HETEROTIC ANALYSIS FOR QUANTITATIVE AND QUALITATIVE TRAITS IN TOMATO *(Solanum lycopersicum* L.*)* GENOTYPES

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BY

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CERTIFICATE

This is to certify that thesis entitled, "HETEROTIC ANALYSIS FOR QUANTITATIVE AND QUALITATIVE TRAITS IN TOMATO (Solanum lycopersicum L.) GENOTYPES" 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 ONUSHA SHARMITA, Registration No. 14-05832 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 been duly been acknowledged.

Dated: June, 2021
Place: Dhaka, Bangladesh

(Prof. Dr. Naheed Zeba)
Supervisor

DEDICATED

TO

MY BELOVED PARENTS

Some commonly used abbreviations

Full Form	Abbreviation	Full Form	Abbreviation
Advanced	*Adv.*	Heterobeltiosis	HB
Agriculture	*Agril.*	Heterosis Over Mid Parent	HMP
Agronomy	*Agron.*	Horticulture	*Hort.*
Agro-Ecological Zone	AEZ	International	*Intl.*
Analysis of Variance	ANOVA	Journal	*J.*
Bangladesh Agricultural	BARI	Kilogram	Kg
Research Institute		Mean Sum of Square	MSS
Bioscience	*Biosci.*	Milligram	mg
Biology	*Biol.*	Millimeter	mm
Biotechnology	*Biotechnol*.	Muriate of Potash	MOP
Breeding	*Bred.*	Non-significant	NS
Botany	*Bot.*	Parts per million	ppm
Component of Variance	CV	Percentage	%
Cation Exchange Capacity	CEC	Pathology	P*athol.*
Centimeter	cm	Plant Genetic Resources	PGRC
Cross	×	Centre	
Days After Transplanting	DAT	Randomized Complete	RCBD
Degree of Celsius	^{0}C	Block Design	
Environmental	*Environ.*	Reciprocal Combining	REC
Experimental	*Expt.*	Ability	
First Generation	F_1	Relative Heterosis	RH
Food and Agriculture	FAO	Research	*Res.*
Organization		Science	*Sci.*
Food and Agriculture	FAOSTAT	Sher-e-Bangla Agricultural	SAU
Organization Statistics		University	
General Combining Ability	GCA	Society	*Soc.*
Genetics	*Genet.*	Soil Resource and	SRDI
Genetics and Plant Breeding	GEPB	Development Institute	
Genotype	G	Specific Combining Ability	SCA
Gram	g	Technology	*Technol.*
Hectare	ha	Total Soluble Solid	TSS
Heritability	H^2	Triple Super Phosphate	TSP
Heterosis over Better parent	HBP	Vegetables	*Veg.*

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The Author

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HETEROTIC ANALYSIS FOR QUANTITATIVE AND QUALITATIVE TRAITS IN TOMATO *(Solanum lycopersicum* L.*)* GENOTYPES

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ABSTRACT

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period of November 2018-April 2019 and November 2019-April 2020 to study the heterosis over better and mid parent in intraspecific cross among ten tomato parental lines. Twenty-four F_1 was generated from ten parental lines in first year experiment and the heterosis was estimated for quantitative and qualitative traits using the ten parents and twenty-four F_1 using Randomized Complete Block Design with three replications. Analysis of variance showed the significant differences among the genotypes for all the agromorphological characters except for number of leaves per plant, leaf area and number of branches per plant. Fruit pH, fruit Brix content and leaf chlorophyll content showed significant differences among the genotypes. G1×G7 showed highest plant height (130.17 cm) and early fruit setting (37.33 DAT). Early flowering (18.33 DAT) and early maturity (83 DAT) were found in G4×G1 and G3×G10 respectively. Highest number flowers per clusters per plant (9.95) and number of fruits per cluster (7.36) were found in G2×G10 and G4×G10 respectively. G7×G10 showed highest number of cluster (41.33) and fruits per plant (320.5). G4×G1 showed the highest single fruit weight (165.54 g) and yield per plant (8.88 kg). G1×G3 showed the highest fruit Brix% (4.5) and fruit pH (5.08) and G4×G5 showed the lowest pH (3.14). G1×G5 showed the highest leaf chlorophyll content (65.03). Heterosis analysis revealed some crossed lines with superiority over their parental lines. G5×G10 showed the highest heterosis over mid (37.28) and better parent (30.62) for plant height. G2×G10, G5×G10 and G9×G10 crossed lines showed the early flowering (-42.72), fruit setting (-30.65) and maturity (-19.38) in term of heterosis over better parent. G1×G8 showed the highest heterosis over mid parent (65.30) and better parent (56.27) for number of clusters per plant. G5×G10 showed the highest heterosis over mid parent number of fruits per plant (219.78) and yield per plant (233.38). G10×G2 showed the highest heterosis over mid (73.56) and better parent (191.14) for fruit weight. In case of qualitative traits, highest heterosis over better parent and mid parent for fruit Brix% (52.03 and 121.67), fruit shelf life (85.78 and 88.30) and leaf chlorophyll content (28.45 and 35.78) were found in G1×G3, G4×G5 and G1×G5 respectively. G4×G1, G1×G7, G5×G10 and G1×G3 could be suggested for early flowering, fruit setting, highest yield per plant and fruit Brix content respectively.

Chapter I
Introduction

CHAPTER I
INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a model plant for several research belongs to genetics and genomic. Tomato is diploid crops having chromosome number 24. Tomato is vegetable crops belongs to the Solanaceae family which contains around 3000 species which originated from both world (Ahanger *et al*., 2020 and Knapp, 2002). All the Solanum species are not cultivated. *Solanum lycopersicum* is the only domesticated species. Tomato is annual with short lived which is cultivated single per single seasons. The fruit is edible only which is called berry containing many seeds inside the cavity called locule. Fruit is green during the unripening stage, but it might be red, yellow color during the ripening depending on the genotypes. Wild tomato is smaller than the cultivated one. Tomato is cultivated because of its nutritional value but the environment can shape the nutrient content in tomato (Ahanger *et al*., 2020 and Purseglove *et al.*, 1981).

Tomato is cultivated all around Bangladesh because of its higher adaptability as well as higher nutrient content. Tomato contains higher vitamins A, B and C including 0.12 mg vitamin B1, 0.06 mg vitamin B2 and 27 mg vitamin C; calcium and carotene; 94 g water, 0.5 g minerals, 0.8 g fiber, 0.9 g protein, 0.2 g fat and 3.6 g carbohydrate. 48 mg calcium, 0.4 mg iron, 356 mg carotene, is present in each 100 g edible ripen tomato (Ali *et al*., 2021; Husna *et al*., 2020; Brown *et al*., 2013; BARI, 2010; Ahamed, 1995). In Bangladesh, more than 7 % of vitamin C comes from only tomato. Because of its higher adaptability and nutritious value, Consumption of tomatoes has been increased ~ 4.5% each year after 1990 to 2004 (Mishra *et al*., 2019 and Aherne *et al*., 2009). Worldwide tomato is cultivated in 144 countries covering 4.5 million ha of lands (FAOSTAT, 2013; BARI, 2010; Aditya, 1997). In Bangladesh, the average tomato production is 10 tons/ha covering 72878.64-acre area of lands with a production of 447815.43 Mtons (Anonymous 2014). Tomato is mainly cultivated during the robi season (winter) in Bangladesh when the temperature remains 15-20 ^{0}C which is optimum for tomato fruit setting and flowering.

Recently some summer tomato varieties have been cultivated under partial shed condition. Though there are several number tomato varieties in Bangladesh developed by BARI, it is important to increase the number of tomato varieties having specific traits considering both the quantitative and qualitative.

Tomato varieties those are cultivated in Bangladesh have some good traits. The limitation of all the tomato varieties are that a single variety does not have both the good morphological and qualitative traits. Some varieties are good depending on their quality and some are good depending on their yield capability. Having both the yield with higher good qualitative and nutritional traits are rare. Besides, the demand of consumer varies depending on the person, area and changes with the time. So, it is important to focus on the development of tomato cultivars having higher yield with high qualitative and nutritive traits. For this purpose, hybridization followed by the general combining ability, specific combining ability and heterosis estimation are important steps.

Improvement of traits of tomato by means of conventional breeding involves some specific and chronological steps such as enhancement of germplasms, estimation of diversity followed by crossing among the parents having good traits depending on the objectives, estimation of heterosis and combining ability for selection the best combiner with specific cross combination followed by continuous selection and selfing for homogenous. For development of hybrid variety, heterosis in means of better and mid parent is important to find out the best cross and parents. Combining analysis can be estimated in two broad categories such as General combining analysis and specific combining analysis. General combining ability analysis is done for identifying the best combiner among the parents involved in crossing program which is also called the main effect. On the other hand, Specific combining analysis is carried out to find out the specific combination which produce best offspring. In another word, SCA is considered as the interaction effect.

