) conducted an experiment using twenty-one tomato germplasm. Higher genotypic and phenotypic coefficient variation values were recorded by the character fruit clusters per plant, indicating the presence of variability among the genotypes and the scope to improve these characters through selection.

Singh *et al.* (2006) observed a considerable range of genetic variability for yield and yield components in the materials under study and maximum genotypic coefficient of variation found for a number of clusters per plant.

2.3.5 Number of fruits per plant

Thakur (2009) assessed seventeen different tomato genotypes for their performance and interaction with varying settings using traits such as fruit yield and number of fruits per plant. For all of the traits investigated, the analysis of variance revealed extremely significant differences in genotypes and environments. The variance in accessions was observed by Saeed *et al.* (2007). They found that the number of fruits per plant had the highest coefficient of variation, followed by number of flowers per plant and yield per plant.

Samadia *et al.* (2006); evaluated 14 cultivars of tomato where he found PCV and GCV for this character almost similar. In contrast Arun *et al.* (2003); evaluated 37 genotypes of tomato and observed the GCV was lower than PCV for Number of fruits per cluster.

Joshi and Kohil (2003); conducted a field experiment with forty tomato cultivars to assess their genetic variability, counting the number of fruits per plant that provided the highest phenotypic and genotypic coefficient of variation.

The quantity of fruits per plant had a favourable direct effect on yield and a negative indirect effect on average fruit weight, according to Mohanty (2003). Similar result was observed by Aradhana and Singh (2003).

Singh *et al.* (1997) derived information on genetic variability, heritability and yield correlations from data on 14 agronomic and yield-related traits in 23 genotypes of tomato. They reported that based on heritability and genetic advance values, effective selection may be made for fruit weight and number of fruits per plant as fruit yield showed a strong positive correlation with a number of fruits per plant and number of fruits per cluster. They also recommended that number of fruits per plant and number of fruits per cluster are the most important characteristics for consideration in a selection programme for improvement of yield.

Brar *et al.* (2000) calculated the phenotypic and genotypic coefficients of variation for 186 tomato genotypes and found considerable variability in the features of a number of fruits per plant.

For a number of fruits per plant, Islam *et al.* (1996) found a wide range of genotypic variance. Singh *et al.* (1997) investigated yield-related character variability in 23 tomato genotypes and found that phenotypic variation was high but genotypic variation was low in 14 of them.

2.3.6 Fruit diameter (cm)

Saleem *et al.* (2013), reported that twenty-five F_1 hybrids generated from 5×5 dialled crosses were evaluated to study the quantitative genetics of yield and some yield related traits. The highest estimates of genotypic and phenotypic coefficients of variability were recorded for number of fruits per plant. In the other hand fruit diameter was the most heritable trait.

Kumari *et al.* (2007) recorded data for fruit diameter, and they figured out that there were highly significant differences among parents.

Anupam *et al.* (2002) evaluated 30 genotypes of tomato. Similar results for this character were found. Singh *et al.* (2002) concluded that for this character phenotypic co-efficient of variation was greatest.

2.3.7 Fruit length (cm)

Chishti *et al.* (2008); was performed an experiment where they worked on the analysis of combining ability for yield, yield components, and quality characters in tomato (*Lycopersicon esculentum* Mill.), on plant material comprising 12 parental lines and their F_1 hybrids (direct crosses). The data was recorded on days to flowering, number of flowers per cluster, number of fruits per cluster, number of marketable fruits per plant, fruit length, fruit width, and fruit weight, fruit yield per plant, pericarp thickness, and fruit firmness at the red stage, total soluble solids and pH of juice. Analysis of variance revealed highly significant differences among genotypes, parents and hybrids and also shown highly significant mean squares due to GCA and SCA for all the characters.

Kumari *et al.* (2007) recorded data for fruit length. He found that there were highly significant differences in this character among parents. Where Singh *et al.* (2002) reported a high phenotypic coefficient of variation for fruit length.

2.3.8 Single fruit weight

Farzaneh *et al.* (2013) conducted an experiment and found significant variation due to general combining ability (GCA) as well as specific combining ability (SCA) in which except number of fruits per plants it also indicated the importance of additive and nonadditive types of gene action in inheritance of all characters.

Kumar *et al.* (2004); and Shravan *et al.* (2004); studied genetic variability where they used 30 tomato genotypes in Utter Pradesh of India and found a significant difference in average fruit weight among the genotypes.

Mohanty (2003) carried out in a field experiment and finding out genetic variability of 18 tomato cultivars and observed that positive direct effects shown on the average fruit weight on the yield and negative indirect effects on number of fruits per plant.

Singh *et al.* (2002) performed a field experiment to study genetic variability of fifteen heat tolerant tomato. He showed high phenotypic (PCV) and genetic (GCV) coefficients of variation for average fruit weight. Kumar and Tewari (1999) also got the similar results in their experiments with tomato.

Aditya and Phir (1995) said in his experiment that analysis of variances showed highly significant mean squares due to variety for average fruit weight among the 44 varieties of tomato. Phenotypic variance and phenotypic co-efficient of variation were bigger than genotypic variance associated with genotypic co-efficient of variation. In the study of genetic variability in 23 genotypes of tomato. Singh *et al.* (1997) concluded that phenotypic variation was quite large but genotypic variation was low.

Padmini and Vadivel (1997) performed an experiment where they studied genetic variability of six F2 crosses and their parental cultivars and found that progeny of cross In Memory 5.30 p. m. X PKM-1 produced the highest mean values for individual. They also reported that fruit weight small difference was observed between genotypic and phenotypic variance for individual fruit weight.

Sahu and Mishra (1995), reported that in 16 lines of tomato, fruit weight had high genotypic co-efficient of variation. Reddy and Reddy (1992) worked on phenotypic and genotypic variances, phenotypic and genotypic co-efficient of variation for individual fruit weight. For average individual fruit weight considerable variation was observed. F

Ahmed *et al.* (2016), reported that for individual & unit weight among four genotypes of tomato a wide range of variation was observed. He also reported that in four tomato varieties namely EC32099, HS102, HS107 and Columbia, genotypic co-efficient of variation was very high for individual fruit weight.

Sonone *et al.* (1986) reported that genotypic and phenotypic variances were high for individual fruit weight in the study of genetic variability with 13 genetically diverse tomato lines. Arora *et al.* (1982) reported that a wide range of variation in fruit weight of four genotypes of tomato was observed. He also reported that in four tomato varieties, genotypic coefficient of variation was very high for individual fruit weight.

2.3.9 Fruit yield per plant (kg)

Singh *et al.* (2009) used Mahalar statistics to examine the genetic divergence of 48 genotypes. They discovered that the clustering pattern revealed no correlation between genotype distribution and genetic divergence. They came to the conclusion that fruit yield per plant, fruit number, average fruit weight, plant height, and fruit output were the most important factors in genetic divergence.

Singh *et al.* (2006); observed in their study that considerable range of genetic variability for yield, yield components, and biochemical characters in the materials. They also reported the maximum genotypic coefficient of variation was recorded for number of leaves per plant, which was followed by number of clusters per plant.

Kumar *et al.* (2004) studied the higher genotypic co-efficient of variation for average yield per plant among thirty-two tomato genotypes. According to Matin and Kuddus (2001), for yield per plant among the genotypes, significant differences tested. He also added that phenotypic variance was little higher than genotypic variance indicating slight environmental influence on this trait.

Sachan (2001) conducted an experiment where he used certain tomato genotypes. He also reported among the genotypes for yield per plant significant differences were found. Brar *et al.* (2000) reported for average yield per plant among the 186 genotypes, high degrees of variation tested.

Reddy and Gulshanlal (1990) observed considerable variations for yield per plant in 139 tomato varieties. Sonone *et al.* (1986) and Dudi *et al.* (1983) concluded that genotypic and phenotypic variances were high for average yield per plant.

2.4 Heritability and genetic advance

Selection of plants based on phenotypic features is the most critical undertaking in all plant breeding procedures. The efficacy of yield selection is determined by heredity. A character with a high heritability responds to selection well. Heritability and genetic advance are the most important parameters to judge the breeding potentiality of a population which is very important for future development through selection. Many researchers have studied heritability and genetic advance of yield and many yield-contributing characteristics of tomatoes. The literature which is very relevant to the present study is reviewed below:

Naime (2016) discovered that all of the characters studied in her study, such as plant height, number of branches per plant, number of flowers per plant, number of fruits per plant, and so on, had the greatest heritability value.

During her work with 28 tomato genotypes to explore diversity, Nur-unnahar (2015) discovered strong heritability as well as high genetic progress as a percent of mean in plant height, individual fruit weight, and fruit output per plant.

At the genotypic and phenotypic level, Bhuiyan (2014) found a substantial positive link with fruit yield per plant in single fruit weight, number of branches per plant, and number of fruits per plant. Plant height had a non-significant negative link with seed yield per plant, whereas days to maturity, fruits per cluster, and percent brix content had a high significant negative correlation at the genotypic and phenotypic level.

Saleem *et al.* (2013) conducted a study of quantitative genetics of yield and some yield-related traits. The highest estimates of genotypic and phenotypic coefficients of variability (GCV and PCV) were recorded for number of fruits per plant. On the other hand fruit width was the most heritable trait.

Buckseth *et al.* (2012) figured out throughout his experiment that high heritability with high genetic advance for number of fruits per plant, average fruit weight, and yield per plant and pericarp thickness indicating that most likely the heritability is due to additive gene effects and selection may be effective.

Narolia *et al.* (2012) conducted an experiment where thirteen quantitative characters were studied in 55 genotypes of tomatoes. High heritability coupled with high genetic advance as percent of mean was observed for all the characters except days to 50% flowering indicating the presence of additive gene action in the expression of these characters.

Pandit *et al.* (2010) evaluated 12 varieties of tomatoes to estimate heritability. He reported that high heritability coupled with high genetic advance as a percentage of the mean for average fruit weight, indicating the control of such character by the additive gene. High heritability coupled with low genetic advance as a percentage of the mean for rest of the characters except pericarp thickness, indicating most of the characters were governed by non-additive genetic components were also recorded.

According to Ponnusviamy and Muthukrishnan (2010), were evaluated of 12 varieties of tomatoes to estimate heritability and reported that high heritability coupled with high genetic advance as a percentage of the mean for average fruit weight, indicating the control of such

character by the additive gene. He also recorded that high heritability coupled with low genetic advance as a percentage of mean for the rest of the characters except pericarp thickness, indicating most of the characters were governed by non-additive genetic components.

Shashikanth *et al.* (2010) observed that for plant height, days to 50% flowering and average fruit weight the range of variation and mean values were high. He also figured out that high genotypic variance for most of the characters indicates a high contribution of the genetic component for the total variation.

Golani *et al.* (2007) evaluated 20 tomato genotypes and observed high heritability with a high genotypic coefficient of variation where genetic gain for 10-fruit weight, number of locules per fruit and fruit yield, could be improved by simple selection. Kumari *et al.* (2007) reported that the estimates of heritability were high for all the characteristics and for plant height, moderate for total number of fruit bearing branches, weight per fruit and days to maturity, genetic advance was high while the remaining characteristics had low values of genetic advance.

Nardar *et al.* (2007) studied with 20 tomato genotypes and observed high heritability with high genotypic coefficient of variation and genetic gain for fruit weight and fruit yield, where through simple selection it could be improved.

According to Padda *et al.* (2007), broad sense heritability was highest for number of fruits per plant (96.56%), which was followed by number of flowers per plant (93.45%), reflecting the effectiveness of selection in the present germplasm of tomato improvement.

Saeed *et al.* (2007); observed that for number of fruits per plant (96.56%), followed by number of flowers per plant (93.45%) broad sense heritability was highest which reflecting the effectiveness of selection in the present germplasm of tomato improvement. Kumar *et al.* (2006) observed high genetic advance (35.55) and low heritability (4.40%) for plant height.

Number of leaves per plant, average weight of fruits, number of fruits per plant, and plant height were estimated to have high heritability with high genetic advance, whereas number of locules per fruit, dry matter content, pericarp thickness, and yield per plant had high heritability with low genetic advance (Singh *et al.*, 2006).

Mahesha *et al.* (2006) estimated expected genetic advance and heritability and in 30 genotypes of tomato and observed that fruit weight, fruits per plant and plant height exhibited very high

heritability values along with high genetic gain. It indicated the importance of considerable additive gene effects and therefore greater emphasis should be given on these characters while selecting the better genotypes in tomato. Kumar *et al.* (2006) found that plant height has a high genetic progress (35.55) and a low heritability (4.40%).

Heritability for nineteen genotypes of tomato and were estimated and found high heritability for ascorbic acid content, average weight of fruits and number of fruits per plant. Estimates of high heritability with high genetic advance was recorded in case of number of leaves per plant, average weight of fruits, number of fruits per plant and plant height, whereas high heritability with low genetic advance was recorded for number of locules per fruit, dry matter content, pericarp thickness and yield per plant (Singh *et al.*, 2006).

Heritability was estimated by Singh *et al.* (2005) and showed that heritability estimates (in the broad sense) were high for all the characters. According to Joshi *et al.* (2004); moderate heritability and moderate genetic gain for number of fruits per cluster, fruit length, fruit breadth, stem end scar size, number of locules per fruit, whole fruit firmness, ascorbic acid content and plant height indicating additive gene effects were observed. Moderate heritability and low genetic gain for harvest duration suggests the presence of dominance and epistatic effects.

Kumar *et al.* (2004) estimated in 30 tomato genotypes heritability and genetic advance for the characters like number of primary branches per plant, plant height, number of fruits per plant, fruit yield per plant and average fruit weight. The average fruit weight showed high heritability that ranged from 89.10% to 96.50%. The rest of the characters showed moderate heritability and low genetic advance.

Heritability and genetic advance estimated by Shravan *et al.* (2004) in 30 tomato genotypes for the characters like number of primary branches per plant, plant height, number of fruits per plant, fruit yield per plant and average fruit weight. The average fruit weight showed high heritability. The rest of the characters showed moderate heritability and low genetic advance. Moderate heritability associated with moderate genetic advance for plant height of 37 tomato genotypes of tomato were reported by Arun *et al.*, (2004).

Joshi and Singh (2003); conducted a field experiment with forty tomato genotypes to evaluate their genetic variability and noticed that plant height gave the highest heritability. Mohanty (2003) observed that high heritability with high genotypic coefficient of variation was for fruit

weight, plant height, number of fruits and number of branches per plant. Hanson *et al.* (2002) proposed heritability as the ratio of genotypic variance to the total variance in a non-segregating population. Since, the estimate of heritability gives indication of the amount of progress expected from selection, as they are most meaningful when accompanied by estimate of genetic advance. Genetic advance is the measure of improvement that can be achieved by practicing selection in a population.

Singh *et al.* (2002) reported that for all characters except days from fruit setting to red ripe stage heritability was high. The highest genetic advance was predicted for average fruit weight, followed by shelf life of red ripe fruits. High degrees of heritability and genetic advance for fruits per plant, individual fruit weight and number of seeds per fruit were reported by Matin and Kuddus (2001).

Brar *et al.* (2000) figured out that low to moderate estimates of heritability shown on the number of fruits per plant, total yield per plant and marketable yield per plant had and genetic advance and number of marketable fruits per plant had high values of heritability and genetic advance.

Nessa *et al.* (2000) reported that for number fruits per plant, plant height had high heritability where moderate heritability for yield per plant. Prasad and Mathura (1999) and Vikram and Kohli (1998) found very high heritability along with high genetic advance by fruit weight.

Phookan *et al.* (l998) studied and estimated that high heritability and genetic advance in percentage of mean were 4 estimated for fruits per plant and average fruit weight suggesting their importance in selection for tomato improvement.

Singh *et al.* (1997) estimated that in 23 genotypes of tomato heritability and genetic advance. High values of heritability and genetic advance indicated that effective selection may be made for fruit weight and number of fruits per plant.

Islam *et al.* (1996); conducted an experiment where he studied heritability and genetic advance in 26 diverse genotypes of tomato. High heritability and genetic advance was observed in number of fruits per plant, plant height, fruit yield and individual fruit weight.

Mittal *et al.* (1996) estimated heritability in 27 genotypes of tomato with genetic advance. High heritability associated with high genetic advance was observed by them indicating the

character, predominantly under the control of additive gene, could be improved through selection.

Aditya and Phir (1995), concluded that for number of fruits per plant, individual. Fruit weight and plant height high heritability (in broad sense) with high genetic advance in percentage of mean. However, moderate heritability had shown in case of yield per plant and low genetic advance but highest genetic advance as percentage of mean under selection.

According to Pujari *et al.* (1995), high heritability coupled with high genetic advance was observed for number of fruits per plant, plant height and average fruit weight which indicated additive gene action.

Naidu (1993) reported number fruits per plant, plant height and moderate heritability for yield per plant shown high heritability. Godekar *et al.* (1992) found high values for heritability along with high genetic advance by fruit weight.

Reddy and Reddy (1992) performed an experiment where heritability and genetic advance studied in 139 tomato varieties. Heritability values were high for yield per plant, number of fruits per fruits per plant and average individual fruit weight.

Bai and Devi (1991) worked and studied with five varieties and nine hybrids of tomato. Heritability estimates high for plant height, number of fruits per plant and individual fruit weight. Islam and Khan (1991) studied 12 tomato genotypes where they figured out that heritability values were high for most of the characters but moderate for days to first flowering, maturity and plant height.

Kasrawi and Amr (1990) reported that in a study of seven quality characters using F_2 populations, pH gave comparatively higher heritability estimates. Singh *et al.* (1988) studied 32 genotypes for agronomic characters and obtained high heritability values for yield per plant only.

Abedin and Khan (1986) conducted a study where high values of heritability in a broad sense and high genetic advance for plant height, number of fruits per plant, and individual fruit weight.

Sonone *et al.* (1986) reported on tomatoes that the heritability estimates for fruit number, plant height, and individual fruit weight were high. They also reported that in the case of fruit yield, plant height, individual fruit weight, and number of fruits per plant was high genetic advance.

Mallik (1985), reported high genetic advance for plant height, number of fruits per plant, individual fruit weight and yield per plant where in another hand low heritability for yield per plant. Dudi *et al.* (1983) found that heritability and genetic advance were high in the case of number of fruits per plant, individual fruit weight and yield by per plant. Singh and Singh (1980) concluded that high heritability for average fruit weight, total fruits and days to first picking.

Nandpuri *et al.* (1977) conducted an experiment and observed that heritability estimates were high for fruit size, plant height and yield per plant in tomato. Expected genetic advance was found high for fruit size, yield and number of fruits per plant.

2.5 Correlation coefficient

Correlation is an estimate between the characters to evaluate the inter-relationships between traits. It will help the breeders to choose selection techniques. Because of yield is one of the main targets of most of the breeders for that in most cases, correlation between yield and yield contributing traits was studied. The yield contributing characters are also correlated among the traits. For effective selective planning of breeding programme for maximization of yield, association of traits with yield and among its components is important. Such association studies may vary due to agro climatological variable change from year to year. If any component of yield has higher heritability than yield itself and there is positive correlation between these, then there may be some possibility to increase in the total yield by selecting that component. But, in case of negative correlation co-efficient among yield components were generally observed indicating selection for any component might not bring improvement for yield. It has already found that many authors have studied correlation between yield and yield contributing characters of tomato. Some recent literatures which are related are reviewed in this section.

Kumar *et al.* (2013) evaluated forty nine genotypes of tomato (*Solanum lycopersicum* L.) For various quantitative and quality traits by. The character association analysis indicated that total numbers of fruits/plant were significantly and positively correlated with gross yield (g/plant), marketable yield (g/plant), number of marketable fruits/plant and plant height (cm).

Mahapatra *et al.* (2013) figured out that fruit yield had positive and significant correlation with plant height, number of primary branches per plant, number of flower clusters per plant, number of fruits per plant, fruit length, fruit width, and average fruit weight. With increase in plant height, there was corresponding increase in number of primary branches per plant, days to 50% flowering and number of flower clusters per plant was observed.

Monamadi *et al.* (2013) found there was a strong positive significant correlation between numbers of branches per plant with fruit number per plant. This was because the more the branch number in a plant, such plant will produce more fruits in a plant.

Buckseth *et al.* (2012) carried out an experiment by consisting of 40 genotypes of tomato to study the correlation among different quantitative and qualitative traits in tomato genotypes. The study showed highly significant differences among the genotypes for all the characters studied.

Rani *et al.* (2010) revealed that fruit weight, pericarp thickness, acidity, ascorbic acid and lycopene were positively and significantly associated with yield per plant and on another hand number of fruits per plant was associated negatively.

Ya Dong *et al.* (2010) figured out that the lycopene content is very significantly positively correlated with single inflorescence flower numbers, single inflorescence fruit numbers and soluble solids content. But with pedicel length and single fruit weight showed very significantly negative correlation. He also reported that the lycopene content is significantly positively correlated with fruit shape index, but significantly negatively correlated with fruit firmness, flesh thickness, longitudinal diameter fruit.

Ara *et al.* (2009) concluded that there was a strong positive significant correlation between numbers of trusses per plant with fruit number per plant. This was because the more the truss number in a plant, such plant will produce more fruits resulting in more fruit weight. This is supported by the observed strong positive association between fruit number per plant and fruit weight per plant.

Anitha *et al.* (2007) reported that their corresponding phenotypic values and oxalate genotypic correlations were lower than content showed significant positive correlation with seediness and a non-significant positive correlation with lycopene, TSS and locule number. Golani *et al.*

(2007) observed that fruit weight had significant and as well as positive correlation with fruit length at both levels.

In thirty diverse tomato genotypes Correlation coefficient analysis was studied and noticed that correlation coefficients at the genotypic level were generally higher than the corresponding phenotypic ones and yield per plant was positively and significantly associated with plant height, fruit number per plant, fruit shape index and pericarp thickness (Kumar *et al.*, 2007).

Wagh *et al.* (2007) performed Correlation analysis which showed that yield improvement can be achieved by selection for 50% flowering, plant height, number of fruits per plant along with fruit quality characters such as lycopene, beta -carotene, ascorbic acid and titratable acidity.

According to Wright (2007) correlation analysis and observed that yield improvement can be achieved by selection for 50% flowering, plant height, number of fruits per plant. Kumar *et al.* (2006) performed correlation coefficient analysis of 30 tomato genotypes and observed that number of fruits per plant had significant and fruit yield per plant shown positive correlation.

Megha *et al.* (2006) carried out a study in where correlation in exotic tomato cultivars to determine the correlation of 26 tomato cultivars for number of flowers per cluster, flower clusters at first picking, number of fruits per cluster, weight per fruit, yield per plant and total yield. They observed that improvement in yield could be managed by selection for number of flowers per cluster, flower clusters at first picking, number of fruits per cluster and weight per fruit.

Singh *et al.* (2005) performed correlation coefficient analysis on 15 advance generation breeding lines of tomato. He also observed that the phenotypic coefficients of variation were higher than genotypic coefficients of variation indicating that the genotypic effect is lessened under the influence of the given environment.

Manivannan *et al.* (2005); carried out an experiment in cherry to estimate correlation coefficient analysis and observed that fruit yield was significantly and positively correlated with the number of leaves and fruit weight. According to Arun *et al.* (2004) observation that in case of tomato yield per plant was positively and significantly correlated with average fruit weight and plant height.

Joshi *et al.* (2004) performed correlation analysis where he used 37 tomato genotypes and showed that yield per plant was positively and significantly correlated with average fruit weight, fruit length, plant height and harvest duration. The average fruit weight was positively correlated with fruit length, fruit breadth. However, fruit weight was negatively correlated with the number of fruits per plant, number of fruits per cluster and ascorbic acid content.

Kumar *et al.* (2004) performed Correlation coefficient analysis of 30 tomato genotypes was performed and observed that number of fruits per plant had significant and positive correlation with fruit yield per plant. Similarly, inter-relationships were studied in 92 tomato genotypes.

According to Singh *et al.* (2004), highly significant positive correlation was observed between the number of fruits per plant and yield and between plant height and number of fruits per plant. Negative correlation was noticed between the number of primary branches per plant and number of fruits per plant.

Kumar *et al.* (2003) studied thirty diverse tomato genotypes for Correlation coefficient analysis and observed that correlation coefficients at the genotypic level were generally higher than the corresponding phenotypic ones. He also observed that yield per plant was positively and significantly associated with plant height, fruit number per plant, fruit shape index and pericarp thickness.

Mohanty (2003), studied correlation coefficient analysis of 18 tomato cultivars. He also reported that yield was significantly and positively correlated with number of fruits per plant and number of day to harvest, and significantly. But negatively correlated with plant height, number of branches per plant and average fruit weight and the number of fruits per plant was inversely related to average fruit weight. He also reported that most early cultivars were small fruited and low yielders.

Dhaliwal *et al.* (2002) studied genetic parameters and correlations concerning fruit weight, yield plant-1. The correlation studies indicated that firm fruited - high yielding true breeding lines can be developed.

Harer *et al.* (2002) studied correlation where he used thirty-seven tomato genotypes and showed that the number of fruits per cluster and number of fruits per plant were significantly

and positively correlated with fruit yield per plant, whereas the number of primary branches per plant, fruit weight had negative association with fruit yield.

Mohanty (2002) reported that fruit yield were significant in case of phenotypic and genotypic correlations and positive with days to first harvest, number of branches and fruits/plant, significant and negative with plant height and average fruit weight and number of fruits per plant was inversely related with average fruit weight.

Nesgea *et al.* (2002) studied correlation coefficient analysis in 13 tomato genotypes and revealed that plant height, number of branches per plant, plant spread, fresh plant weight, number of fruiting clusters, number of days to 50% flowering, number of fruits per cluster and number of fruits per plant should be considered for the enhancement of the yield of tomato. Padma *et al.* (2002) found the negative correlation was observed between fruit weight and fruit number, plant height and fruit weight, fruit weight and fruit yield and plant height.

Susic *et al.* (2002); showed that a significant negative correlation was between mean fruit mass and number of fruits per plant. Between fruit length and fruit width a significant positive correlation was found. Tiwari (2002) observed that between the yield and length of fruit there was highest positive and significant association. At the genotypic level, the highest positive association was observed between the yield and length of fruit.

Bhushana *et al.* (2001) conducted an experiment in correlation co-efficient in sixty genotypes of tomato and observed a positive and significant correlation between fruit yield per plant and total soluble solids, ascorbic acid, PH and titratable acidity. A positive and significant correlation was recorded among rind thickness, ascorbic acid and PH . They also found similar association between total soluble solids and ascorbic acid, and between titratable acidity and P^H. According to Dhankar *et al.* (2001) study the average fruit weight under normal condition showed the highest positive effect on yield, therefore selection for average fruit weight, number of fruits per plant and number of fruits per cluster is important in case of fruit yield improvement.

Kumar *et al.* (2001) reported that a positive genotypic correlation was found which significant bet is wean pericarp thickness and juice viscosity and between lycopene and ascorbic acid contents and locule number was negatively correlated with pericarp thickness.

Matin and Kuddus (2001), conducted an experiment in where they studied phenotypic and genotypic correlations of 13 qualitative and quantitative characters of 26 genotypes of tomato and found that individual fruit weight had significant positive correlations with plant height and yield per plant. He also added that number of fruits per plant also had significant positive correlations with fruit dry matter content and found significant negative correlations between number fruits per plant and individual fruit weight. Dry matter was negatively correlated with individual fruit weight.

Sharma and Verma (2000) stated that Information on yield correlations is derived from data on eight yield components recorded in eighteen genetically diverse genotypes. It is concluded that when selected for high yield in tomato, the main emphasis should be placed on number of fruits/plant. Fruit diameter and average fruit weight are also important components.

Prasad and Mathura (1999), observed that between yield and fruit weight it had shown very high and significant positive correlation co-efficient. Das *et al.* (1998) carried out an experiment in where correlation co-efficient estimated in fruit characters of tomato. They observed significant positive correlation of fruit yield per plant with number of fruits per plant.

Aditya and Phir (1995) studied phenotypic and genotypic correlation co-efficient to figure out the associations between eight characters of 44 genotypes of tomato. He studied that yield of fruits per plant showed significant positive correlations with plant height and number of fruits per plant; and insignificant positive correlation with weight of individual fruit and number of seeds per fruit.

Naidu (1993) performed an experiment and studied correlation coefficient analysis in 13 tomato genotypes. He revealed that plant height, number of branches per plant, plant spread, fresh plant weight, number of fruiting clusters, number of days to 50% flowering, number of fruits per cluster and number of fruits per plant should be considered for the enhancement of the yield of tomato.

Abedin and Khan (1986) studied correlation of 20 cultivars of tomato and found that there was negative correlated between yield per plant and number of fruits per plant but positively and significantly correlated with individual fruit weight and plant height.