In breeding program both SCA and GCA estimation along with heterosis is very important for the above objectives. GCA, SCA and heterosis has been practiced

since many years ago in different crops. These methods help the breeder to take the decision for the selection of good parent as a best combiner and a specific cross combination for development of hybrid variety. As the crossing technique is not so difficult in tomato and a single cross can produce many seeds, this breeding approaches have been practiced in tomato varietal development. Among all the breeding tools, heterosis analysis is one of the most effective tools to understand the genetic capability of their hybrids to identify the best F_1 as well as to know the genetic architecture of various characters among the parents. Heterosis breeding helps the breeder to combine the more than one characters in a single offspring that will increase the demand of consumer as well improvement of a good parents.

Considering the importance, demand and necessity of tomato breeding program for Bangladesh perspective, this present study was carried out with the following objectives:

1. To estimate the mean performance for quantitative and qualitative traits of crossed genotypes and parents
2. To estimate the heterosis over mid parent and heterosis over better parent for quantitative and qualitative traits of F_1.

Chapter II

Review of Literature

CHAPTER II
REVIEW OF LITERATURE

Tomato has been cultivated along different parts of the world because of its higher nutritious value. Breeding approaches through the crossing and heterosis analysis have been continuously practiced because of the easy crossing methods, easy to select the better plants because of its higher variability. In this chapter, literature and research related to tomato focusing heterosis and combining ability have been reviewed and presented chronologically.

2.1 Tomato

The tomato (*Solanum lycopersicum* L.) is a self-pollinated species that is 1-3 m tall. The stem is woody. At first European thought tomato plant as a poisonous due to leaf toxicity (Mishra *et al*., 2019 and Siddique, 2018). Tomato originated from southern American countries such as Chile, Bolivia, Ecuador, Colombia and Peru where Mexico has been considered as the domestication of the origin of tomato (Brown et al., 2013). From Mexico it was transferred to Europe and then to Asia. Secondary origin of tomato is Spain and Germany (Kumer and Gowda, 2016). But the origin of cultivated tomato is different place. It is speculated that cultivated tomato has been originated from Peru-Ecuador-Bolivia. Some reviews showed that the native of tomato is northern American country (Soresa *et al*., 2020 and Khan *et al*., 2015). China, India, USA, Turkey, Egypt, Italy, Iran, Spain, Brazil, Mexico and Russia are the top tomato producing countries according to FAOSTAT (2020).

Among all the vegetables, tomato is considered as the most popular vegetables as soups, juice, ketchup, sauces, conserves, puree, paste, powder, and other products (Soresa *et al*., 2020 and Nahar and Ullah, 2011). Tomato is also rich in nutritious value such as vitamins and minerals. Vitamin C, total soluble solids (TSS), percent acidity, pH, Lycopene contents are commonly considered as fruit quality determining properties in tomato among them Vitamin C is considered as principal nutrient of tomato fruit. Among all vegetables tomato counts more

than 7% vitamin C in Bangladesh. Tomato contains other elements such as 94 g water, 0.5 g minerals, 0.8 g fiber, 0.9 g protein, 0.2 g fat and 3.6 g carbohydrate. Tomato has some other elements like 48 mg calcium, 0.4 mg iron, 356 mg carotene, 0.12 mg vitamin B1, 0.06 mg vitamin B2 and 27 mg vitamin C in each 100 g edible ripen tomato (BARI, 2010). Besides the higher nutrient value, tomato has some medicinal value. Higher lycopene content is considered as the most powerful natural antioxidant which prevents the prostate, lung, stomach, oral and breast cancer (Helyes *et al*., 2012).

2.2 Heterosis

Heterosis can be defined as the superiority of F_1 compared with the parents. Depending on the comparison, heterosis can be divided into several types. Heterosis over better parent that indicates the superiority of F_1 over the better parents. Mid parent heterosis can be defined as the superiority of F_1 over the mid parent. There are another type heterosis that is called commercial or economic heterosis where the F_1 is superior over commercial variety. Heterosis can be negative or positive depending on the traits are under studied. For yield and yield contributing traits, generally positive heterosis is expected whereas for the disease and insect severity, negative heterosis is expected. Heterosis was first coined by Shull at 1914 (Shull 1948). Heterosis is synonymous with hybrid vigor which can be explained by two theory called dominance model of heterosis and over dominance model of heterosis (Soresa *et al*., 2020 and Birchler *et al*., 2003).

Heterosis has been practiced and still being practiced a lot in several crops to develop the hybrid variety and to combine the traits from two different distinct plants. The commonly heterosis research have been done on maize, sorghum, sugar beet, onion, spinach, sunflower, broccoli and also in several self- and cross-pollinated species.

From the early 20^{th} century, heterosis has been used as commercially in agriculture. It plays vital role in development of hybrid varieties though the genetics mechanism is still not fully known (Rood *et al*., 1988). Hayes and Jones in 1952 first suggested that hybrid vigor be exploited in vegetables (Hayes, 1952)

but the commercial exploitation was first used in 1930s. The hybrid eggplants were first cultivated in Japan in 1952. Development and utilization of heterosis has been the most important practical accomplishment of genetics so far.

2.3 Heterosis analysis in Tomato

Hedrick and Booth first introduced the heterosis in tomato first in 1907 and after that many researches demonstrated heterosis in tomato for yield and yield contributing traits. Then, heterosis for yield and its component has been demonstrated by many researchers (Husna, 2020; Soresa *et al*., 2020; Singh and Singh, 1993; Daskalof *et al*., 1967; Burdick, 1954,). Recently, Huseynzade *et al*. (2020) carried out an experiment for estimation of heterosis, combining ability and gene action in tomato hybrids with 10 tomato parents to identify the combining ability of 10 tomato (*Lucopersicon esculantum* Mill.) parents and 45 F_1 hybrids obtained from 10 × 10 half diallel. They compared the mean performance of F_1s with their respective parental lines and determined the better and mid parent heterosis. They found the significant heterosis in case of yield and quality traits which indicated the existence of immense potential for population improvement and heterosis breeding for enhancing productivity and qualities.

Soresa *et al*. (2020) conducted experiment for heterosis in tomato for yield and yield component traits for F_1 hybrids over mid parent and better parent. They estimated the heterosis for F_1 hybrids over mid and better parent were computed for traits that showed significant differences between genotypes on analysis of variance. They found heterosis for yield components and yield was studied using 8×8 half diallel cross in tomato (*Solanum lycopersicum* L.). They showed that heterosis for marketable fruit yield per plant ranged from (-63.4%) (P3×P8) to (33.8%) (P6 × P8) and (-62.5%) (P3 × P8) to (52.6%) (P5 × P7), for mid parent and better parent respectively. All traits showed significant heterosis over better and mid-parent. Number of marketable fruit per plant (29.3%; 29.2%) in crosses (P3 × P6 for both) and pericarp thickness (46.3%; 57.6%) in crosses (P2 × P6 and P4 × P8), number of fruit cluster per plant (32.8%; 35.9%) in cross (P3 × P6

for both), individual fruit weight (36.1%; 41.2%) in cross (P2 × P8, P3 × P5) and fruit diameter (28.4%; 28.3%) in cross (P3 × P5; P2 × P6), fruit length (23.07%; 20.4%) in cross (P2 × P6 for both) were found in for best parent and mid parent heterosis. Positive and desirable heterosis by 10 crosses over better parent and 17 crosses over mid-parent were observed for total fruit density in tomato out of 28 F_1.

Tamta and Sing (2017) carried out an experiment for the heterosis in tomato for growth and yield traits using line × tester design with ten parents with three testers with a total thirty hybrids. 30 hybrids showed heterotic vigour was present for growth and yield characters among hybrids and significant differences for all characters indicated the presence of genetic variability. Plant height, number of branches per plant, days to first harvest, fruit length, fruit width, and number of seeds per gram showed negative heterosis but positive for average fruit weight, number of fruit/plants, and fruit yield/plant. Average fruit weight ranged from 23.5 to 56.4 g; the heaviest fruit were from hybrids from the crosses 'AC-824 × Sweet-72', 'CLN2237 × Sweet-72', CLN2070 × Sweet-72', and 'CLN2070-09 × Punjab Chhuhara'; the smallest fruit were from hybrids from crosses 'Selection 06-01 × PT-3', 'CLN2237 × PT-3', 'PT2007-09 × Punjab Chhuhara', and 'EC-519784 × Punjab Chhuhara'. This experiment suggested several combinations with high heterotic vigour for several traits in tomato.