In an experiment Mallik (1985) studied phenotypic and genotypic correlations where 19 varieties of tomato was used and observed that individual fruit weight had positive significant correlations with plant height and yield.

Alvarez and Torres (1983) reported that correlation between ten characters including yield in 34 varieties/lines of tomato shown positive correlation between yield and plant height, yield and fruit number per plant also. All three were positively correlated with each other but negatively correlated with weight.

Dudi and Kalloo (1982) carried out a study in where they estimated yield per plant and seven yield related characters in 40 lines of tomato and observed that yield per plant and fruits per plant are positively correlated with total yield at the phenotypic level.

2.6 Path co-efficient analysis

Path coefficient analysis is the partitioning of correlation coefficient into direct and indirect effect. It becomes difficult when more characters are involved in correlation study to ascertain the traits which really underwrite towards the yield. In this such situation the path analysis helps to determine the direct and indirect involvement of these traits towards the yield. Therefore, is a useful tool for considerate yield except chain of relationship between yield and yield conducive characters. It also offers valuable additional information for improving fruit yield via selection for its yield components. Recent publications involving path co-efficient analysis between yield and components of yield relevant to the present study are reviewed in this section.

Under open field condition Meena and Bahadur (2015), studied the character association for tomato germplasm. They worked with nineteen indeterminate tomato germplasm to estimate the nature and magnitude of associations of different characters with fruit yield and among themselves. In order to obtain a clear picture of the interrelationship between fruit yield per plant and its components, direct and indirect effects were measured using path coefficient analysis. Through selection the character 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 based on no. of flowers per plant, fruits per plant and fruit weight. Low residual effect indicates that the characters used explained almost all variability towards yield.

Monamodi *et al.* (2013) carried out an experiment in where he used six determinate tomatoes. Path coefficient analysis results showed that marketable fruit number and single fruit weight were directly related to yield because the direct effects of marketable fruit number and fruit weight on fruit yield were positive and large.

Rani *et al.* (2010); performed an experiment to study path coefficient for yield components and quality traits in 23 hybrids of tomato. He also exhibited that fruit weight had the highest positive direct effect on yield per plant, while, fruit weight was also having high positive indirect effect on yield per plant.

Anitha *et al.* (2007) performed path analysis and reported that oxalates, acidity, ascorbic acid and TSS showed positive and high direct effects on lycopene. Golani *et al.* (2007) studied path analysis. He reported that the 10-fruit weight had the highest positive direct effect.

Dhankhar and Dhankhar (2006) resulted that number of fruits per plant had the maximum positive direct effect. Marivanna *et al.* (2005) conducted an experiment where he performed path coefficient analysis in cherry tomato and showed that fruit weight had the highest direct effect on fruit yield.

Mayavel *et al.* (2005); reported that the highest positive direct effect on fruit yield shown on the number of branches per plant. Whereas, plant height, number of fruits per cluster, number of fruits per plants and number of locules per fruit had negative direct effects on fruit yield.

Singh (2005) conducted an experiment in where the genotypic and phenotypic path coefficient studies described that number of fruits per plant had the maximum positive effect on yield followed by average fruit weight. Regarding indirect effects, it was observed that number of fruits per plant exhibited positive indirect effect towards fruit yield via number of branches per plant; it was negative via plant height, days to 50 per cent flowering.

Singh and Cheema (2006) have reported that positive direct effect of number of fruits per plant on yield. Kumar *et al.* (2003) was also reported that. Through average fruit weight positive indirect effects mainly contributed towards its strong association with yield. The findings were on consonance with Mohanty (2002).

Singh *et al.* (2004) performed on 92 tomato genotypes where path analysis between yield and yield contributing characters were estimated and reported that number of fruits per plant

exerted the high positive direct effect on yield followed by average weight per fruit, number of primary branches per plant, plant height, days to 50% flowering, number of fruits per cluster and days to first fruit harvest. However, days to first fruit set, number of primary branches per plant, plant height, number of fruit clusters per plant.

Arun *et al.* (2003) reported that the most important yield contributing character was the number of fruits per plant is followed by plant height through path co-efficient analysis. Kumar et al. (2003); evaluated an experiment to estimate path analysis of thirty diverse tomato genotypes. He reported that fruit number per plant had the highest positive direct effect on yield per plant followed by average fruit weight.

Mohanty (2003) conducted a field experiment with eighteen tomato cultivars to study path coefficient analysis and reported that the number of fruits per plant and average fruit weight had positive direct effects on the yield and negative indirect effects on each other. Bodund (2002) carried out a field experiment on path coefficient analysis. According to his observation plant height and fruit diameter directly affected yield in tomato.
Harer *et al.* (2002); held a field experiment to study path analysis of thirty-seven tomato genotypes. He resulted that number of fruits per cluster, average fruit weight and number of fruits per plant had direct maximum effects on fruit yield.

Mohanty (2002) performed path analysis where he found that the number of branches per plant and average fruit weight exerted high positive direct effect on yield. And also reported that high positive indirect effect with each other.

Padma *et al.* (2002) performed path analysis. In this revelation it was said that number of branches, fruit weight, fruit length and number of fruits per plant exhibited positive effect on yield per plant at the genotypic and phenotypic levels.

Bhushana *et al.* (2001) worked with sixty genotypes of tomato to estimate path analysis for fruit quality traits on fruit yield and showed that all the four variables (total soluble solids, ascorbic acid, pH and titratable acidity) exhibited low positive direct effects on fruit yield.

Matin and Kuddus (2001) found that the maximum direct contribution towards yield was through individual fruit weight followed by number of fruits per plant. He also resulted that

days to first flowering, plant height and number of seeds per fruit had negative direct effect on yield per plant.

Verma and Sarnaik (2000) held an experiment to perform path analysis of yield components in thirty tomato genotypes. They reported that total number of fruits per plant, average weight of fruit and number of branches per plant exhibited positive as well as high direct effects.

Domini and Maya (1997) performed an experiment on 18 tomato varieties for the relationship of six yield components to yield in two different seasons. They added that fruit number per plant was the most important character having a direct effect on yield either in early sowing.

Aditya and Phir (1995) carried out an experiment in where genotypic and phenotypic path co-efficient analysis were done and reported that plant height and number of fruits per plant had high positive direct effect on yield and on the other hand, weight of individual fruit had positive indirect effect on yield per plant.

McGiffen *et al.* (1994) reported that number of fruits was the most important yield component in where had direct effect on yield. According to Supe and Kale (1992) study plant height had negative direct effect on yield per plant on twelve indigenous varieties of tomato. Islam and Khan (1991) experimented on tomato and reported that fruits per plant, average fruit weight, plant height and days to first flowering had positive direct effects on yield of tomato.

Alam *et al.* (1988) evaluated 19 cultivars of tomato to estimate path co-efficient and found that maximum direct contribution towards yield was through individual fruit weight followed by number of fruits per plant. According to Gomez (1987) experiment, days to first flowering has negative direct effect on yield of tomato. Highest direct effect of plant height and fruit weight on fruit yield of tomato were reported by Sonone et al. (l987).

Gorbatenko and Gorbatenko (1985) carried out an experiment where path co-efficient analysis of economically useful characters of tomato. In their findings they reported that individual fruit weight had an appreciable direct effect on yield per plant. Path analysis in tomato was studied by Dudi and Kalloo (1982) and reported highest direct effects of early yield per plant, fruit weight and fruits per plant.

2.7 Heterosis

An experiment conducted in tomato by Kumar *et al.* (2012) revealed that positive and highly significant heterosis was found for number of fruits per plant 25.27%, 25.13% and 21.13% over better parent and 29.95%, 25.27% and 24.46% over standard parent and for total yield per plant 32.06%, 18.34%, 13.36% and 11.27% over better parent and 31.83%, 31.14%, 30.10% and 25.26% over standard check 'Azad T-5'. The hybrid also showed significantly high percentage of positive heterosis over better and standard parent for number of fruits per cluster, average fruit weight and the hybrids showed negative heterosis for plant height and day to 50% flowering which are desirable characters.

Suresh Kumar Sah *et al.* (2020) studied heterosis on tomato and reported that most of these hybrids proved to have unique variation for growth and yield traits in tomato. Standard heterosis over check for total yield per plant was recorded 99.76 %. Highest Heterosis variation was fund to be in number of primary branches per plant, followed by average fruit weight, fruit yield (q/ha), number of fruits per plant, number of fruits per cluster. The statistically highest significant positive standard heterosis for fruit yield (q/ha) was recorded in hybrid EC-570028 × EC-520061 (99.76 %), followed by hybrids EC-552141 × EC520061 (96.57 %) and EC-552141 × Hisar Arun (96.43 %). The hybrid EC620500×Hisar Arun (-29.82 %) found to have the statistically highest significant positive standard heterosis for days to 50 % flowering, followed by hybridsEC538405×EC-520061 (-13.06 %) and EC-538405 × Hisar Arun (-16.26). Thus these hybrids can be utilized by breeders for developing early flowering, maturing and fruiting types of tomato varieties.

Kumar and Paliwal (2016) conducted an experiment on six tomato (*Solanum lycopersicum* L.) diverse cultivars. Three cross combinations viz, ArkaMeghali x Punjab Chhuhara, ArkaSaurabh x ArkaAbha and ArkaSaurabh x Punjab Chhuhara resulted in significantly positive heterosis over mid parent, better parent, for pericarp thickness. For total soluble solids, positive and significant heterosis over mid and better parents were observed in three cross combinations viz,ArkaSaurabh x ArkaMeghali, Punjab Chhuhara x Best of All and ArkaMeghali x Sioux. Best of All x Sioux and Punjab Chhuhara x Sioux showed highest significant positive heterosis over mid parent and better parentfor shelf life.

Archana Mishra *et al.* (2021) investigated heterosis on ten tomato lines were crossed in half diallel mating design to produce 45 F1 hybrids. Heterobeltiosis and standard heterosis were estimated for growth, fruit yield and quality traits in F1 hybrids. The parental lines, viz. BT-22-4-1, BT-507-2-2 and BT-19-1-1-1 were found most promising for exploiting heterosis. Appreciable amount of heterobeltosis and standard heterosis was noticed for majority of the traits studied. Considering all the cross combinations individually, the hybrid combinations that out fielded their parents for a maximum number of components for heterobeltiosis and standard heterosis coupled with high per se values were; BT-19-1-1-1 x BT-22-4-1, BT-22-4-1 x BT-507-2-2 and BT-19-1-1-1 x BT-3.

CHAPTER III
MATERIALS AND METHODS

This chapter illustrates the information concerning the methodology of this experiment. This discussion emphasizes methodologies related to the location of the experimental site, planting materials, climate and soil, preparation of seed bed, experimental design, and layout, pot preparation, transplantation of seedlings, fertilizing, intercultural operations, harvesting, data recording procedure, physiological, nutritional, and statistical analyzing procedure.

3.1 Experimental site

The experiment was done in the experimental field at Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from October 2020 to April 2021. The location of the experimental site was 23°74' N latitude and 90°35' E longitude with an elevation of 8 meters from sea level (Anon., 2004) in the Agro-ecological zone of "Madhupur Tract" (AEZ-28) (Anon.,1988). The experimental site is shown in the map of AEZ of Bangladesh in (Appendix I).

3.2 Soil and climate

The experimental site was situated in the subtropical zone. The soil of the experimental site belongs to the Agroecological region of “Madhupur Tract” (AEZ No. 28). The texture of the soil was clay loam and olive-gray with common fine to medium distinct dark yellowish-brown mottles. The pH was 5.47 to 5.63 and the organic carbon content is 0.82% (Appendix II). The data of recorded air temperature, humidity, and rainfall during the time of the experiment were noted from the Bangladesh Meteorological Department, Agargaon, Dhaka.

3.3 Planting materials

Fourteen (14) F_2 populations, their five parents and two check hybrids varieties were used as plant materials in the experiment. The healthy seeds of these lines were collected from the Department of genetics and plant breeding of Sher-e-Bangla Agricultural University, Dhaka. The name and descriptions of these populations are presented in Table 1.

Table: 1 Name and descriptions of twenty-one tomato genotypes used in the present study

Sl. No.	Parental and F_2 population	Generation	Source of collection*
01	BARI Tomato-3	P1(parental line)	GEPB, SAU
02	BARI Hybrid Tomato -8	P2 (parental line)	GEPB, SAU
03	BARI Tomato-14	P3 (parental line)	GEPB, SAU
04	BARI tomato-15	P4 (parental line)	GEPB, SAU
05	BARI tomato-16	P5 (parental line)	GEPB, SAU
06	Mintu Super Hybrid	F_1 (Check-1)	GEPB, SAU
07	Ananya Hybrid Tomato	F_1 (Check-2)	GEPB, SAU
08	P1x P2 (C_1)	F_2	GEPB, SAU
09	P1x P3 (C_2)	F_2	GEPB, SAU
10	P2x P1 (C_3)	F_2	GEPB, SAU
11	P2x P3 (C_4)	F_2	GEPB, SAU
12	P2xP4 (C_5)	F_2	GEPB, SAU
13	P2xP5 (C_6)	F_2	GEPB, SAU
14	P3xP2 (C_7)	F_2	GEPB, SAU
15	P3xP4 (C_8)	F_2	GEPB, SAU
16	P3xP5 (C_9)	F_2	GEPB, SAU
17	P4xP1 (C_{10})	F_2	GEPB, SAU
18	P4xP2 (C_{11})	F_2	GEPB, SAU
19	P4xP3 (C_{12})	F_2	GEPB, SAU
20	P5xP2 (C_{13})	F_2	GEPB, SAU
21	P5xP4 (C_{14})	F_2	GEPB, SAU

*GEPB = Genetics and Plant Breeding

3.4 Seedbed preparation and seedling raising

Sowing of seeds was done on 30th November 2020. Before sowing seeds were treated with Bavistin for five minutes. Seedlings of the genotypes were raised in the soil pot at the rooftop of the Dept. of Genetics and Plant Breeding of Sher-e-Bangla Agricultural University, Dhaka-1207. The soil pot were watered regularly. Seedlings were raised using regular nursery practices. All the recommended cultural practices were taken to raise the seedling properly. After 25 days, the seedlings were transplanted in the main field.

3.5 Design and layout

The experiment was carried out under field conditions during the rabi season 2020-2021 following randomized Complete Block Design (RCBD) in the three replications. The experimental plot size was 225 m^2 while the unit plot size was 1 m^2. The genotypes were distributed randomly to every unit plot. The spacing were 60 cm (row to row) and 40 cm (plant to plant). The date of transplanting was 24.12.2020.

3.6 Land preparation

Several ploughing and cross ploughing were used to prepare the land by using a ladder, tractor, and power tiller. Cow dung was added for good tilth. All the weeds and stubbles were removed from the field and levelled carefully. The final land preparation was done on December 23, 2020.

3.7 Manure and fertilizer dose

One-third of urea, total TSP (Triple Super Phosphate), half of the MoP (Muriate of Potash), and cow dung were used one day before transplanting. The remaining Urea and MoP were used at the time of 15 days after transplanting (DAT) and 1st flowering. Fertilizer and manure doses are given in Table 2.

Table 2. Doses of fertilizer and manure

Sl. No.	Fertilizer/Manure	Applied in plot (225 m^2)	Dose per ha
01	Urea	12 kg	550 kg
02	TSP	10 kg	450 kg
03	MoP	5.5 kg	250 kg
04	Cowdung	200 kg	10 ton

Plate 1: A partial view of the plot of tomato raised during Rabi season, 2020-2021

3.8 Transplanting of seedlings

The seedlings were transplanted in the main field on 24th December 2020 when they were 25 days old. The seedlings were watered regularly so that the root could make a firm relation with the soil to stand along.

3.9 Intercultural operations

After establishing seedlings, 1st mulching and weeding were done. Then second weeding was done during the application of 2nd instalment of urea at 15 (DAT). When the seedlings became tall enough, bamboo sticks and ropes were used for supporting the plants. Some lateral branches and leaves were pruned out for obtaining proper sunlight and to reduce the infestation of insects.

3.9.1 Thinning and gap filling

Within three days of transplanting when the seedlings became established, some new seedlings were transplanted at the place of dead seedlings to fill up the gap. Also thinning was done to avoid crowded of seedlings, wherever necessary.

3.9.2 Weeding and mulching

Weeding and mulching were done several times after transplanting in the main field. Mulching was done for proper aeration and weeding was done to reduce the competition with the tomato plant.

Plate 2: Pictorial view of the experimental tomato field.

3.9.3 Staking

Staking was done by using bamboo sticks and rope to keep the plants erect and for proper aeration.

3.9.4 Pesticide application

During whole growth period, “Ripcord” was applied at seven days intervals in sunny days in order to prevent insect infestation. No herbicide was used to control the weeds, only hand weeding was done.

3.9.5 Irrigation and drainage

The seedlings were properly irrigated for consecutive seven days after transplanting. The flood irrigation was done after the application of urea. Final irrigation was applied during the fruiting stage. Drainage was done at the time of requirements.

3.10 Harvesting and processing

All the tomato lines that were used in this experiment were dissimilar to each other. So, ripening and marketable harvest time were not the same. It was continual on an average for one and half months as matured dates of fruits of many lines progressively at different times. The fruits at every entry were allowed to ripe and then seeds were collected and stored at 4^0C for future use. Harvesting was started from February 25, 2021, and completed by April 15, 2021.

3.11 Data recording

Data were collected from each plot based on different yield and growth-related traits. A view of data collection in the experiment shown in Plate 8. The following parameters were collected from five randomly selected plant from each replication and each genotypes.

3.11.1 Days to first flowering

The number of first days was counted as the days passed from sowing to flowering in five percent of the plants. Average value of five plants was measured as the days to first flowering for each plot.

3.11.2 Days to first fruiting

The total number of days counted from sowing to first fruit appears in the plant of each genotype. Average value of five plants was measured as the days to first fruiting for each plot.

3.11.3 Plant height (cm)

The total length from the base of the plant to top of the plant is called plant height. I was measured as centimetre. Five plants from each genotype from each plot were selected at random and plant height was measured at the maturity stage when harvesting was the last stage. The mean value of five plants was considered as the plant height for each plot.

3.11.4 Number of branches per plant

The total number of branches per plant was calculated from each of the selected plants during the maturity stage from each plot of each replication. The mean value of five plants was average in each replication.

3.11.5 Number of fruit clusters per plant

The total number of fruit clusters per plant was measured in each plot of each replication at the marketable harvest time. The mean value of five plants was average in each replication.

3.11.6 Number of fruits per plant

All fruits in single plant were recorded by randomly selecting five plants at maturity. Mean value of five plants' fruit was considered as the number of fruits per plant for each plot in each replication.

Plate 3: Showing data collection operation.

3.11.7 Fruit diameter (cm)

Five fruits of each replication of every genotype were cut into an equatorial part horizontally and their fruit diameter was measured by digital slide callipers. The mean value of five representative fruits diameter of each genotype were calculated and considered as the fruit diameter of the fruit. It was measured in centimetre.

3.11.8 Fruit length (cm)

Fruit length was measured with digital slide callipers from the proximal end to the distal end of each fruit. Five representative fruits of each genotype of each replication and their average were taken as the length of the fruit.

3.11.9 Single fruit weight

Individual fruit weight was measured by picking fruit from each genotype from each replication by electric precision balance and their mean value was calculated.

3.11.10 Fruit yield per plant (kg)

Some tomato genotypes were indeterminate type, while some were semi-indeterminate type, so fruits ripped at different times in the same plant of same genotype. So, ar every harvesting time, number of fruits harvested from each plant and their weight were recorded and finally after the final harvest their average weight were calculated as yield per plant. It was denoted as a kilogram (kg).

3.12 Statistical analysis

The mean data of the traits were used to investigate genetic variability. Univariate analysis of the individual trait was performed for all traits following Singh and Chaudhury, (1985) and was estimated using computer programme STAT-10. Duncan's Multiple Range Test (DMRT) was performed for all the traits to test the differences between the means of the genotypes. Mean, range, and coefficient of variation (CV %) were also estimated using MS EXCEL.

3.12.1 Estimation of genotypic and phenotypic variances

Genotypic and phenotypic variances were measured following the formula given by Johnson *et al.* (1955).

Genotypic variance, $\sigma^2 g = \frac{GMS - EMS}{r}$

Where,

GMS = Genotypic mean sum of squares
EMS = Error mean sum of square
r = number of replications

Phenotypic variance, $\sigma^2 P = \sigma^2 g + EMS$

Where,

$\sigma^2 g$ = Genotypic variance
EMS = Error mean sum of square
Environmental variance ($\sigma^2 e$)=EMS

3.12.2 Estimation of genotypic and phenotypic coefficient of variation

Genotypic and phenotypic coefficient of variation was estimated by the formula recommended by Burton (1952)

Genotypic coefficient of variation, GCV % = $\frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$

Where,
$\sigma^2 g$ = Genotypic variance
$\bar{x}$ = Population mean

Similarly,
The phenotypic co-efficient of variation was calculated from the following formula.

Phenotypic co-efficient variation, PCV% = $\frac{\sqrt{\sigma^2 p}}{x}$ x 100

Where, $\sigma^2 p$= Phenotypic variance
$\overline{x}$ = Population mean

3.12.3 Estimation of heritability

Broad-sense heritability (Lush, 1949) was assessed by the subsequent formula, proposed by Johnson *et al.* (1955).

Heritability, $h^2 b\%$ = $\frac{\sigma^2 g}{\sigma^2 p} \times 100$

Where,

$h^2 b$ = Heritability in broad sense

$\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

3.12.4 Estimation of genetic advance

The expected genetic advance for different traits under assortment was assessed consuming the formula proposed by Lush (1943) and Johnson *et al.* (1955).

Genetic advance, GA = K. h^2. σ_p
Or Genetic advance, GA = K. $\frac{\sigma^2 g}{\sigma^2 p}$. σ_p

Where,

K = Selection intensity, the value which is 2.06 at 5% selection intensity

σ_p = Phenotypic standard deviation

$h^2 b$= Heritability in broad sense

$\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

3.12.5 Estimation of genetic advance mean's percentage

Genetic advance as a percentage of the mean was measured from the following formula as suggested by Comstock and Robinson (1952):

$$\text{Genetic advance (\% of mean)} = \frac{\text{Genetic Advance (GA)}}{\text{Population mean } (\bar{x})} \times 100$$

3.12.6 Estimation of simple correlation coefficient

Simple correlation coefficients (r) was assessed with the following formula (Singh and Chaudhary, 1985).

$$\text{Simple correlation coefficient, } r = \frac{\sum xy - \frac{\sum x . \sum y}{N}}{1\sqrt{[\{\sum x^2 - \frac{(\sum x)^2}{N}\}\{\sum y2 - \frac{(\sum y)^2}{N}\}]}}$$

Where,

$\sum$ = Summation

x and y are the two variables correlated

N = Number of observation

3.12.7 Estimation of genotypic and phenotypic correlation coefficient

For measuring the genotypic and phenotypic correlation coefficient for all conceivable amalgamations the formula recommended by Johnson *et al.* (1955), and Hanson *et al.* (1956) were assumed. The genotypic co-variance component between two traits and have the phenotypic co-variance component were derived in the same way as for the corresponding variance components. The covariance components were used to compute the genotypic and phenotypic correlation between the pairs of characters as follows:

$$\text{Genotypic correlation, } r_{gxy} = \frac{GCOV_{xy}}{\sqrt{GVx.GVy}} = \frac{\sigma_{gxy}}{\sqrt{\sigma^2 gx.\sigma^2 gy}}$$

Where,

σ_{gxy}= Genotypic co-varince between the traits x and y

$\sigma^2 gx$ = Genotypic variance of the trait x

$\sigma^2 gy$ = Genotypic variance of the trait y

Phenotypic correlation, $r_{pxy} = \frac{PCOV_{xy}}{\sqrt{PVx.PVy}} = \frac{\sigma pxy}{\sqrt{\sigma^2 px.\sigma^2 py}}$

Where,

σ_{pxy}= Phenotypic co-variance between the traits x and y

$\sigma^2 px$ = Phenotypic variance of the trait x

$\sigma^2 py$ = Phenotypic variance of the trait y

3.12.8 Estimation of path co-efficient

It was measured giving to the technique working by Dewey and Lu (1959) also quoted in Singh and Chaudhary (1985), consuming phenotypic correlation coefficient values. In path analysis, correlation coefficients between yield and yield related traits were partitioned into direct and indirect effects on yield per plant. For measurement of direct and indirect effects of the correlated characters, i.e. 1, 2, 3…. and 9 on yield y, a set of simultaneous equations (ten equations in this example) is required to be formulated as shown below:

$r_{1.y} = P_{1.y} + r_{1.2} P_{2.y} + r_{1.3} P_{3.y} + r_{1.4} P_{4.y} + r_{1.5} P_{5.y} + r_{1.6} P_{6.y} + r_{1.7} P_{7.y} + r_{1.8} P_{8.y} + r_{1.9} P_{9.y}$

$r_{2.y} = r_{1.2} P_{1.y} + P_{2.y} + r_{2.3} P_{3.y} + r_{2.4} P_{4.y} + r_{2.5} P_{5.y} + r_{2.6} P_{6.y} + r_{2.7} P_{7.y} + r_{2.8} P_{8.y} + r_{2.9} P_{9.y}$

$r_{3.y} = r_{1.3} P_{1.y} + r_{2.3} P_{2.y} + P_{3.y} + r_{3.4} P_{4.y} + r_{3.5} P_{5.y} + r_{3.6} P_{6.y} + r_{3.7} P_{7.y} + r_{3.8} P_{8.y} + r_{3.9} P_{9.y}$

$r_{4.y} = r_{1.4} P_{1.y} + r_{2.4} P_{2.y} + r_{3.4} P_{3.y} + P_{4.y} + r_{41.5} P_{5.y} + r_{4.6} P_{6.y} + r_{4.7} P_{7.y} + r_{4.8} P_{8.y} + r_{4.9} P_{9.y}$

$r_{5.y} = r_{1.5} P_{1.y} + r_{2.5} P_{2.y} + r_{3.5} P_{3.y} + r_{4.5} P_{4.y} + P_{5.y} + r_{5.6} P_{6.y} + r_{5.7} P_{7.y} + r_{5.8} P_{8.y} + r_{5.9} P_{9.y}$

$r_{6.y} = r_{1.6} P_{1.y} + r_{2.6} P_{2.y} + r_{3.6} P_{3.y} + r_{4.6} P_{4.y} + r_{5.6} P_{5.y} + P_{6.y} + r_{6.7} P_{7.y} + r_{6.8} P_{8.y} + r_{6.9} P_{9.y}$

$r_{7.y} = r_{1.7} P_{1.y} + r_{2.7} P_{2.y} + r_{3.7} P_{3.y} + r_{4.7} P_{4.y} + r_{5.7} P_{5.y} + r_{6.7} P_{6.y} + P_{7.y} + r_{7.8} P_{8.y} + r_{7.9} P_{9.y}$

$r_{8.y} = r_{1.8} P_{1.y} + r_{2.8} P_{2.y} + r_{3.8} P_{3.y} + r_{4.8} P_{4.y} + r_{5.8} P_{5.y} + r_{6.8} P_{6.y} + r_{7.8} P_{7.y} + P_{8.y} + r_{8.9} P_{9.y}$

$r_{9.y} = r_{1.9} P_{1.y} + r_{2.9} P_{2.y} + r_{3.9} P_{3.y} + r_{4.9} P_{4.y} + r_{5.9} P_{5.y} + r_{6.9} P_{6.y} + r_{7.9} P_{7.y} + r_{8.9} P_{8.y} + P_{9.y}$

$P_{9.y}$ = indirect effect of 1 via 9 on y

Where,
r_{1y} = Genotypic correlation coefficients between y and I^{th} character (y = Fruit yield)

P_{iy} = Path coefficient due to i^{th} character (i= 1, 2, 3,….10)

1 = Days to first flowering

2 = Days to first fruiting

3 = Plant height (cm)

4 = Number of branches per plant

5 = Number of clusters per plant

6 = Number of fruits per plant

7 = Fruit diameter (cm)

8 = Fruit length (cm)

9 = Single fruit weight

10 = Fruit yield per plant (kg)

Total correlation, say between 1 and y i.e., r_{1y} is thus partitioned as follows:

$P_{1.y}$ = the direct effect of 1 on y

$r_{1.2}$ $P_{2.y}$ = indirect effect of 1 via 2 on y

$r_{1.3}$ $P_{3.y}$ = indirect effect of 1 via 3 on y

$r_{1.4}$ $P_{4.y}$ = indirect effect of 1 via 4 on y

$r_{1.5}$ $P_{5.y}$ = indirect effect of 1 via 5 on y

$r_{1.6}$ $P_{6.y}$ = indirect effect of 1 via 6 on y

$r_{1.7}$ $P_{7.y}$ = indirect effect of 1 via 7 on y

$r_{1.8}$ $P_{8.y}$ = indirect effect of 1 via 8 on y

$r_{1.9}$ $P_{9.y}$ = indirect effect of 1 via 9 on y

Where,

$P_{1.y}$, $P_{2.y}$, $P_{3.y}$…… P9.y = Path coefficient of the independent variables 1, 2, 3,….,9 on the dependent variable y, respectively.