Diallel crossing including 8 parents of tomato, their F_1s and reciprocal crosses have been evaluated (Husna, 2020). That research focused on the heterosis and combining ability analysis for both yield, yield contributing morphological traits and nutritional traits. The research was carried out study with nineteen characters including both agromorphogenic, nutritional and physiological. They found high general combining ability observed in parents G1, G3, G5 and G6 for one or more yield contributing traits. Days to 1st and 50% flowering, number of clusters per plant, fruit per cluster, fruit per plant, fruit weight, fruit area, relative water content, fruit pH and yield were found governed by non-additive gene action. Cross combinations G2 × G1 for higher yield and lowest in G2×G7 for days to

first and 50% flowering and G2×G1 for early maturity showed highest SCA effect. The F_1 hybrids G2×G6 (Plant height), G3×G6 (branch number), G2×G8 (cluster number), G4×G3 (average fruit in one cluster), G2×G8 (fruit per plant), G1×G6 (fruit wt.), G5×G2 (fruit area) showed highest positive heterobeltiosis whereas, negative heterosis was highest in the crosses G3×G5 (1st flowering), G3×G5 (50% flowering) and G1×G8 (maturity days). Most of the chemical traits showed significant heterosis. This research suggested the utilization of three promising utilization for future selection procedure.

Vekariya *et al*. (2019) conducted an experiment focusing combining ability and heterosis analysis for yield and its components in tomato for combining ability of parents and crosses for fruit yield and quality components in tomato using 40 hybrids involving 10 lines and 4 testers in line × tester fashion. They found that analysis of variance for combining ability and the estimates of variance components indicated that the mean squares due to lines were significant for all characters which revealed significant contribution of lines towards general combining ability variance components for most of traits. The mean sum of squares due to lines × testers interaction observed significant for all yield attributing traits which revealed the significant contribution of hybrids for specific combining ability variance components which indicated the involvement of additive as well as non-additive type of gene actions in the inheritance of these characters. They found the best general combiners for various characters were GP-5 for plant height; GP-18 for number of branches per plant; GP-17 for number of fruits per cluster; GP-32 for days to 50% fruit set, days to 50% flowering, total number of fruits per plant, days to marketable maturity and number of clusters per plant; GP-39 for average fruit weight and number of locules per fruit; GP-12 for marketable yield per plant and pericarp thickness; GP-3 for total soluble solid. Best cross combinations viz., GP-5 × JT-3, GP-29 × AT-3 and GP-18 × AT-3 were found to be best specific combiners for marketable yield per plant. They mentioned some lines with higher heterotic value as well for some agromorphological traits.

Agarwal *et al*. (2017) carried out an experiment for determining the combining ability and heterosis analysis in tomato based on the yield, quality, earliness and other yield contributing characters with ten diverse parental lines of tomato with four tester line. All 40 F_1 hybrids, along with their parents, were evaluated. Analysis of variance for combining ability indicated variation for all traits under study due to lines. Crosses for all traits indicated availability of sufficient diversity to choose the best crosses for yield, quality, and yield-attributing traits. Days to first fruit set, average fruit weight, and average fruit diameter caused the variation in testers. EC93 × 'CLN 2264F' and EC95 × 'CO3' cross combination exhibited higher specific combining ability for yield and yield-attributing traits; crosses EC86 × 'CO3', EC89 × 'CLN 2264H', and EC95 × 'Punjab Chhuhara' were good for quality attributing traits and crosses EC86 × 'CO3', EC88 × 'Punjab Chhuhara', EC89 × 'Punjab Chhuhara', EC93 × 'CLN 2264H', and EC94 × 'CO3' were good for earliness, indicating that these crosses may be further tested for commercial utilization. They mentioned some lines with high heterotic value for lycopene, carotenoid and vitamin C content.

Farzane *et al*. (2012) experimented on a 10×10 diallel cross set of tomato including reciprocals to find out the extent of heterosis, combining ability for yield per plant (kg) and yield components (number of fruits per plant, individual fruit weight (g)) and locule number. Significant differences among genotypes were obtained for all of traits. The variances for general combining ability (GCA) and specific combining ability (SCA) were highly significant indicating the presence of additive as well as non-additive gene effects except the number of fruits per plant and relative magnitude of these variances indicated that additive gene effects were more prominent for all of the traits. The tomato genotype Mb3 proved to be the best general combiner for yield and number of fruits per plant. Aisyah *et al*. (2016) carried out an experiment for the estimation of combining ability and heterosis effect for yield and yield components in tomato from a 6 × 6 full diallel cross combination. They analyzed data from F_l generation and parents using the Griffing Method. Genotypes showed significant differences for all the traits and variances for general combining ability (GCA) and specific

combining ability (SCA) were highly significant indicating the presence of additive as well as non-additive gene effects except the fruit thickness. This experiment showed both positive heterosis in some traits and negative heterosis in some traits.

Figueredo *et al*. (2015) carried out an experiment for combining ability and heterosis of relevant fruit traits of tomato genotypes for industrial processing with an objective to estimate the combining ability of lines and heterosis in industrial tomato genotypes for the identification of those with good potential for breeding programs. They used ten lines of industrial tomato, 45 hybrids derived from a complete diallel, and two commercial check cultivars were evaluated. They estimated the combining ability of tomato lines and heterosis of hybrid combinations for fruit-quality related traits. Non-additive effects predominated in the genetic control of all traits. They mentioned that parent lines RVTD-04, RVTD-10 and RVTD-08 had an exceptionally high presence of favorable alleles for most traits. They observed the high genetic divergence between the parents, contributing positively to significant heterosis values. The above lines can be used in breeding programs to develop tomato hybrids with high performance for characteristics related to industrial processing.

Rehana *et al*. (2019) conducted an experiment for the estimation of heterosis for yield and yield attributing traits in tomato crossed with line and tester method with 32 crosses for the yield and yield attributes traits. The experiment was designed in a Randomized Complete Block Design (RCBD) with three replications. The analysis of variance (ANOVA) showed highly significant difference for all the characters suggesting the presence of genetic variability among the studied materials. Four cross combinations (L1 × T1, L3 × T2, L3 × T3, L5 × T1) showed desirable negative significant heterosis for days to first flowering in both relative heterosis (RH) and heterobeltiosis (HB) ranged from -2.56% to -19.05%, respectively. Highest positive significant heterosis in both RH and HB was observed in four crosses L4 × T4 (63.48% and 48.25%), L5 × T2 (46.77 % and 46.27 %), L5 × T4 (62.58 % and 34.78 %) and L8 × T3 (37.39

% and 35.12 %) for individual fruit weight (g), while six crosses L1 × T2, L1 × T4, L3 × T2, L4 × T4, L5 × T4 and L6 × T1 exhibited highest positive significant heterosis for yield per plant (kg) in both HB and RH ranged from 16.09 % to 88.46 % respectively. Heterotic hybrids with maximum number of studied desirable yield contributing traits (8) of both RH and HB were identified only two crosses L1 × T2 and L4 × T4.

Emami *et al*. (2018) carried out an experiment to find out the combining ability and gene action of some tomato genotypes under low light condition. Seven inbred lines of tomato *(Solanum lycopersicum* L.) and their F_1 hybrids, including reciprocals, developed through a 7×7 full diallel cross was evaluated under two different levels of light. Mean square for light (L) effect was significant for total yield, average fruit weight and days to first flower. They failed to mention specific F_1 with high heterosis over mid parent and heterosis over better parent. Variation attributable to Genotypes and genotype × light (G×L) interaction had significant effect on all studied traits except days to ripening for which G×L interaction was not significant. Diallel analysis across two environments indicated that general (GCA), specific (SCA) and reciprocal combining ability (REC) were significant for all characters implying importance of additive and non-additive gene action along with cytoplasmic effects on genetic expression of yield, yield components and earliness. Ratio of GCA variance to SCA variance and estimates of narrow sense heritability (h^2 n.s) demonstrated higher weight of additive effects in inheritance of yield, fruit number and days to ripening, while indicating predominance of non-additive effects for fruit weight and early flowering. Interactions GCA×L and SCA×L were significant for almost all studied features. A particular genotype could not be recommended for all traits, but variation among genotypes in response to ambient light was promising for feasibility of plant breeding for non-optimal light intensity and duration.

Kumer and Gowda (2016) carried out an experiment for the estimation of heterosis and combining ability in tomato for fruit shelf life and yield component

traits using line × tester method with an evaluation 10 hybrids along with two checks for fruit shelf life and yield components. Analysis of variance revealed the variance due to the lines effects and crosses were highly significant for fruit shelf line. Arka Alok showed highest shelf life for GCA effects. For SCA effects, Vaibhav × RIL-160 and L121 × RIL-108 showed good combinations. These two crosses also showed good potential to be used as a hybrid for other traits. The RIL-160 and RIL-108 can be used as the best testers for improving the fruit shelf life and it can be forwarded for multilocational trial. Similarly, Mishra *et al*. (2019) studied the combining ability and heterosis in tomato for vegetative growth, yield, and quality traits for the cross and parents. They used ten parents in half diallel fashion. Forty-five crosses along with ten parents were evaluated in RCBD design with three replications. Analysis of variance for combining ability and the estimates of variance components were found that the mean squares due to parents were significant for all characters which revealed significant contribution of parents towards general combining ability variance components for most of traits. All traits showed significant for the mean sum of squares that indicated the significant contribution of hybrids for specific combining ability variance components due to the involvement of additive as well as non-additive type of gene actions in the inheritance of these traits. They identified the best general combiners for various traits in BT-507-2-2 for plant height, branches / plant, flowers / cluster, fruits / cluster, yield / plant, yield / plot. Similarly, BT-22-4-1 for number of cluster plant^{-1}, fruits plant^{-1}, diameter of fruit, average fruit weight. Utkal Deepti for days to 1st flowering, TLCV incidence while BT-317 for days to 50% flowering, acidity content; BT-21 for fruit length; BT-19-1-1-1 for pericarp thickness; BT-1 for number of locules fruit^{-1}, total soluble solid content, ascorbic acid content and BT-17-2 for bacterial wilt incidence. They suggested best cross combinations viz., Utkal Kumari × BT-22-4-1, BT-19-1-1-1 × BT-3, Utkal Kumari × BT-19-1-1-1, BT-22-4-1 × BT-3 and BT-19-1-1-1 × BT-507-2-2 were found to be best specific combiners for yield plant^{-1}. Along with the parental selection, they proposed some crossed lines with higher heterotic value.