$r_{1.y}$, $r_{2.y}$, $r_{3.y}$, …., $r_{9.y}$ = Correlation coefficient of 1, 2, 3,…., 9 with y, respectively.

After calculating the direct and indirect effect of the characters, residual effect (R) was calculated by using the formula (Singh and Chaudhary, 1985) given below

$P^2_{RY} = 1- (r_{1.y}P_{1.y} + r_{2.y}P_{2.y} + \ldots\ldots\ldots\ldots\ldots + r_{9.y}P_{9.y})$

Where,

$P^2_{RY} = R^2$

and hence residual effect, $R = (P^2_{RY})^{1/2}$

$P_{1.y}$ = Direct effect of the i^{th} character on yield y.

$R_{1.y}$ = Correlation of the character with yield y.

3.13 Estimation of heterosis

Heterosis was estimated over the better parent and over the check variety by using the formulae (Kempthorne, 1957).

Heterobeltiosis (%) $= \frac{F2-BP}{BP} x\ 100$

Standard Heterosis (%) $= \frac{F2-C}{C} x\ 100$

F_2 = mean value of F_2

BP = mean value of better parent,

C = mean value of check variety.

3.14 Significant test of heterosis

The significance of heterobeltiosis and standard heterosis were determined by a t-test as follows:

t-test for Hbp $= \frac{F2-BP}{S_{Hbp}}$

t-test for Hcv $= \frac{F2-CV}{S_{Hcv}}$

where SHbp and SHcv are the standard error of estimates of Hbp and Hcv which can be derived as shown in the attached note.

The degree of freedom (df) for each test was obtained by summing up the df of each generation involved in the estimate. Thus, the df for testing Hbp is $(n_1-1)+(n_2-1)+(n_3-1)$, and the df for testing Hcv is $(n_1-1)+(ni-1)$, i = 2 or 3, depending on whether the high parent is P_1 or P_2.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Analysis of variance for the experimental design

The values of the mean sum of squares of analysis of variance (ANOVA) revealed highly significant differences ($P \leq 0.01$) among the tested genotypes for all the traits studies viz., days to first flowering, days to first fruiting, plant height, no. of branches per plant, no. of cluster per plant, no. of fruits per plant, fruit length (cm), fruit diameter (cm), single fruit weight (g) and fruit yield per plant (kg) (Table 3). It was clearly endorsed the justification of studying genetic variability of different characters employing these genotypes. The significant variations among the genotypes showed the presence of adequate variability which can be exploited through selection Hidayatullah *et al.*, (2008); Kaushik *et al.*, (2011); Dar and Sharma, (2011); Meena and Bahadur, (2015); Sanchez *et al.*, (2019); Sinha *et al.*, (2020) were reported similar results.

4.2 Mean performance of genotypes

4.2.1 Days to first flowering

Earliness is the utmost desirable parameter, as the early crop produce can obtain a higher price in the market due to its high demand and less production at that time. Days to first flowering is one of the crucial parameters observed to determine the earliness of a particular genotype. The mean values of genotypes for the number of days to first flowering varied from 23.33 to 42.67 days with an overall mean of 32.07 days (Table 4). Among all genotypes, C9 (27.33 days) took a minimum number of days to first flower and was earlier, however, it was found to be statistically similar with the genotype CV1 (25.33 days). Whereas, genotype C4 took the maximum number of days to first flowering (37.67 days) and was late among all the tested genotypes. Sharanappa and Mogali (2014) observed wide variations for days to first flowering in different tomato genotypes. Wider variation in respect to days to first flower was also reported by Prema *et al.* (2011b) among six Cherry tomato lines.

Table 3: Analysis of variance (ANOVA) for 10 characters in tomato Genotypes

Characters	Degrees of Freedom (DF)			Mean sum of square (MSS)		
	Replication	Genotypes	Error	Replication	Genotypes	Error
Days to first flowering	2	20	40	0.25	57.18**	0.67
Days to first fruiting	2	20	40	3.30	10.65**	1.10
Plant height (cm)	2	20	40	226.22	245.43**	59.38
Number of branches per plant	2	20	40	0.76	0.70**	0.28
Number of clusters per plant	2	20	40	3.16	4.66**	1.19
Number of fruits per plant	2	20	40	8.73	66.34**	3.84
Fruit diameter (cm)	2	20	40	35.42	47.54**	12.24
Fruit length (cm)	2	20	40	49.77	60.21**	8.02
Single fruit weight	2	20	40	11.26	412.61**	4.93
Fruit yield per plant (kg)	2	20	40	0.46	0.32**	0.05

**= significant at .01% level of significance

Table 4: Mean performance of growth, yield and yield contributing parameters

Genotype	DFF	DF	PH (cm)	BPP	CPP	FPP	FD (cm)	FL (cm)	SFW (g)	FYP (kg)
P1	42.67a	48.00a	105.50a-d	4.33ab	8.93ab	30.11de	56.28ab	45.33g-i	87.42c	2.08d-f
P2	34.00de	44.33b-e	81.00ef	3.00e-g	7.67b-d	31.44cd	54.75a-c	38.71j	75.56g-i	1.82e-h
P3	23.33m	40.33j	75.28f	2.89fg	5.93d-g	20.89k	48.09d-g	51.18a-f	60.83kl	1.28i
P4	32.67efg	44.33b-e	85.87c-f	3.33c-g	4.22g	30.00de	46.59fg	54.46ab	64.17jk	1.53hi
P5	35.67c	45.00bc	87.11c-f	3.89b-d	7.33b-e	36.22ab	55.12a-c	**55.01a**	80.19ef	1.92d-g
CV-1	25.33l	43.67c-f	78.06ef	3.89bcd	6.22c-f	21.67jk	45.82g	52.98a-d	67.22j	1.74fgh
CV-2	29.33ij	43.33c-g	89.39b-f	2.67g	7.56b-e	25.44hi	47.78efg	43.48ij	58.69l	1.68gh
P1*P2 (C1)	30.33hi	41.67g-j	90.33b-f	3.33c-g	8.00bc	34.00bc	51.14b-g	45.86f-i	74.14hi	2.52ab
P1* P3 (C2)	33.67def	44.67bcd	107.56abc	3.33c-g	5.78efg	24.89hij	52.51a-e	47.40e-i	75.89ghi	2.30def
P2* P1 (C3_	34.33cd	45.67b	75.44f	3.22defg	6.33c-f	27.56e-h	51.52b-g	47.66d-i	74.06hi	2.24bcd
P2* P3 (C4)	37.67b	44.00b-f	110.44ab	4.11abc	5.89d-g	25.44hi	58.33a	50.77a-g	100.47a	2.25bcd
P2* P4 (C5)	32.33fg	42.67efgh	96.56a-f	3.67b-f	9.89a	38.89a	49.71c-g	46.83e-i	84.39cd	2.64a
P2* P5 (C6)	28.33jk	42.33f-i	88.44cdef	3.67b-f	7.56b-e	34.78b	51.23b-g	48.77c-i	66.81j	2.51abc
P3* P2 (C7)	29.67ij	40.67ij	114.56a	3.8889bcd	5.33fg	22.89ijk	55.71ab	48.14d-i	81.94de	2.07def
P3* P4 (C8)	31.67gh	42.67e-h	99.22a-e	3.7778b-e	6.33c-f	26.33gh	54.89abc	47.34e-i	96.72b	2.22bcd
P3* P5 (C9)	27.33k	42.33f-i	86.39c-f	3.7778b-e	6.56c-f	30.56de	52.38b-f	52.29a-e	77.69fgh	2.07def
P4* P1 (C10)	29.33ij	40.67ij	84.22def	3.7778b-e	7.44b-e	29.33d-g	52.71a-e	45.16hi	79.08efg	2.00d-g
P4* P2 (C11)	31.33gh	43.00d-g	91.00b-f	3.7778b-e	7.67bcd	29.67def	48.54d-g	50.62a-h	54.28m	1.81e-h
P4* P3 (C12)	31.67gh	41.00hij	118.22a	4.7778a	6.56c-f	27.33e-h	52.78a-e	48.91b-i	67.42j	2.04d-g
P5* P2 (C13)	33.67def	41.67g-j	91.67b-f	3.4444c-g	6.67c-f	26.56fgh	53.72a-d	49.23b-h	73.39i	2.14cde
P5* P4 (C14)	37.33b	42.33f-i	86.11c-f	3.6667b-f	7.11c-f	25.89hi	48.82d-g	53.92abc	65.58j	1.91d-g
Range	23.33-42.67	40.33-48.00	75.28-118.22	2.67-4.78	4.22-9.89	20.89-38.89	45.82-58.33	38.71-55.01	54.28-100.47	1.28-2.64
Mean	32.07	43.16	92.86	3.64	6.92	28.68	51.85	48.60	74.81	2.02
CV (%)	2.56	2.44	14.32	14.68	15.78	6.86	6.85	6.94	2.98	11.12
LSD (0.05)	1.35	1.73	21.86	0.88	1.80	3.24	5.86	5.58	3.66	0.37

Same letter(s) in a column did not differ significantly at $p \leq 0.05$ by DMRT.

DFF: days to first flowering, DF: days to first fruiting, PH: Plant height (cm), BPP: branches per plant, CPP: clusters per plant, FPP: fruits per plant, FD: fruit diameter (cm), FL: fruit length (cm), SFW: Single fruit weight (g) and FYP:fruit yield per plant (kg).

4.2.2 Days to first fruiting

Early crop attains high market value, so we should select only those genotypes of tomato which are early in fruiting to avoid a market glut. So, early fruit maturity and picking is a very important trait of a superior genotype. Significant variations for days to first fruiting were observed among the genotypes under study (Table 4). The observation ranged from 40.33 to 48.00 days with an overall mean of 43.16 days. Mean values for different genotypes revealed that genotype C7 AND C10 took a minimum number of days to first fruiting and was the earliest in maturity (40.67 days), whereas C3 took the highest days to first fruiting (45.67 days). Considerable variation for this character was also reported earlier (Chapagain *et al.*, 2011; Patel *et al.*, 2013; Mitul *et al.*, 2016).

4.2.3 Plant height (cm)

It is evident from Table 3 that significant differences were recorded in plant height by tomato genotypes. In high rainfall regions, indeterminate types of genotypes are preferred over semi-determinate and determinate types. The observation showed that the mean values ranged from P3 (75.28 cm) to C12 (118.22 cm) with an overall mean of 92.86 cm (Table 4). The tallness, shortness, and other morphological differences are the varietal characteristics, which are controlled and expressed by certain genes. These results conform with the findings (Sharma and Singh, 2015; Ahmad *et al.*, 2016), who reported a wide range for plant height in different tomato genotypes.

4.2.4 Number of branches per plant

Highly significant differences ($P \leq 0.01$) was observed for branches per plant (Table 3). The ranged of said trait were from 2.67 to 4.78 with an overall mean value of 3.64. Maximum number of branches per plant were observed for C12 (4.77) followed by C4 (4.11) while minimum number was recorded for C3(3.22) (Table 4).

4.2.5 Number of clusters per plant

Highly significant differences ($P \leq 0.01$) were observed among the tomato genotypes for number of clusters per plant (Table 4). Mean values for clusters per plant ranged between 4.22 and 9.89 with overall average of 6.92. Maximum number of clusters per plant were obtained for C5 (9.89), followed by C1(8.00), C11 (7.67), and C10 (7.44) while the minimum data were recorded for C7(5.33) followed byC2 (5.78) and C4(5.89) as shown in (Table 4).

4.2.6 Number of fruits per plant

The number of fruits per plant is one of the most desirable parameters which plays an important role as yield contributing trait. Range mean value of data recorded for this trait lies between 20.89 and 38.89 fruits per plant (Table 4). Among all genotypes, maximum numbers of fruits per plant were recorded in line C5(38.89), which were significantly similar with C6(34.78) and C1 (34.00). The significant increase in fruit number might be due to the reason this genotype was early in fruiting and plant height was also maximum than others. Earlier researchers (Prajapati *et al.*, 2015; Meena *et al.*, 2015; Kumar and Singh 2016; Thapa *et al.*, 2016; Lekshmi and Celine, 2017), also mentioned maximum number of fruits per plant due to these reasons.

4.2.7 Fruit diameter (cm)

Analysis of variances showed significantly differences ($P \leq 0.01$) for fruit diameter (Table 3). Fruit diameter range varied from 45.82 to 58.33 with mean value of 51.85. The maximum number fruit diameter was observed for C4 (58.33 cm) and it was followed by C7 (55.71 cm) and C13 (53.72 cm) whereas; minimum amount were obtained in C11(48.54) followed by C14(48.82) (Table 4).

4.2.8 Fruit length (cm)

Analysis of variances showed significantly differences ($P \leq 0.01$) for fruit length (Table 3). Fruit length range varied from 38.71 cm to 55.01 cm with mean value of 48.60. The maximum fruit length was observed for C14 (53.92 cm) and it was followed by C9 (52.29 cm) whereas; minimum amount were obtained in C10 (45.16cm) (Table 4).

4.2.9 Single fruit weight

Single fruit weight ranged from 54.28-100.47 g (Table 4). Genotype C11 produced the smallest single fruit (54.28 g) and it was followed by C14 (65.58g). The highest fruit weight was observed in F2 line C4 (100.47 g) and it was statistically significantly followed by C8 (96.72 g) and C7 (81.94 g).

4.2.10 Fruit yield per plant (kg)

Yield per plant is one of the crucial parameters attaining utmost consideration in crop breeding programs. The recorded data on fruit yield per plant revealed significant variation among various genotypes (Table 4). Its mean values ranged from 1.28 kg to 2.64 kg having an overall mean of 2.02 kg. Comparison of data recorded on fruit yield per plant indicated that the F_2 populations C5 (2.64 kg) had the highest fruit yield per plant it was statistically similar with C1 (2.52 kg) and C6 (2.51 kg). The minimum yield per plant was recorded in C11 (1.81 kg). The F_2 popiulations C5 was significantly superior because of its genetic makeup and said the combination had a maximum number of fruits per plant, clusters per plant, and more plant height; and was early in flowering and fruiting. Such kind of genetic differences for marketable fruit yield and other plant characters in different tomato genotypes had also been reported (Chernet *et al.*, 2014; Meena *et al.*, 2015; Ahmad *et al.*, 2016; Lekshmi and Celine 2017; Prakash *et al.*, 2019).