Alsadon *et al*. (2020) carried out experiment for the heterosis, potence ratio and correlation of vegetative, yield and quality traits in tomato genotypes and their performance under arid condition with four commercial tomato cultivars with two breeding lines and their 15 hybrids. They showed that various degrees of dominance effects for some traits were detected in the general performances of the F_1 hybrids, while other traits illustrated the presence of partial- to under-recessiveness. Heterosis percentages reflected positive desirable effects in ten F_1 hybrids for some traits. In case of fruit set, fruit length, fruit diameter, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant, most F_1 hybrids outperformed their respective parents. Some of the genotypes (*i.e*., parents and/ or hybrids) offer opportunities as a genetic source of heat tolerant breeding genetic material adapted to high temperature under the arid conditions reported in this study. They found significant positive and desirable correlations were found between 41 possible pairs of traits, whereas significant negative and undesirable correlations were found between 13 possible pairs of the traits.

Katteegoudar *et al*. (2017) carried out an experiment for the estimation of combining ability and heterosis studies in tomato for yield, quality and bacterial wilt resistance by using full diallel analysis. Tomato genotypes and crosses showed highly significant differences for all observed characters. PKM-1 × Utkal Raja showed highest heterosis in better and mid parent. Similarly, Roy and Choudhary (1972) found lower number of locules in their experiments with variation whereas the locule number ranged between 4 or 5 among F_1 hybrids like Mangla, Rupali and Vaishali. Anita *et al*. (2005) and Ahmed *et al*. (2011) also found the similar results for locule number. Kumar *et al*. (2013) reported that significant negative heterosis for number of locules per fruit was reported by Ahmad *et al*., (2002). Sherif and Hussein (1992) also observed Significant heterosis for fruit yield per plant, as reflected by differences in the highest yields of parents and F_1 hybrids: 845.6 and 2084.7 g per plant for 'Yellow Pear' and Sweet 100 × Yellow Pear, respectively were observed by Sherif and Hussain (1992).

In one experiment conducted by Sharma *et al*., (2014) estimated the line tester matting design with 10 genotypes where they used as female genotypes and they used three genotypes as male line to find out the most promising cross combinations. They found that hybrids PT-11 × PT-3 and PT-20 × Punjab Chhuhara were most promising for earliness exhibiting highest negative heterosis. PT-09-06 × PT-3 and PT-20 × Roma were found most promising for tallness and dwarfness. In case of number of locules, PT-20 × Roma which exhibited negative heterosis. They identified the best hybrid and crossing combination for several traits such as PT-2009-02 × PT-3 for average fruit weight, PT-09-06 × Punjab Chhuhara for number of fruits per plant, PT-1 × Punjab Chhuhara for number of seeds per gram, PT-20 × Punjab Chhuhara for pericarp thickness, PT-20 × Roma for number of locules, PT-20 × Punjab Chhuhara for pericarp thickness and fruit width, PT-09-06 × Punjab Chhuhara for fruit shape index, S-06-1 × Punjab Chhuhara for TSS at turning and red ripe stage.

Saeed *et al*. (2014) conducted an experiment using the Line × tester methods using three lines as female and four lines as tester combining 12 cross combinations to find out the best hybrid and combination for higher yield, plant height, number of fruits per plant, branches per plant and traits related to fruits. Desired heterobeltiosis were observed in cross combination LA-2662 × CLN-2418A and LA-2662 × BL-1078 where hybrid LA-2662 × CLN-2418A showed the best cross in overall performance. Ahmad (2002) conducted experiment focusing the heterosis over better parent and found that highest heterosis over better parent in the cross TM026 × TM025 which were 32.24% and 26.90% respectively for May and July sowing. Mid-parent heterosis and better parent heterosis were observed for various quantitative characters in tomato Chattopadhya *et al.* (2012) found out mid parent and better parent heterosis in several quantitative traits in tomato where they mentioned that obvious heterosis over better-parent was observed for fruit yield per plant (148.82%), fruiting clusters per plant (111.64%), number of fruits per plant (103.33%), fruit weight (62.79%) and plant height (50.57%).

In an experiment conducted by Kumar and Singh (2013) used six diverse tomato parental lines for 6 × 6 diallel matting design without reciprocal that include 15 F_1 hybrids and two standard checks. Positive standard heterosis was found in ArkaAbha × Punjab Chhuhara, ArkaMeghali × Punjab Chhuhara, Punjab Chhuhara × Best combiner with overall performance. Fruit length and Fruit breadth was found highly significant heterosis over both checks for most of the cross combinations. They mentioned the cross combinations with high heterosis for plant height, number of fruits per plant and clusters per plant which was found in other studies done by Kumari and Sharma (2012), Ahmed *et al*. (2011), Singh and Sastr (2011), Kumari and Sharma (2011), Kumar and Singh (2009), Hannan *et al*. (2007).

Wang *et al*. (1998) carried out several experiments for the estimation of heterosis for fruit size where heterosis over better parent for fruit size in few cases in tomato. Cross TM051 × TM025 (22.25 percent in May sowing and 2.87 percent in July sowing) for fruit length showed highest better parent heterosis (Ahmad, 2002). Wang *et al*. (1998) studied five lines along with two cultivars and showed higher heterosis for fruit length, fruit size and fruit diameter. Islam *et al*. (2012) studied the heterotic performance in F_1 generation of tomato focusing the heterosis for the higher fruit weight. The hybrids showed that significant variation in heterosis. Chattopadhyay and Paul (2012) reported that mid-parent heterosis and better parent heterosis for various quantitative traits in tomato. Fruit yield per plant (148.82 %), fruiting clusters per plant (111.64%), number of fruits per plant (103.33 %), fruit weight (62.79 %) and plant height (50.57 %) showed prominent heterosis over better parent. Heterosis over better parent for fruit weight was estimated by Ahmad (2002). To estimate the heterosis for yield and yield contributing traits in tomato, Souza *et al*. (2012) and Sharma (2013) carried an experiment. They studied the average fruit weight, number of clusters per plant, number of fruits and flowers per cluster, fruit wall thickness and locules per number. They also estimated heterosis for qualitative traits such as total soluble solids, titratable acidity. Number of fruits per cluster ranged from -34.39 to 33.00 percent and significant heterosis over better parents were

observed in days to first fruit setting and total soluble solids, yield, plant height, fruit number and fruits per cluster. Heterosis for yield and yield component such as plant height at 60 days after transplantation, days to first flowering, number of flowers per cluster, number of fruits per plant, fruit weight per plant, days to first fruit ripening, number of flowers per cluster, number of fruits set per cluster, fruit length, fruit width, fruit weight and fruit yield per plant. The degree of heterosis for plant height, fruit weight, bacterial wilt incidence and yield per plant were estimated by Hannan *et al*. (2007). All the traits showed heterosis over better parents in these studies.

An experiment with 8 × 8 diallel set of tomato without reciprocal was conducted by Ahmad (2002) where they found highest heterosis over better parent for yield and several yield contributing traits. They carried out Line × Tester matting design for 8 lines with 3 as a tester and mentioned the 12 F_1s superiority in case of bacterial wilt diseases, days to fifty percent flowering, and days to first fruit setting. Similarly, A line × tester matting design using a set of 40 genotypes including seven as females and four as males and 28 F_1s were used by Panchal *et al.* (2016) to find out the best combining cross combination for ten characters. They mentioned JTL-12-04, JTL-12-10 and JTL12-12 are identified as the best female for general combiners for fruit yield per plant and Parents, JTL-12-14 and GT-1 were found to be poor general combiners for all other traits. High GCA effects for such characters have also been reported in tomato by Yadav *et al.* (2013), Angadi *et al*. (2012), Kumari and Sharma (2012), Souza *et al*. (2012) and Singh and Sastry (2011) also described the high GCA for tomato for these traits.

An experiment was conducted with forty hybrids from four testers crossed with ten lines to estimate the heterosis by Reddy *et al*. (2017). They found Flawery × Sel-7, Fla-7171 × Azad T-5, GT-20 × Azad T-5, C0-3 × Sel-7, B-S-31-3 × H-24 with positive and significant heterosis for primary branches per plant, fruits per plant, average fruit weight and yield per plant. An experiment was conducted with a set of six lines and 2 testers by Izge and Garba (2012) to determine the

heterosis for yield and yield combining ability for consecutive two years. 4 hybrids were found to be good specific combiners for number of flower clusters and plant height, and 5 for number of fruits per plant over both the environment combined. General combining ability (GCA), specific combining ability (SCA) was studied by Souza *et al.* (2012) in a complete diallel cross of fifteen genotypes (five parents and ten hybrids) tomato breeding lines for plant fruit yield, 'IAC-2' was the best parental line with the highest GCA followed by IAC-4 and IAC-1 lines.

Fruit yield per plant showed significant high SCA in several experiments conducted by Shankar *et al*. (2013), Angadi *et al.* (2012), Kumari and Sharma, (2012), Shende *et al*. (2012), Souza *et al*. (2012), and Singh and Sastry (2011). Panchal *et al*. (2016) studied on diallel analysis to find out the best combining lines as well as F_1 with higher heterotic value for fourteen traits in tomato and stated both additive and non-additive variances for fruit yield per plant. They found high magnitude of non-additive variance for fruit yield and its contributing traits that indicates predominant role of non-additive gene action in the inheritance of the traits. Kumar and Singh (2013) studied Line × Tester matting system experiment with ten lines and three testers for estimation of GCA and SCA for yield and yield components. They found T-3 Plant (a variety name) with higher general combining ability for yield and earliness and for fruit weight.

Chapter III

Materials and Methods

CHAPTER II
MATERIALS AND METHODS

The experiment entitled “Heterotic analysis for quantitative and qualitative traits in tomato (*Solanum lycopersicum* L.) genotypes” which was carried out in the experimental farm of Sher-e-Bangla Agricultural University during the Rabi season of 2018-2019 and 2019-2020. This chapter discusses about the details materials and methods used for this study.

3.1 Experimental site

The experiment was carried out at agronomy farm field at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh. The experimental site is located in Madhupur Tract AEZ 28 having the 23°74" N latitude and 90°35" E longitudes and 8 meters of elevation from the sea level. The experimental site is shown in Appendix I.

3.2 Climate and soil

The two years experiment was conducted from the month of November 2018 to April 2019 and November 2019 to April 2020 respectively. The monthly average temperature, humidity, rainfall and temperature was presented in Appendix II. The site is located at the subtropical zone in case of climate. The soil was clay loam in texture and gray and it is fine to medium distinct dark yellowish browns mottles. The pH in this area was 5.47 to 5.63. The physical and chemical properties was analyzed and presented in Appendix III.

3.3 Plant materials

During winter season 2018-2019, ten parents’ genotypes were used for the crossing in field condition. Ten genotypes are listed in Table 1 mentioning their accession number and sources of collection. Among ten genotypes, six genotypes were collected from department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University and the last four genotypes from Bangladesh Agriculture Research Institute, Gazipur, Dhaka, Bangladesh.

Table 1. Genotypes used as parents with their accession number and source of collection

SL. No.	Genotypes	Name/Accession No.	Source
1	G1	SL 020	GEPB, SAU.
2	G2	SL 021	
3	G3	SL 022	
4	G4	SL 023	
5	G5	SL 024	
6	G6	SL 025	
7	G7	BARI Tomato 16	PGRC, BARI.
8	G8	BARI Tomato 3	
9	G9	BARI Tomato 14	
10	G10	BARI Tomato 11	

GEPB: Genetics and Plant Breeding; SAU: Sher-e-Bangla Agricultural University; PGRC: Plant Genetic Resources Centre; BARI: Bangladesh Agriculture Research Institute

3.4 Emasculation, hybridization, and seed collection

Ten parents were grown in field conditions in Randomized Complete Block Design with three replications. After the flowering, emasculation was done for each of the parents and pollen was collected for pollination according to the crossing design and matting partner. Different steps involved in crossing technique among the parental lines illustrated in Plate 1. Finally fruits from twenty-four cross combinations were collected and seeds were extracted from the crossed fruits as well as the parental seeds. Seeds were stored in freeze for the utilization in heterosis analysis experiments during November 2019 to March 2020. The successful cross combinations are presented in Table 2**.**

Plate 1. Different steps involved in crossing technique among parental lines (A-E). A. Emasculation of male part; B. Pollination; C. Bagging and Tagging; D. Fruit setting from crossed flower and E. Harvesting of fruits for seed collection for second year experiment

Table 2. Lists of successful cross combinations among ten parental genotypes.

Serial No.	cross combinations
01	SL 020 (G1) × SL 022 (G3)
02	SL 020 (G1) × SL 023 (G4)
03	SL 020 (G1) × SL 024(G5)
04	SL 020 (G1) × SL 025(G6)
05	SL 020 (G1) × BARI Tomato 16(G7)
06	SL 020 (G1) × BARI Tomato 3 (G8)
07	SL 020 (G1) × BARI Tomato 14 (G9)
08	SL 020 (G1) × BARI Tomato 11 (G10)
09	SL 021 (G2) × BARI Tomato 16 (G7)
10	SL 021 (G2) × BARI Tomato 11 (G10)
11	SL 022 (G3) × SL 021 (G2)
12	SL 022 (G3) × SL 024 (G5)
13	SL 022 (G3) × BARI Tomato 11 (G10)
14	SL 023 (G4) × SL 020(G1)
15	SL 023 (G4) × SL 025 (G5)
16	SL 023 (G4) × BARI Tomato 14 (G9)
17	SL 023 (G4) × BARI Tomato 11 (G10)
18	SL 024 (G5) × BARI Tomato 11 (G10)
19	SL 025 (G6) × SL 021 (G2)
20	BARI Tomato 16 (G7) × BARI Tomato 11 (G10)
21	BARI Tomato 3 (G8) × BARI Tomato 11 (G10)
22	BARI Tomato 14 (G9) × BARI Tomato 11 (G10)
23	BARI Tomato 11 (G10) × SL 021 (G2)
24	BARI Tomato 11 (G10) × SL 023 (G4)

3.5 Seedbed preparation

During the November 2019, the seeds were sown in the seed bed at Sher-e-Bangla Agricultural University farm. The distance between two rows was 10 cm. The seeds were treated with Autosin 50 WDG for five minutes. Regular nursery practices such as watering and shading was done for the whole time. Weeding was also practiced when it was needed. Seedlings were kept in the seedbed until it was one months old. Plate 2 shows the seedbed with seedlings.

3.6 Design and layout of experiment

The experiment was conducted under field condition during rabi season 2018-2019 for hybridization purpose and robi season 2019-2020 for heterosis analysis. Both experiments were designed in Randomized complete Block Design (RCBD) with three replications. Twenty-four random crosses with ten parents were included with spacing 40 cm × 60 cm. Six plants of same genotypes were planted per small plot. Plate 2 shows the experimental field view.

3.7 Land preparation and fertilizer application

In both season, land was cross ploughed, and laddering was done for the breaking of clods to make good tillage condition. Weeds along with other stubbles were removed. Cow dung as a source of organic fertilizer was mixed during the second ploughing. Slight irrigation was given to make the soil moist. Besides the organic manure, other fertilizers were applied during the ploughing according to the recommendation guide (BARI, 2018). During the final land preparation, full of cow dung and all TSP were applied. Total urea and MP were applied in three equals splits as top dressing after 15, 30 and 45 days of transplanting respectively. Table 3 shows the quantities of manures and fertilizers applied in the filed in per ha area.