4.3 Genetic variability

The extent of variability in respect to ten different characters among the genotypes measured in terms of range, genotypic variance, phenotypic variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) along with heritability, genetic advance and genetic advance (in per cent of mean) are presented (Table 5). The nature and extent of genetic variability is one of the most important criteria in formulating an efficient breeding programme and knowledge of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is much helpful in predicting the amount of variation present in a given assemblage of genotypes. In the present investigation, the phenotypic coefficient of variations were slightly higher than the corresponding genotypic coefficient of variations for all the characters studied (Table 4), 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. However, the influence of environment for the expression of characters was not very high suggesting appreciable genotypic worth for all the characters.

Table 5: Estimation of different genetic parameters in ten characters of F_2 populations of tomato with parents and check varieties.

Parameters	Environmental Variance	Genotypic variance	Phenotypic Variance	Genotypic Coefficient of Variance	Phenotypic Coefficient of Variance	Heritability (Broad Sense)	Genetic Advance	Genetic Advance as Percentage
Days to first flowering	0.50	42.87	43.37	20.55	20.67	98.85	13.41	42.09
Days to first fruiting	0.78	4.92	5.70	5.03	5.41	86.35	4.25	9.62
Plant height (cm)	32.92	88.37	121.29	10.93	12.80	72.86	16.53	19.21
Number of branches per plant	0.35	0.27	0.62	15.05	22.98	42.90	0.70	20.31
Number of clusters per plant	1.20	1.91	3.11	20.23	25.80	61.44	2.23	32.66
Number of fruits per plant	3.69	29.63	33.31	19.46	20.64	88.93	10.57	37.81
Fruit diameter (cm)	5.23	18.77	24.00	8.56	9.68	78.20	7.89	15.59
Fruit length (cm)	11.75	35.40	47.15	12.21	14.09	75.09	10.62	21.79
Single fruit weight	5.81	112.95	118.76	15.06	15.44	95.11	21.35	30.25
Fruit yield per plant	0.02	0.06	0.08	14.48	16.70	75.22	0.44	25.88

4.3.1 Days to first flowering:

Genetic variance (42.87) was less than the phenotypic variance (43.37) whereas; environmental variance value was 0.50 which indicated that the traits were under genetic control. High PCV (20.67%) and GCV (20.55%) values were observed among F_2 populations of tomato. High broad sense heritability (h^2bs) and high genetic advance as percent of mean were recorded with values of 98.85 and 42.09, respectively (Table 5).

4.3.2 Days to first fruiting

For days to first fruiting the genetic and environmental variances were 4.92 and 0.78 while phenotypic variance was 5.70. High broad sense heritability followed by low genetic advance as percent of mean values were obtained value of 86.35 and 9.62. The magnitude of GCV and PCV values were 5.03% and 5.41%. (Table 5). The estimate of genetic advance were recorded low for this trait was also observed by Somraj *et al.*, 2017. Hence moderate to low genetic advance suggested the role of both additive and non additive gene. Therefore, the breeder should adopt suitable breeding methodology to utilize both effects simultaneously.

4.3.3 Plant height (cm)

For plant height genetic variance, phenotypic, environmental variances, were recorded 88.37, 121.29 and 10.93 respectively. Moderate PCV (12.80%) and GCV (10.93%) was observed among tomato genotypes as shown in (Table 5). High heritability (bs) and moderate genetic advance as percent of mean were obtained with values of 72.86%, and 19.21. High heritability also observed by Ali *et al.*, 2012 in tomato.

4.3.4 Number of branches per plant

For number of branches per plant genotypic, phenotypic and environmental variances, values were 0.37, 0.62 and 0.35. The value of GCV (15.05%) was less than PCV (22.98%). The GCV was moderate value but the PCV was high. Low broad-sense heritability and low genetic-advance were recorded with values of 42.90, and 20.31 (Table 5).

4.3.5 Number of clusters per plant

Genotypic, phenotypic and environmental variance values were 1.91, 3.11, and 1.20 for cluster per plant. High heritability (bs) and genetic advance were observed with values of 61.44 and 32.66. The (PCV) value (25.80) was greater than (GCV) 20.23 as shown in (Table 5).

4.3.6 Number of fruits per plant

Environmental and genetic variances were 3.69 and 29.63, respectively. High heritability (bs) and high genetic advance with the values of 88.93 and 37.81 were observed for tomato genotypes, respectively. The genotypic coefficient of variation (GCV) value 19.46 was less than PCV 20.64 value (Table 5).

4.3.7 Fruit diameter (cm)

Genotypic, phenotypic and environmental variances values were recorded for fruit diameter 18.88, 24.00 and 5.23, respectively. Low of GCV and PCV values of 8.56 and 9.68 were observed for this trait. High heritability (bs) and moderate genetic advance as percent of mean were obtained with values of 78.20, 15.59 (Table 5).

4.3.8 Fruit length (cm)

Genotypic, phenotypic and environmental variances values were recorded for fruit diameter 35.40, 47.15 and 11.75, respectively. Moderate of GCV and PCV values of 12.21 and 14.9 were observed for this trait. High heritability (bs) and high genetic advance as percent of mean were obtained with values of 75.09, 21.79 (Table 5).

4.3.9 Single fruit weight

Phenotypic and genetic variances values were 118.76 and 112.95, respectively, while environmental variance was 5.81. The moderate PCV and GCV were 15.44 and 15.06, respectively obtained for single fruit weight. High heritability (bs) and high genetic advance as percent of mean were recorded with values of 95.11 and 30.25, respectively as shown in (Table 5).

4.3.10 Fruit yield per plant (kg)

For fruit yield per plant the genetypic, phenotypic and environmental variances were recorded 0.06, 0.08 and 0.02, respectively. High heritability (bs) and genetic advance as percent of mean values were obtained 75.22 and 25.88, respectively as given in (Table 3). The moderate GCV and PCV values were 14.48% and 16.70% respectively. High value of heritability is important parameter for betterment through selection due to high variability, thus this trait is likely to show high selection response practice in the F_2 breeding populations.

4.4 Correlation Coefficient analysis

The genotypic and phenotypic correlation coefficients for all pairs of ten characteristics are presented (Table 6). The highest positive correlation coefficient was observed between plant height and fruit diameter (0.823**); plant height and branches per plant (0.748**); and days to first flowering and days to first fruiting (0.714**) at genotypic level.

4.4.1 Days to first flowering

Days to first flowering had positive and highly significant association with days to first fruiting (0.714** and 0.612**), plant height (0.488** and 0.263*), fruit diameter (0.677** and 0.401**) and single fruit weight (0.454** and 0.434**) at both genotypic and phenotypic levels. It had positive and significant correlation with branches per plant (0.442**), cluster per plant (0.278*), fruits per plant (0.259*) and fruit yield per plant (0.296*) at genotypic level only.

4.4.2 Days to first fruiting

Days to first fruiting had positive and insignificant correlation with clusters per plant (0.180NS and 0.122NS), fruits per plant (0.225NS and 0.149NS), fruit diameter (0.192NS and 0.193NS), single fruit weight (0.243NS and 0.218NS) and fruit yield per plant (0.025NS and 0.017NS) at both levels and negative insignificant association with plant height (-0.064NS), branches per plant (-0.015NS) and fruit length (-0.151NS) at phenotypic level only.

4.4.3 Plant height (cm)

Plant height showed positive and significant correlation with the branches per plant (0.748** and 0.530**), fruit diameter (0.823** and 0.371**), single fruit weight (0.593** and 0.310*) and fruit yield per plant (0.417** and 0.317*) at both genotypic and phenotypic levels. Rani and Anitha (2011) reported that association of plant height with yield per plant was positive. It was insignificant negative correlation with fruits per plant (-0.136NS and -0.006NS).

Table 6. Genotypic and phenotypic correlation coefficients among different pairs of yield and yield contributing characters for different genotype of tomato

Traits		DFF	DF	PH	BPP	CPP	FPP	FD	FL	SFW	FYP
DFF	r_g	1									
	r_p	1									
DF	r_g	0.714**	1								
	r_p	0.612**	1								
PH	r_g	0.488**	0.023NS	1							
	r_p	0.263*	-0.064NS	1							
BPP	r_g	0.442**	0.096NS	0.748**	1						
	r_p	0.211NS	-0.015NS	0.530**	1						
CPP	r_g	0.278*	0.180NS	-0.187NS	0.046NS	1					
	r_p	0.200NS	0.122NS	0.081NS	0.107NS	1					
FPP	r_g	0.259*	0.225NS	-0.136NS	0.116NS	0.719**	1				
	r_p	0.232NS	0.149NS	-0.006NS	0.081NS	0.545**	1				
FD	r_g	0.677**	0.192NS	0.823**	0.629**	0.019NS	0.114NS	1			
	r_p	0.401**	0.193NS	0.371**	0.274*	0.109NS	0.118NS	1			
FL	r_g	-0.103NS	-0.151NS	-0.259*	0.339**	-0.569**	-0.153NS	-0.626**	1		
	r_p	-0.083NS	0.020NS	0.030NS	0.249*	-0.318**	-0.094NS	0.007NS	1		
SFW	r_g	0.454**	0.243NS	0.593**	0.502**	0.110NS	0.149NS	1.018**	-0.205NS	1	
	r_p	0.434**	0.218NS	0.310*	0.289*	0.046NS	0.122NS	0.578**	-0.112NS	1	
FYP	r_g	0.296*	0.025NS	0.417**	0.370**	0.519**	0.573**	0.355**	-0.396**	0.586**	1
	r_p	0.227NS	0.017NS	0.317*	0.276*	0.393**	0.507**	0.493**	-0.062NS	0.447**	1

**= Significant at 1% , * = Significant at 5% and NS= Non-significant

DFF: days to first flowering, DF: days to first fruiting, PH: Plant height (cm), BPP: branches per plant, CPP: clusters per plant, FPP: fruits per plant, FD: fruit diameter (cm), FL: fruit length (cm), SFW: Single fruit weight (g) and FYP: fruit yield per plant (kg).

4.4.4 Number of branches per plant

Number of branches per plant showed highly significant correlation with the fruit diameter (0.629** and 0.274*), fruit length (0.339** and 0.249*), single fruit weight (0.502** and 0.289*) and fruit yield per plant (0.370** and 0.276*) at both genotypic and phenotypic levels.

4.4.5 Number of clusters per plant

Number of clusters per plant showed positive and significant correlation with fruits per plant (0.719** and 0.545**) and fruit yield per plant (0.519** and 0.393**); negative and significant correlation with fruit length (-0.569** and -0.318**) at both genotypic and phenotypic levels (Table 6). It was not significant positive correlation with fruit diameter (0.019NS and 0.109NS) and single fruit weight (0.110NS and 0.046NS) at both levels.

4.4.6 Fruits per plant:

Number of fruits per plant is an important parameter for high yield. This parameter is significantly positive correlated with number of cluster per plant (0.719** and 0.545**) and fruit yield per plant (0.573** and 0.507**) at both genotypic and phenotypic levels, respectively. On the contrary, the number of fruits per plant was negatively correlated with fruit length (-0.153NS and -0.094NS) at both genotypic and phenotypic levels. Number of fruits per plant was not significantly correlated with fruit diameter (0.114NS and 0.118NS) and single fruit weight (0.149NS and 0.122NS) at both levels.

4.4.7 Fruit diameter (cm)

Fruit diameter showed positive and highly significant correlation with single fruit weight (0.918** and 0.578**) and fruit yield per plant (0.355** and 0.493**) at both levels; negative and significant correlation with fruit length at genotypic level (-0.626**) and positive not significant at phenotypic level (0.007NS).

4.4.8 Fruit length (cm)

Fruit length showed negative correlation with single fruit weight (-0.205NS and -0.112NS) and fruit yield per plant (-0.396** and -0.062NS) at both genotypic and phenotypic levels.

4.4.9 Single fruit weight

Single fruit weight showed positive and highly significant correlation with fruit yield per plant (0.586** and 0.447**).

4.4.10 Fruit yield per plant (kg):

Fruit yield per plant had positive significant correlation with plant height (0.417** and 0.317*), branches per plant (0.370** and 0.276*), cluster per plant (0.519** and 0.393**), fruits per plant (0.573** and 0.507**), fruit diameter (0.355** and 0.493**) and single fruit weight (0.586** and 0.447**) at both levels. Some other characters such as days to first fruiting had no significant correlation with fruit yield per plant. The present results show similarity with the results reported by Mohanthy (2003) in tomato.

4.5 Path analysis

Path coefficient analysis provides an effective means of partitioning direct or indirect causes of relationships. The estimates of correlation coefficient mostly indicated inter-relationship of different characters but it did not furnish information on cause and effect. Under such situation path analysis, that developed by Wright (1921) and demonstrated by Dewey and Lu (1959), helps the breeder to identify the index of selection. Path coefficient analysis was done in order to study the direct and indirect effects of individual component characters on the dependent variable i.e., fruit yield per plant. Study of path coefficients enable the breeders to concentrate on the variables which show high direct effect on fruit yield. Such information would be of great value in enabling the breeder to specifically identify the important component traits of yield and utilize the genetic stock for improvement in a planned way. Since crop yield is affected by many factors, selection based on correlation alone may be misleading because it measures only the mutual association between two characters (Izge *et al.* 2012). Path coefficient analysis, however, specifically measures the relative importance of different yield components. The genotypic correlation coefficients of fruit yield per plant with other yield and quality traits was further partitioned into direct and indirect effects and the results is presented in Table 7.