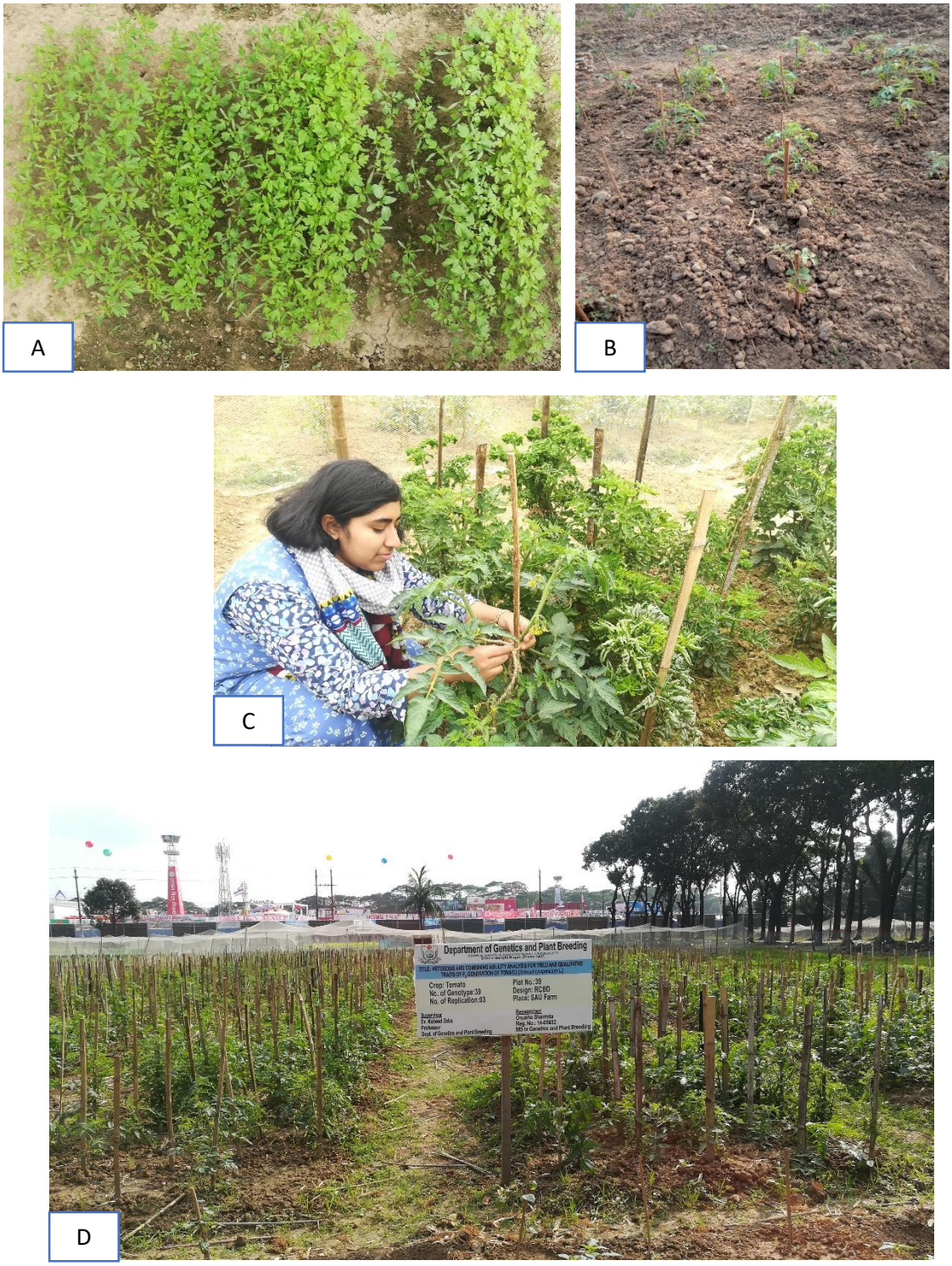

Plate 2. Seedbed preparation (A), seedling transplantation (B), stalking (C) and field view (D) during the second-year experiment

Table 3. Fertilizer and manure doses used in the experiments

Sl. No.	Fertilizers/ Manures	Doses	
		Applied in the plot	Quantity/ha
1	Urea	10.5 kg	550 kg
2	TSP	08 kg	450 kg
3	MOP	4.5 kg	250 kg
4	Cow dung	200 kg	10 ton

Here, TSP: triple Super Phosphate; MOP: Muriate of Potash.

3.8 Transplanting of seedlings

Thirty days seedlings were uprooted and transplanted in the experimental field maintain the experimental design in the afternoon. Seedlings were irrigated for increasing the firmness of roots with soil. Seedlings transplantation is shown in Plate 2.

3.9 Intercultural operations

First weeding was done after the seedlings established and second weeding was done twenty days after first one. Thinning and gap filing were also done. For supporting, bamboo sticks ware placed so that the plants can grow as straight. Pruning was done by removing the side branches during the early growth of plants. Staking, pesticide application, irrigation and after care were also followed when it was required. Plate 2 shows different intercultural operations during second year experiment.

3.10 Harvesting and processing

When fruits were matured with deep red stage, fruits were harvested, and harvesting was continued for more than one month. After harvesting, data related to fruits and qualitative traits were recorded from some fruits and some fruits were used for the seed purpose. The seeds were stored in the freeze at 4 °C.

3.11 Data recording

During the plant growing time and after harvesting, different data were recorded as shown in Plate 3 during the second-year experiment. The methods that were followed during different data collection is discussed in the following subsection.

3.11.1 Agromorphogenic traits

Agromorphogenic data such as plant height, number of leaves per plant, leaf area, days to first flowering, days to first fruit setting, days to maturity, number of branches per plant, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, individual fruit weight, fruit length, fruit diameter, and fruit yield per plant were recorded.

3.11.1.1 Plant height (cm)

Four plants from each of the plot were selected at random at maturity stage and plant was determined (75 days after transplanting) in centimeter and average was done for the genotypes for that replication.

3.11.1.2 Number of leaves per plant

Number of leaves of four plants from each of the replication were counted and average was done for the genotypes for that replication.

3.11.1.3 Leaf area (cm^2)

Leaf area was measured from random leaf from three plants from each of the genotypes in each of the replications and average was done for the genotype for that replication.

3.11.1.4 Days to first flowering

Days were counted for the first flower appearance from the date of transplantation was calculated.

A

B

C

Plate 3. Field data recording during second year experiment (A-C). A. Flowers, clusters, branches, leaf related (number and area) and plant height data collection; B. Fruits and fruits clusters related data collection and C. Leaf chlorophyll data collection

3.11.1.5 Days to first fruit setting

Days were counted for the first fruit appearance from the date of transplantation was calculated.

3.11.1.6 Days to maturity

The number of days required for the plant to reach at mature stage was counted for calculating the days to maturity for each of the genotypes in each of replication from the date of transplanting.

3.11.1.7 Number of branches per plant

Three plants were selected randomly from each of the genotypes each of the replications and number of branches per plant were counted. Average was done for that genotype for that replication.

3.11.1.8 Number of clusters per plant

Clusters from three randomly selected plants in each of the plot were counted and average was calculated for that genotype for that plot.

3.11.1.9 Number of flowers per cluster

Number of flowers per cluster from three randomly selected plants were counted and average was calculated for that genotype for that replication.

3.11.1.10 Number of fruits per cluster

Number of fruits per cluster from three randomly selected plants were counted and average was calculated for that genotype for that replication.

3.11.1.11 Number of fruits per plant

Total number of fruits were counted three from four randomly selected plants in each of the plot and average was done for the number of fruits per plant.

3.11.1.12 Fruit length

Fruit length of five randomly selected fruits from each of the plot was weighed and mean value was calculated for the genotype for that replication.

3.11.1.13 Fruit diameter

Fruit diameter of five randomly selected fruits from each of the plot was weighed and mean value was calculated for the genotype for that replication.

3.11.1.14 Individual fruit weight

Fruit weight of five randomly selected fruits from each of the plot was weighed and mean value was calculated for the genotype for that replication

3.11.1.15 Yield per plant

All fruits from each of the plants from each of the plot were measured and mean was done for the yield per plant for that genotype for that replication. The yield per plant was expressed as Kg/plant.

3.11.2 Qualitative traits

Fruit pH, fruit Brix%, fruit shelf life, dry matter content, moisture content and chlorophyll content were measured as part of physiological and biochemical traits as described below. Plate 4 shows the different physiological and biochemical traits.

3.11.2.1 Fruit pH

Fruit juice was extracted from each of the single fruit for each of the genotype using blending. REX pH meter model -PHS-3C was used for the pH measurement.

3.11.2.2 Brix%

Fruit juice was extracted from single fruit and one drop of juice was placed on the glass tube of portable Refractometer (ERMA, Tokyo, Japan). The Brix content was expressed in percentage.

Plate 4. Different qualitative traits analyses in laboratory (A-C). A. Shelf-life determination; B. Fruit pH determination and C. Fruit Brix content estimation.

3.11.2.3 Shelf life

Single fruit from each of the genotype of each replication was placed on hard paper and date was counted until the fruit reached in bad condition. The middle time was counted as shelf lifetime for that fruit.

3.11.2.4 Fruit moisture and dry matter content

Wight of fresh fruit of each plant was taken. Fruit was pressed so that some moisture was released, and it was kept in hot air oven at 80°C for 48 hours. After 48 hours, dry weight of fruit was measured, and percentage of Moisture content was measured by following formula;

$$\%\text{Moisture Content} = \frac{\text{weight of fresh fruit} - \text{Weight of oven dry fruit}}{\text{Weight of fresh fruit}} \times 100$$

Dry Matter content was determined by following formula.

% Dry matter content= 100-%Moisture content

3.11.2.5 Leaf chlorophyll content

Leaf chlorophyll content was measured by using SPAD-502 plus Portable Chlorophyll meter. The chlorophyll content was measured from randomly selected leaves at four different portion of the leaf and then averaged for analysis.

3.12 Statistical analysis

All collected data were analysed statistically to measure the significant differences among different tomato genotypes both parents and F_1 offspring. This subsection presents the statistical procedure used for data analysis. Two types of ANOVA were done. One is for the general ANOVA for determining of significant among all the characters for each of the genotypes. “Statistix 10” was used to find out the MS value for the F test for each of the traits for all genotypes. Another ANOVA was done for the combining ability to find out the GCA and SCA effects on each of the traits under studied for each of the genotypes as shown in Table 4 by OPSTAT online software. Mean value with minimum,

range, maximum and standard deviation for each of the parameters were analyzed by using Statistix 10 software. The heterosis of the F_1 was calculated by using the following formula:

Heterosis over better parent (%) = $\frac{(\overline{F_1}-\overline{BP})}{\overline{BP}} \times 100$

Here,

$\overline{F_1}$= Mean of F_1 individuals

$\overline{BP}$= Mean of the better parent values

Heterosis over mid parent (%) = $\frac{(\overline{F_1}-\overline{MP})}{\overline{MP}} \times 100$

Here,

$\overline{F_1}$= Mean of F_1 individuals

$\overline{MP}$= Mean of the mid parent values

CD (Critical Difference) values were used to test significance of heterotic effects.

Critical Differences (CD) = t × $\sqrt{\frac{2EMS}{r}}$

Here, EMS= Error Mean Sum of square

r = No. of replication

t = Tabulated t value at error d.f.

CD values were compared with the values come from $(\overline{F_1} - \overline{BP})$and $(\overline{F_1} - \overline{MP})$ to test significant effect of heterosis.

Chapter IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to perform the heterosis and mean performance analysis of agromorphological and qualitative traits. This chapter comprises the important results and discussion for the findings including the ANOVA, mean performance and heterosis analysis for plant height, number of leaves per plant, leaf area, days to first flowering, days to first fruit setting, days to maturity, number of clusters per plant, number of flowers per plant, number of fruits per cluster, number of fruits per plant, individual fruit weight, fruit length, fruit diameter, yield per plant, fruit pH, fruit Brix content, chlorophyll content, fruit moisture and fruit dry matter content.

4.1 ANOVA and mean performance

ANOVA for agromorphological and qualitative traits were analysed and presented in Appendix IV. Mean performance of parents along with cross combinations are presented in Table 4-7. Mean performance of parental line with their F_1 along with ANOVA has been discussed in this section.

4.1.1 Plant height (cm)

Genotypes showed significant variation in term of plant height (Appendix IV). The range for plant height among all the genotypes were found 75.83-130.17 cm with a population mean 103.36 cm (Table 4). Among parents, G8 and G4 both showed highest plant height (111.17 cm) whereas G5 showed lowest height (87.67 cm) (Table 5). Among the cross combinations, G1×G7 showed the highest (130.17 cm) and G1×G5 showed the lowest (75.83 cm) (Table 4).

4.1.2 Number of leaves per plant

Number of leaves per plant were found non-significant among the genotypes (Appendix IV). Range for number of leaves per plant among all the population

Table 4. Mean Performance of plant height, No. of leaves/plant, leaf area, days to first flowering and fruit setting of parents and crosses.

Genotypes	Plant Height (cm)	No. of leaves/Plant	Leaf Area (mm^2)	Days to1st flowering	Days to 1st fruit setting
G1	102.63	73.67	853.4	30	41.667
G2	92.73	86.67	557.3	34.333	46
G3	93	73.33	1020.5	32.333	45.333
G4	111.17	73.67	949.3	28.333	40
G5	87.67	68	1044.5	36.667	62
G6	89.93	61.33	928.6	52	58.667
G7	103.33	79.67	1044.9	36.333	52
G8	111.17	66.67	774.7	39	45.667
G9	103.33	56.67	914.4	40.667	51
G10	97.1	44.33	532.9	25.333	43.333
G1×G3	76.57	40	827.7	48.667	60.333
G1×G4	120.17	91.33	1064.2	24.667	39.667
G1×G5	75.83	63	852.1	43	59.333
G1×G6	93.83	52.67	1142.2	36.667	47.667
G1×G7	130.17	82.67	845.2	23.333	37.333
G1×G8	124.33	118.67	1157.5	27.333	45.667
G1×G9	119.27	62.67	1358.5	30.333	38.333
G1×G10	105.43	65	723	37	44
G2×G7	102	57.33	1108.2	40	52
G2×G10	98.67	62.67	604.5	19.667	42.667
G3×G2	84.5	75	788.6	39.333	61.667
G3×G5	97.17	74.67	1131.7	38.667	60.667
G3×G10	98.83	96.33	1019.7	24.667	38.667
G4×G1	130.03	107.33	811.1	18.333	44.333
G4×G5	103.67	69.33	1158.3	39	57
G4×G9	104	42	1424	43	52.333
G4×G10	97.5	43.33	608.5	28	58.333
G5×G10	126.83	78	830	27.333	43
G6×G2	86.13	66.67	882	40	57.667
G7×G10	104.83	71	909.7	23	38
G8×G10	111.17	41	823.7	26.667	45
G9×G10	125.33	67	842	24.667	42
G10×G2	96.83	78.67	827.9	31.333	45.667
G10×G4	109.17	72.33	757.5	32.333	40.667
Mean	103.36	69.49	915.24	33	48.17
Minimum	75.83	40	532.9	18.33	37.33
Maximum	130.17	118.67	1424	52	62
CV	11.71	34.76	25.35	18.37	14.66
SD	14.07	17.56	203.7	8.02	7.81

Table 5. Mean Performance of days to maturity, No. of branches / plant, No. of clusters / plant, No. of flowers /cluster and No. of fruits / cluster of parents and crosses.

Genotypes	Days to maturity	No. of branches /plant	No. of clusters /plant	No. of flowers /cluster	No. of fruits /cluster
G1	97	10.67	21.33	5.96	2.29
G2	102	10.67	18.33	6.07	2.75
G3	98.67	11.33	18.67	4.97	2.81
G4	97.67	12.33	20.67	6.67	2.54
G5	103	10	18	5.34	1.88
G6	109.33	8.67	24.67	5.22	2.42
G7	105.33	10	22	5.58	3.68
G8	100	11.33	19	4.75	3.13
G9	106.67	8	20	6.19	3.35
G10	89.33	6.33	35.67	8.65	6.27
G1×G3	107.67	7	12	6.17	3.23
G1×G4	92.67	14	21	7.49	3.32
G1×G5	103.33	9.67	17.33	5.21	3.41
G1×G6	97.67	9	21.67	5.68	3.21
G1×G7	96	12.67	32.33	5.81	2.97
G1×G8	92.67	14	33.33	5.4	2.89
G1×G9	98.33	10	14.67	5.65	3.56
G1×G10	90.67	10.33	38	9.64	7.26
G2×G7	106.33	12.67	26.33	7.79	5.11
G2×G10	85	10.33	22.67	9.95	6.36
G3×G2	102	13	20.33	6.15	3.82
G3×G5	102.33	10	18	5.52	2.53
G3×G10	83	14	30.33	6.96	4.79
G4×G1	86	13.67	25.33	6.58	1.71
G4×G5	106.67	9	15.33	4.54	1.91
G4×G9	115.67	7.67	17.33	5.69	3.84
G4×G10	88	7.33	33.67	9.82	7.36
G5×G10	90.33	12.67	32.33	8.66	6.74
G6×G2	103.67	12	15.33	6.01	3.29
G7×G10	85.67	12.33	41.33	8.56	6.62
G8×G10	87.33	7	31.67	8.73	7.33
G9×G10	86	10.33	38	7.99	6.75
G10×G2	102.33	12.33	25.33	5.75	3.25
G10×G4	93.33	12.67	20.33	6.88	2.95
Mean	97.40	10.67	24.18	6.64	3.97
Minimum	83	6.33	12	4.54	1.71
Maximum	115.67	14	41.33	9.95	7.36
CV	5.87	28.85	32	12.34	21.66
SD	8.17	2.17	7.60	1.51	1.73

Table 6. Mean Performance of No. of fruits / plant, fruit length, fruit diameter and fruit weight and yield / plant of parents and crosses.