Table 7. Genotypic Path coefficient analysis showing direct (bold) and indirect effects of different characters on yield of tomato

Characters	Days to first flowering	Days to first fruiting	Plant height (cm)	Number of branches per plant	Number of clusters per plant	Number of fruits per plant	Fruit diameter (cm)	Fruit length (cm)	Single fruit weight	Genotypic correlation with Fruit yield per plant
Days to first flowering	**-0.480**	0.248	3.057	-1.816	0.726	0.095	-2.950	-0.224	1.641	0.296*
Days to first fruiting	-0.343	**0.347**	0.145	-0.393	0.471	0.083	-0.835	-0.328	0.879	0.025
Plant height (cm)	-0.234	0.008	**6.263**	-3.073	-0.489	-0.050	-3.584	-0.565	2.141	0.417**
Number of branches per plant	-0.212	0.033	4.684 -	**-4.110**	0.119	0.042	-2.739	0.739	1.814	0.370**
Number of clusters per plant	-0.134	0.063	-1.173	-0.188	**2.610**	0.264	-0.081	-1.240	0.398	0.519**
Number of fruits per plant	-0.124	0.078	-0.854	-0.475	1.876	**0.367**	-0.498	-0.333	0.537	0.573**
Fruit diameter (cm)	-0.325	0.067	5.152	-2.584	0.048	0.042	**-4.357**	-1.364	3.677	0.355**
Fruit length (cm)	0.049	-0.052	-1.624	-1.394	-1.486	-0.056	2.729	**2.178**	-0.739	-0.396**
Single fruit weight (g)	-0.218	0.084	3.713	-2.064	0.288	0.055	-4.436	-0.446	**3.611**	0.586**

**= Significant at 1% , * = Significant at 5% level of probability

Residual effect 0.23

4.5.1 Days to first flowering

Days to first flowering (-0.480) expressed a negative direct effect on yield. But it was positively significant correlation with fruit yield (0.296*). The direct selection for this character would be beneficial for crop improvement since this character showed a significant positive genotypic coefficient of correlation on yield (0.296*) and supported by Rani and Anitha (2011). Days to first flowering had a high positive indirect effect (3.057) on yield via plant height. It, therefore, means that plant height character contributed very much to the fruit yield of tomato. It was also positive indirect effect via single fruit weight (1.641), number of cluster per plant (0.726), days to first fruiting (0.248) and it showed negative indirect effects via fruit diameter (-2.950), numb er of branches per plant (-1.816) and fruit length (-0.224).

4.5.2 Days to first fruiting

Days to first fruiting showed direct and positive effects (0.347) on fruit yield per plant and it also had indirect and positive effects through single fruit weight (0.879), number of cluster pe plant (0.471) and plant height (0.145) and negative indirect effect via fruit diameter (-0.835), number of branches per plant (-0.393), days to first flowering (-0.343), fruit length (-0.328). It was insignificant positive correlation with fruit yield (0.025).

4.5.3 Plant height (cm)

Plant height had highest direct and positive effects (6.263) on fruit yield per plant and it also had indirect and positive effects via single fruit weight (2.141). It had negative indirect effect via fruit diameter (-3.584), number of branches per plant (-3.073), fruit length (-0.565), number of cluster per plant (-0.489) and days to first flowering (-0.234). But plant height had the significant positive correlation with fruit yield (0.417**).

4.5.4 Number of branches per plant

Number of branches per plant had moderate direct and negative effects (-4.110) on fruit yield per plant and it had indirect and positive effects through plant height (4.684), single fruit weight (1.814), fruit length (0.739) and number of cluster per plant (0.119). Number of branches per plant had negative indirect effects through fruit diameter (-2.739) and days to first flowering (-0.212). It had positive correlation with fruit yield per plant (0.370**).

4.5.5 Number of clusters per plant

Number of clusters per plant had higher direct and positive effects (2.610) on fruit yield per plant and it also had indirect positive effects through single fruit weight (0.398) and number of fruits per plant (0.264). It showed indirect negative effects through plant height (-1.173), fruit length (-1.240), number of branches per plant (-0.188) and days to first flowering (-0.134). But it had significant positive correlation with fruit yield at genotypic level (0.519**).

4.5.6 Number of fruits per plant

Number of fruits per plant had moderate direct and positive effects (0.367) on fruit yield per plant and it also had indirect and positive effects through number of cluster per plant (1.876) and single fruit weight (0.537) while it showed negative indirect effect via plant height (-0.854), fruit diameter (-0.498), fruit length (-0.333), number of branches per plant (-0.475) and days to first flowering (-0.124). It had positive significant correlation with fruit yield per plant (0.573**).

4.5.7 Fruit diameter (cm)

Fruit diameter showed highest direct and negative effects (-4.357) on fruit yield per plant. It had indirect and positive effects through plant height (5.152) and single fruit weight (3.677). It had positive significant correlation with fruit yield per plant (0.355**). Fruit diameter had negative indirect effect via number of branches per plant (-2.584), plant height (-1.364) and days to first flowering (-0.325).

4.5.8 Fruit length (cm)

Fruit length showed direct and positive effects (2.178) on fruit yield per plant. It had also indirect and positive effects through fruit diameter (2.729) and days to first flowering (0.049). It had negative significant correlation with fruit yield per plant (-0.396**). Fruit length had negative indirect effect via plant height (-1.624), number of cluster per plant (-1.486), number of branches per plant (-1.394) and single fruit weight (-0.739).

4.5.9 Single fruit weight

Single fruit weight had direct and positive effects (3.611) on fruit yield per plant. It also had indirect and positive effects via plant height (3.713) and number of cluster per plant (0.288). It had negative indirect effect via fruit diameter (-4.436), number of branches per plant (-2.064), fruit

length (-0.446) and days to first flowering (-0.218). But single fruit weight had the significant positive correlation with fruit yield (0.586**).

Residual effect

From genotypic path analysis the magnitude of residual effects was 0.23 indicated that characters included in path analysis explained about 77% of the variation in fruit yield contributing traits were considered in the present investigation. However, the remaining variation in fruit yield was 23% can be attained by incorporating in the path analysis as far as studies involving genetic variability and characters association is concerned.

4.6 Heterosis

The manifestation of heterotic effect of different F_2 populations over better parent ((heterobeltiosis) and standard heterosis over the check varieties were calculated and is presented in Table 8(a).

4.6.1 Plant height

The plant height is an important trait by which growth and vigour of plants are measured. The cross C7 exhibited the highest significant heterosis over better parent (41.43%) for plant height (Table 8a). It was highest for standard heterosis over check cross C12 (51.45%). Heterosis for plant height varied from -28.49 to 41.43% over better parents and -3.36% to 51.45% over standard check. Among fourteen crosses, three cross were significantly positive to better parent and six crosses positive significant to standard check.

4.6.2 Days to first flowering

The highest heterosis was observed for days to first flowering were 10.79% over better parent and 48.69% over check variety from the same cross C4 (Table 8a). Significant and useful negative heterosis was observed for 12 combinations out of 14 combinations over better parent and no negative cross combinations over standard variety. Negative heterosis for days to first flowering was also reported by Premalakshme *et al.* (2005)

Table 8(a). Estimates of Heterosis (heterobeltiosis) over better parent (HBP) and standard heterosis over the check variety (HCV)

Genotypes	Cross	Plant height (cm)		Days to first flowering		Days to first fruiting	
		HBP	HCV	HBP	HCV	HBP	HCV
C1	P1x P2	-14.38	15.72	-28.91**	19.74**	-13.19**	-4.58**
C2	P1x P3	1.95	37.79**	-21.09**	32.90**	-6.94**	2.29*
C3	P2x P1	-28.49*	-3.36	-19.53**	35.53**	-4.86**	4.58**
C4	P2x P3	36.35**	41.48**	10.79**	48.69**	-0.75	0.76
C5	P2x P4	12.45	23.70*	-4.90**	27.63**	-3.76**	-2.29*
C6	P2x P5	1.53	13.30	-20.56**	11.84**	-5.93**	-3.05**
C7	P3x P2	41.43**	46.76**	-12.74**	17.11**	-8.27**	-6.87
C8	P3x P4	15.55	27.11*	-3.06**	25.00**	-3.76**	-2.29*
C9	P3x P5	-0.83	10.67	-23.37**	7.89**	-5.93**	-3.05**
C10	P4x P1	-20.17	7.89	-31.25**	15.79**	-15.28**	-6.87**
C11	P4x P2	5.97	16.58	-7.84**	23.68**	-3.01**	-1.53
C12	P4x P3	37.67**	51.45**	-3.06**	25.00**	-7.52**	-6.11**
C13	P5x P2	5.23	17.44	-5.61**	32.90**	-7.41**	-4.58**
C14	P5x P4	-1.15	10.31	4.67**	47.37**	-5.93**	-3.05**
SE (±)		10.82		0.67		0.86	
LSD (0.05)		21.85		1.35		1.73	
LSD (0.01)		29.21		1.80		2.31	

*,** = Significant at 0.05 and 0.01 level of probability, respectively.

4.6.3 Days to first fruiting

The highest negative heterosis was observed for days to first fruiting were -15.28% over better parent and -6.87% over check variety from the same cross C10. Significant and useful negative heterosis was observed for 13 cross combinations out of 14 over better parent and nine cross combinations over standard variety for days to first fruiting.

4.6.4 Number of branches per plant

The number of branches per plant is a major yield contributing character and maximum number of branches per plant was observed in cross combination C12 (43.34% and 22.86%) over better parent and standard heterosis (Table 8b). The estimate of heterosis varied from -23.08% to 43.34% over better parent and -14.29% to 22.86% over standard parent. Cross C4 (37.04% and 5.71%) and C12 (43.34% and 22.86%) showed highly significant positive heterosis over better and standard check variety. Hannan *et al.* (2007) also found that six crosses gave significantly positive mid parent heterosis and four of them exhibited significant positive heterobeltiosis.

4.6.5 Number of clusters per plant

The number of cluster per plant is a major yield contributing character and maximum highly significant heterosis for number of cluster per plant was observed in cross C5 (28.97% and 58.91%) over the better and standard parent, respectively. The estimate of heterosis varied from -30.44% to 28.97% over better parent and -14.29% to 58.91% over standard parent. Three cross combinations viz., C5 (28.97%), C8 (6.74%) and C12 (10.49%) were found highly significant positive heterosis over better parent and nine cross combination were observed highly significant positive heterosis over standard check (Table 8b).

4.6.6 Number of fruits per plant

The number of fruits per plant is a major yield contributing character. The highest positive significant heterosis for number of fruits per plant was observed in cross C5 (23.68% and 79.48%) over the better and standard parent, respectively. Heterosis varied from 5.64% to 79.48% over standard parent and -28.53% to 23.68% over better parent. Highly significant positive useful heterosis was observed in two cross combinations over better parent and all fourteen cross combinations over standard parent. Twelve crosses were showed negative heterosis for fruits per plant over better parent. Two crosses viz., C1 (8.13%) and C5

Table 8b. (Cont.): Estimates of Heterosis (heterobeltiosis) over better parent (HBP) and standard heterosis over the check variety (HCV)

Genotypes	Cross	Number of branches per plant		Number of clusters per plant		Number of fruits per plant	
		HBP	HCV	HBP	HCV	HBP	HCV
C1	P1* P2	-23.08**	-14.29**	-10.45**	28.57**	8.13**	56.92**
C2	P1* P3	-23.08**	-14.29**	-35.32**	-7.14**	-17.34**	14.87**
C3	P2* P1	-25.64**	-17.14**	-29.10**	1.79	-12.36**	27.18**
C4	P2* P3	37.04**	5.71**	-23.19**	-5.36**	-19.08**	17.43**
C5	P2* P4	10.00**	-5.71**	28.97**	58.91**	23.68**	79.48**
C6	P2* P5	-5.71**	-5.71**	-1.45	21.43**	-3.99*	60.51**
C7	P3* P2	29.63**	0.00	-30.44**	-14.29**	-27.21**	5.64**
C8	P3* P4	13.34**	-2.86**	6.74**	1.79	-12.22**	21.54**
C9	P3* P5	-2.86**	-2.86**	-10.61**	5.36**	-15.64**	41.03**
C10	P4* P1	-12.82**	-2.86**	-16.67**	19.64**	-2.58	35.38**
C11	P4* P2	13.34**	-2.86**	0.00	23.22**	-5.65**	36.92**
C12	P4* P3	43.34**	22.86**	10.49**	5.36**	-8.89**	26.15**
C13	P5* P2	-11.43**	-11.43**	-13.04**	7.14**	-26.69**	22.56**
C14	P5* P4	-5.71**	-5.71**	-3.03**	14.29**	-28.53**	19.49**
SE (±)		0.43		0.89		1.60	
LSD (0.05)		0.87		1.80		3.23	
LSD (0.01)		1.17		2.40		4.32	

*,** = Significant at 0.05 and 0.01 level of probability, respectively.

(23.68%) showed high significant positive heterosis over their parents and check which are desirable traits for high yield. Because of spreading of plants more number of primary and secondary branches per plant, fruit cluster per plant and number of fruits per plant are useful to yield.

4.6.7 Fruit diameter (cm)

Fruit diameter is an important trait by which yield of plants are measured. The cross C8 exhibited the highest significant heterosis over better parent (14.14%) and cross C7 (21.59%) over standard check for fruit diameter. Heterosis for fruit diameter varied from -11.44% to 14.14% over better parents and 6.54% to 21.59% over standard check. Among fourteen crosses, two crosses viz., C4 (6.54%) and C8 (14.14%) were significantly positive heterosis over better parent and all crosses positive significant heterosis over standard check (Table 8c).

4.6.8 Fruit length (cm)

The cross C3 exhibited the highest insignificant heterosis over better parent (5.13%) and cross C14 (1.77%) over standard check for fruit length. Heterosis for fruit length varied from -17.07% to 5.13% over better parents and -14.76% to 1.77% over standard check. Among fourteen cross combinations, no one cross was significantly positive heterosis over better parent and standard check. Out of 14 cross combinations nine cross viz., C2 (-7.40%), C5 (-14.01%), C6 (-11.34%), C6 (-5.95%), C8 (-13.06%), C10 (-17.07%), C11 (-7.05%), C12 (-10.18%) and C13 (-10.51%) were significantly negative heterosis over better parent and ten cross were significantly negative heterosis over standard check (Table 8c).

4.6.9 Single fruit weight (g)

Single fruit weight is of prime importance in breeding high yielding cultivars. The cross C8 (50.72%) exhibited the highest positive significant heterosis over better parent and cross C4 (49.46%) shown the highest positive significant heterosis over standard check. Heterosis varied from -28.16% to 50.72% over better parent and -19.25% to 4C9.46% over standard check. Highly significant positive useful heterosis was observed in cross C8 (50.72%), followed by C4 (32.97%) and C5 (11.69%) over better parent. Cross C4 (49.46%) showed highly significant heterosis followed by C8 (43.8%) and C5 (25.54%) which over standard check. Ten crosses viz., C1 (10.29%), C2 (12.90%), C3 (10.18%), C4 (49.46%), C5 (25.54%), C7 (21.90%), C8 (43.89%), C9 (15.58%), C10 (17.64%) and C13 (9.18%) gave significantly positive

Table 8c. (Cont.): Estimates of Heterosis (heterobeltiosis) over better parent (HBP) and standard heterosis over the check variety (HCV)

Genotypes	Cross	Fruit diameter (cm)		Fruit length (cm)		Single fruit weight (g)		Fruit yield per plant (kg)	
		HBP	HCV	HBP	HCV	HBP	HCV	HBP	HCV
C1	P1* P2	-9.13**	11.62**	1.17	-13.44**	-15.19**	10.29**	21.44**	44.92**
C2	P1* P3	-6.70*	14.60**	-7.40*	-10.54**	-13.19**	12.90**	1.03**	20.56**
C3	P2* P1	-8.46**	12.44**	5.13	-10.05**	-15.28**	10.18**	8.19**	29.10**
C4	P2* P3	6.54*	27.30**	-0.81	-4.18	32.97**	49.46**	23.89**	29.37**
C5	P2* P4	-9.21**	8.48**	-14.01**	-11.61**	11.69**	25.54**	45.39**	51.82**
C6	P2* P5	-7.06*	11.81**	-11.34**	-7.94**	-16.69**	-0.61	30.42**	44.17**
C7	P3* P2	1.77	21.59**	-5.95*	-9.14**	8.44**	21.90**	14.25**	19.31**
C8	P3* P4	14.14**	19.79**	-13.06**	-10.64**	50.72**	43.89**	45.50**	27.92**
C9	P3* P5	-4.97	14.33**	-4.94	-1.30	-3.12	15.58**	7.61**	18.96**
C10	P4* P1	-6.35*	15.04**	-17.07**	-14.76**	-9.54**	17.64**	-3.65**	14.98**
C11	P4* P2	-11.34**	5.94*	-7.05*	-4.46	-28.16**	-19.25**	-0.06	4.37**
C12	P4* P3	9.75	15.19**	-10.18**	-7.67**	5.06**	0.30	33.53**	17.39**
C13	P5* P2	-2.54	17.24**	-10.51**	-7.08*	-8.48**	9.18**	11.39**	23.14**
C14	P5* P4	-11.44**	6.54*	-1.98	1.77	-18.22**	-2.44	-0.42*	10.08**
SE (±)		2.90		2.76		1.81		0.18	
LSD (0.05)		5.86		5.58		3.66		0.37	
LSD (0.01)		7.83		7.46		4.89		0.49	

*,** = Significant at 0.05 and 0.01 level of probability, respectively.

heterosis over standard parent. Positive heterosis over better parent for single fruit weight was also reported by Singh *et al* (2005). Four hybrids possessed significantly useful heterobeltiosis for fruit weight by Rahmani Gul *et al.* (2010). Five cross viz., C4 (32.97%), C5 (11.69%), C7 (8.44%), C8 (50.72%) and C12 (5.06) highly significant positive useful heterosis was observed over better parent.

4.6.10 Fruit yield per plant (kg)

High fruit yield per plant is the ultimate goal of any breeding programme and so requires higher consideration. The cross C5 (45.39% and 51.82%) had the highest significant positive heterosis over better parent and standard check, respectively. Heterosis varied from -3.65% to 45.39% over better parent and 4.37% to 51.82% over standard parent. Significant positive heterosis over standard parent was observed in C5 (51.82%) followed by C1 (44.92%), C6 (44.17%), C4 (29.37%) and C3 (29.10%).

Among the fourteen crosses, all the 14 crosses showed significantly positive heterosis over standard parent and eleven of them over better parent. The increased yield in these crosses may be due to the high yielding parents selected for hybridization as suggested by Courtney and Peirce (1979). Positive high significant heterosis was found for yield over the better parent by Bhatt *et al.* (2001) and significant high positive heterosis over mid-parent and better parent along with better performance in term of yield per plant by Sekhar *et al.* (2010).

CHAPTER V

SUMMARY AND CONCLUSION

During November 2020 to April 2021, the experiment was conducted with twenty one genotypes of tomato (*Solanum lycopersicum* L.) at Sher-e-Bangla Agricultural University's experimental field in Dhaka-1207 following Randomized Complete Block Design (RCBD) with three replications to evaluate genetically potential F_3 lines of tomato through assessment of heritability and character associations using yield contributing traits. Data on ten yield-contributing traits were collected in this study, including days to first flowering, days to first fruiting, plant height, number of branches per plant, number of fruits per cluster, number of fruits per plant, single fruit weight, and fruit yield per plant. For all of the characters under this investigation, analysis of variance revealed significance differences among all genotypes. The presence of adequate variation among the genotypes for all of the traits was revealed by the significant mean squares.

Among all genotypes, P_3 (23.33 days) took a minimum number of days to first flower and was earlier and it was statistically similar with the genotype CV-1 (25.33 days). The mean values of plant height ranged from P_3 (75.28 cm) to C12 (118.22 cm) with an overall mean of 92.86 cm. Maximum numbers of fruits per plant were recorded in the genotype P3 (20.89), which were significantly similar with CV-1 (21.67 cm) and C7 (22.89 cm). The genotype C5 (2.64 kg) had the highest fruit yield per plant it was statistically similar with C1 (2.52 kg) and C6 (2.51 kg).

The phenotypic coefficient of variations were slightly higher than the corresponding genotypic coefficient of variations for all the characters studied. High GCV and PCV were observed in number of clusters per plant (20.23 and 25.80%), days to first flowering (20.55 and 20.67%) and number of fruits per plant (19.46 and 20.64%). High heritability was estimated for days to first flowering (98.85), days to first fruiting (86.35), plant height (72.86), number of clusters per plant (61.44), number of fruits per plant (88.93), fruit diameter (78.20), fruit length (75.09), single fruit weight (95.11) and fruit yield per plant (75.22) indicating that these characteristics were less influenced by the environment. High heritability, genetic advance and GCV were observed in number of fruits per plant, number of clusters per plant and days to first flowering indicated that these characteristics were controlled by additive gene action and the selection based on phenotype for these traits might be effective. Similarly, high heritability coupled with

moderate GA and GCV for fruit diameter suggested that selection might be effective for this trait.

To determine the relationship between yield and yield components, correlation coefficients among the characters were examined. In general, the genotypic correlation co-efficient was larger than the phenotypic correlation co-efficient for most of the traits, indicating a significant strong inherent association among the characters under study. Any plant breeding program's ultimate goal is to increase fruit yield. As a result, the correlation investigation is crucial. plant height (0.417** and 0.317*), branches per plant (0.370** and 0.276*), cluster per plant (0.519** and 0.393**), fruits per plant (0.573** and 0.507**), fruit diameter (0.355** and 0.493**) and single fruit weight (0.586** and 0.447**) all showed significant positive correlation with fruit yield per plant at both genotypic and phenotypic levels. Fruit yield per plant had a negative and insignificant relationship with days to first fruiting at both level and with days to first flowering and fruit length at phenotypic level. The genotypic correlation coefficients for the majority of the traits were larger than the phenotypic correlation coefficients, indicating a strong underlying relationship between the features under investigation.

Path coefficient analysis was done in order to study the direct and indirect effects of individual component characters on the dependent variable i.e., fruit yield per plant. Path coefficient analysis provides an effective means of partitioning direct or indirect causes of relationships. Path coefficient analysis showed that plant height had highest direct positive effect ((6.263)) on fruit yield followed by single fruit weight (3.611), number clusters per plant (2.610), fruit length (2.178) and fruits per Plant (0.367) which indicated that direct selection for these characters might be effective and there is a possibility of improving yield per plant through selection based on these characters. Path coefficient also showed negative direct effect for the characters fruit diameter (-4.357), number of branches per plant (-4.110) and day to first flowering (-0.480).

Highly significant and positive heterosis was found for number of fruits per plant in cross C5 (23.68%) and C1 (8.13%) over better parent and cross C5 (79.48%), C6 (60.51%), C1 (56.92%) and C9 (41.03%) over standard parent. Positive and highly significant heterosis was observed for fruit yield per plant in cross C8 (45.50%), C5 (45.39%), C12 (33.53%) and C6 (30.42%) over better parent and cross C5 (51.82%), C1 (44.92%), C6 (44.17%), C4 (29.37%) and C3 (29.10%) over standard check. The Crosses showed significantly high percentage of positive

heterosis over better and standard parent for number of fruits per cluster, single fruit weight and the cross showed negative heterosis for plant height and days to first flowering which are desirable characters.

Selection of the F_2 populations:

- Based on morphological and yield attributing traits the cross combinations C1(P1*P2), C5(P2*P4),C6(P2*P5), C8(P3*P4), C12(P4*P3) were selected for high yield.
- C3(P2*P1) could be suggested for dwarf plant.
- C1(P1*P2),C9(P3*P5),C10(P4*P1) could be recommended for further selection for early maturity.

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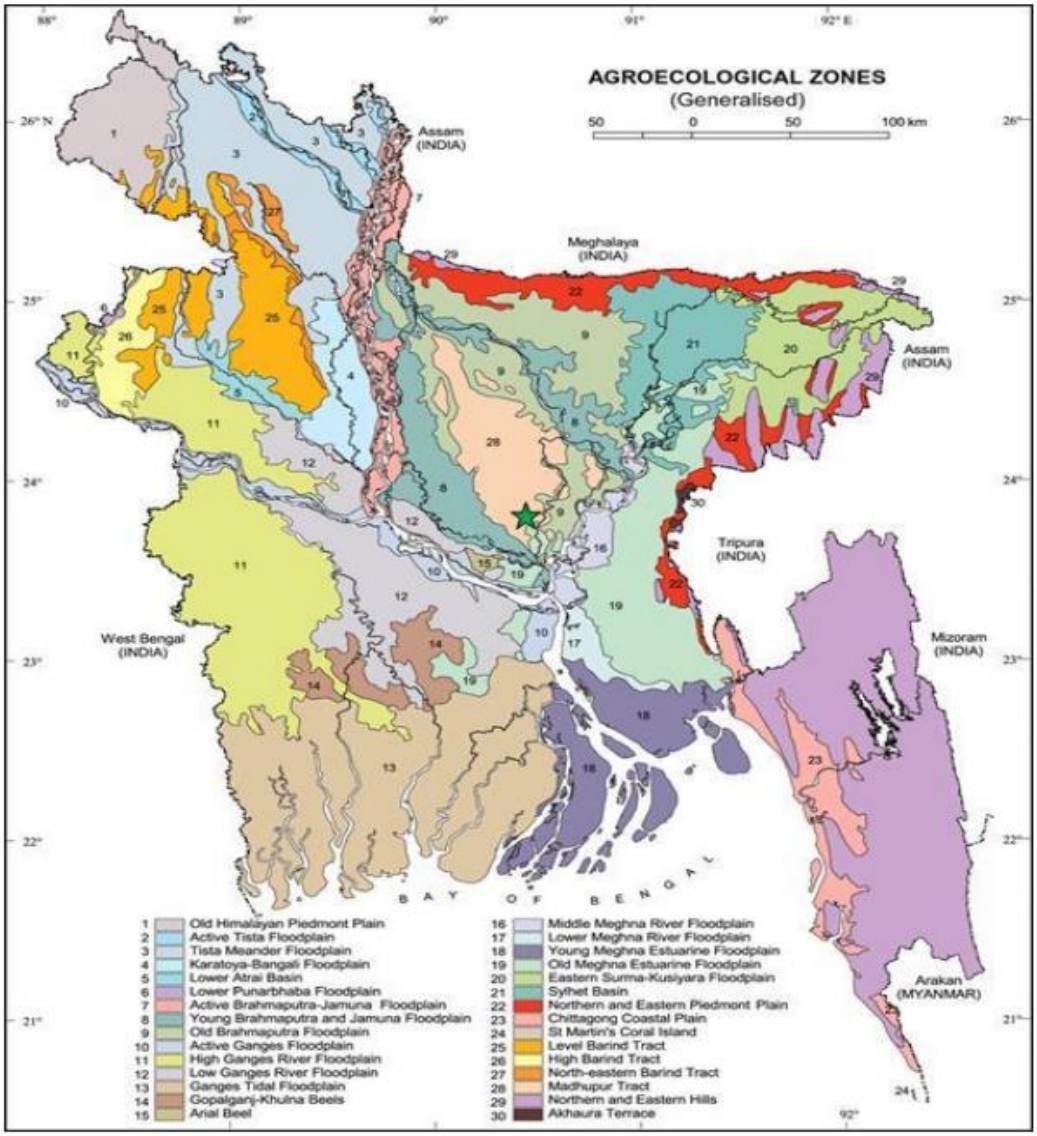
APPENDICES

Appendix I. Map showing the experimental site under the study



The experimental site under the study

Appendix II. Morphological, physical and chemical characteristics of initial soil (0- 15 cm depth) of the experimental site

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly levelled

B. Physical composition of the soil

Soil separates	**%**	Methods employed
Sand	**26**	Hydrometer method (Day, 1915)
Silt	**45**	**Do**
Clay	**29**	**Do**
Texture class	**Silty loam**	**Do**

C. Chemical composition of the soil

Sl. No.	Soil characteristics	Analytical data	Methods employed
01	Organic carbon (%)	0.45	Walkley and Black, 1947
02	Total N (%)	0.03	Bremner and Mulvaney, 1965
03	Total S (ppm)	225.00	Bardsley and Lanester, 1965
04	Total P (ppm)	840.00	Olsen and Sommers, 1982
05	Available N (kg/ha)	54.00	Bremner, 1965
06	Available P (ppm)	20.54	Olsen and Dean, 1965
07	Exchangeable K (me/100 g soil)	0.10	Pratt, 1965
08	Available S (ppm)	16.00	Hunter, 1984
09	pH (1:2.5 soil to water)	5.6	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Source: Soil Resource and Development Institute (SRDI), Farmgate, Dhaka

Appendix III. Monthly meteorological information during the period from September 2020 to February, 2021.

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Average rainfall (mm)
		Maximum	Minimum		
2021	September	32.4°C	25.7°C	80%.	86 mm
	October	31.2°C	23.9°C	76%.	52 mm
	October	31.2	23.9	76	52 mm
	November	29.6	19.8	53	00 mm
	December	28.8	19.1	47	00 mm
2022	January	25.5	13.1	41	00 mm
	February	25.9	14	34	7.7 m

Source: Metrological Centre, Agargaon, Dhaka (Climate Division)