Genotypes	No. of fruits / plant	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	Yield / plant
G1	77.28	52.34	69.98	93.63	7.55
G2	63.33	58.51	32.38	26.32	1.81
G3	49.89	55.91	73.63	90.26	4.61
G4	80.42	55.62	84.38	125.95	8.52
G5	33.06	59.44	42.97	53.38	1.86
G6	48.72	52.62	63.23	83.97	4.09
G7	74.06	54.86	49.02	53.76	3.94
G8	60.39	54.85	73.01	77.58	4.69
G9	68.34	57.68	64.29	92.74	6.39
G10	166.97	24.99	22.63	5.06	0.80
G1×G3	22.28	50.49	65.45	76.03	1.65
G1×G4	94.78	54.78	71.63	132.76	1.25
G1×G5	25.95	60.16	45.12	64.41	1.55
G1×G6	75.53	49.00	62.44	63.16	4.79
G1×G7	99.22	49.91	62.77	65.03	6.54
G1×G8	69.44	48.87	67.74	14.17	1.00
G1×G9	64.56	59.79	70.12	92.37	6.02
G1×G10	253	26.89	24.47	5.29	1.46
G2×G7	54.05	53.23	42.05	54.23	2.88
G2×G10	312.72	26.11	21.53	5.21	1.41
G3×G2	68.16	59.56	55.25	48.29	3.42
G3×G5	50.64	66.52	46.16	61.32	3.18
G3×G10	138.11	36.43	40.14	19.31	2.74
G4×G1	80.03	50.90	79.8	165.54	8.88
G4×G5	59.44	82.35	53.93	63.51	3.66
G4×G9	74.33	51.54	64.15	86.86	6.57
G4×G10	217.11	27.83	20.32	4.68	0.98
G5×G10	319.83	39.6	33.02	13.33	4.43
G6×G2	52.33	66.97	36.51	11.13	0.59
G7×G10	320.5	33.51	33.49	14.11	4.63
G8×G10	177.67	34.88	25.43	4.74	0.85
G9×G10	214.19	34.76	37.85	5.36	1.16
G10×G2	61.44	58.00	30.15	45.68	2.77
G10×G4	76.17	56.52	80.923	105.57	7.98
Mean	109.62	50.16	51.35	57.43	3.66
Minimum	22.28	24.99	20.32	4.68	0.59
Maximum	320.5	82.35	84.37	165.54	8.88
CV	26.18	2.80	2.05	5.94	26.24
SD	84.65	12.87	19.06	41.55	2.42

Table 7. Mean Performance of fruit pH, Brix%, shelf life, fruit moisture and dry matter and chlorophyll content of parents and crosses.

Genotypes	Fruit pH	Brix %	Shelf life (days)	% Dry matter	% Fruit moisture	Chlorophyll content
G1	6.19	2.97	19.67	11.19	88.81	50.63
G2	6.3	3	20.33	11.61	88.39	57.65
G3	4.97	1.1	21	8.71	91.29	45.63
G4	4.68	2.5	9.08	8.89	91.10	50.52
G5	4.31	4	9.33	12.57	87.43	45.17
G6	4.52	2	17.17	13.38	86.62	52.53
G7	4.54	3.3	17.25	11.03	88.97	51.43
G8	4.74	1.33	19.5	8.72	91.28	47.77
G9	4.79	2.13	18.67	10.23	89.77	54.03
G10	4.63	4.5	17.83	37.5	62.5	55.63
G1×G3	5.08	4.5	15.92	11	89	49.43
G1×G4	4.27	1.3	10.33	11.54	88.46	54.67
G1×G5	4.53	3	12.67	12.17	87.83	65.03
G1×G6	4.02	4.03	19.92	12.09	87.90	52.43
G1×G7	4.32	2.03	18.58	9.16	90.84	52.17
G1×G8	4.19	0.93	18.67	8.3	91.7	36.53
G1×G9	4.07	1.5	19.67	11.95	88.05	46
G1×G10	3.93	3.53	27.33	16.9	83.1	40.4
G2×G7	3.97	3.97	22	12	88	42.6
G2×G10	4.1	2.2	17.33	16.81	83.19	45.7
G3×G2	4.15	1.03	16.17	16.48	83.52	43.63
G3×G5	4.17	3.87	14.83	11.74	88.26	28.23
G3×G10	3.71	3.87	15	11.99	88.01	40.37
G4×G1	3.53	4.4	18.67	10.94	89.06	40.2
G4×G5	3.14	1.47	17.33	9.283	90.72	40.37
G4×G9	3.93	2.6	18.33	12.33	87.67	48.2
G4×G10	3.89	3.77	16	17.39	82.61	46.8
G5×G10	4.11	2.5	17.92	17.27	82.73	42.87
G6×G2	3.87	2.6	17.92	17.67	82.33	39.7
G7×G10	3.98	2	18.33	18.62	81.38	39.77
G8×G10	3.95	2.8	18.33	14.98	85.02	41.37
G9×G10	4.04	3	16	16.09	83.91	37.63
G10×G2	3.81	2.53	17.5	11.33	88.67	52.67
G10×G4	3.85	3.97	19.67	9.7	90.3	57.73
Mean	4.30	2.77	17.50	13.28	86.72	46.93
Minimum	3.14	0.93	9.08	8.3	62.5	28.23
Maximum	6.3	4.5	27.33	37.5	91.7	65.03
CV	1.24	3.26	13.19	58.70	8.99	2.90
SD	0.63	1.06	3.44	5.13	5.13	7.33

was found 40-118.67 with a population mean 69.49 (Table 4). G10 showed lowest number of leaves (44.33) and G2 showed highest number of leaves per plant (86.67) (Table 5). Among the cross combinations, G1×G8 showed highest number of leaves per plant (118.67) and G1×G3 showed the lowest number of leaves per plant (40) (Table 4).

4.1.3 Leaf area (mm^2)

Genotypes showed non-significant in term of leaf area (Appendix IV). Mean leaf area was found 915.24 mm^2 with maximum of 1424 mm^2 and minimum 532.9 mm^2 (Table 4). Among the parents, G7 showed the maximum leaf area (1044.9 mm^2) and G10 showed the minimum leaf area (532.9 mm^2) (Table 4). Among the cross populations, G4×G9 showed the maximum leaf area (1424 mm^2) and G2×G10 showed the lowest leaf area (604.5 mm^2) (Table 4).

4.1.4 Days to first flowering

Genotypes showed significant variation for days to first flowering (Appendix IV). Mean days to first flowering was found 33 days with highest 52 and lowest 18.33 days (Table 4). Among the parents, G6 showed the highest (52.00) and G10 showed lowest days for first flowering (25.33) (Table 4). Among the cross populations, G1×G3 showed late flowering (48.67 days) and G4×G1 showed early flowering (18.33 days) (Table 4).

4.1.5 Days to first fruit setting

Genotypes showed significant variation for days to first fruit setting (Appendix IV). Mean days to first fruit setting was found 48.17 days with a maximum of 62 days and minimum of 37.33 days (Table 4). Among the parents, G5 showed late fruit setting (62 days) and G4 showed early fruit setting (40 days) whereas among the cross population, G3×G2 showed the late flowering (61.67 days) and G1×G7 showed the early fruit setting (37.33 days) (Table 4).

4.1.6 Days to maturity

Genotypes showed significant variation for days to maturity (Appendix IV). Mean days to maturity was found 97.40 days with a minimum of 83 days and maximum of 115.67 days (Table 5). Among the parents, G6 showed late maturity (109.33 days) and G10 showed early maturity (89.33 days) (Table 5). Among the cross populations, G4×G9 showed the late maturity (115.67 days) whereas G3×G10 showed early maturity (83 days) (Table 5).

4.1.7 Number of branches per plant

Genotypes showed non-significant variation for the number of branches plant (Appendix IV). Mean number of branches per plant was found 10.67 having the highest 14 and lowest 6.33 (Table 5). Among the parents, G4 showed highest number of branches per plant (12.33) whereas G10 showed lowest number of branches per plant (6.33) (Table 5). Among the cross populations, G1×G4, G1×G8 and G3×G10 showed the highest (14) and both G1×G3 and G8×G10 showed the lowest (7) number of branches per plant (Table 5).

4.1.8 Number of clusters per plant

Number of clusters per plant showed significant variation among the genotypes (Appendix IV). Average number of clusters per plant was found 24.18 with a maximum 41.33 and minimum 12 (Table 5). Among parents, G10 showed highest number of clusters per plant (35.67) whereas G5 showed lowest (18) (Table 5). Among the cross population, G7×G10 showed highest (41.33) and G1×G3 showed lowest (12) number of clusters per plant (Table 5).

4.1.9 Number of flowers per cluster

Genotypes showed significant variation in term of number of flowers per cluster (Appendix IV). The average number of flowers per cluster was 6.64 having maximum 9.95 and minimum 4.54 (Table 5). Among parents, G10 showed highest (8.65) and G8 showed lowest (4.75) number of flowers per cluster (Table

5). Among the crosses, G2 × G10 showed the highest (9.95) and G4 × G5 showed lowest (4.54) number of flowers per cluster (Table 5).

4.1.10 Number of fruits per cluster

Genotypes showed significant variation in term of number of fruits per cluster (Appendix IV). Average number of fruits per cluster was found 3.97 having a maximum of 7.36 and minimum of 1.71 (Table 5). Among the parents, G10 showed the highest (6.27) and G5 showed lowest (1.88) number of fruits per cluster (Table 5). Among cross population, G4×G10 showed the highest (7.36) and G4 × G1 showed lowest (1.71) number of fruits per cluster (Table 5).

4.1.11 Number of fruits per plant

Genotypes showed significant variation in term of number of fruits per plant (Appendix IV). Average fruits per plant was 109.62 having maximum 320.5 and minimum 22.28 (Table 6). Among the parents, the highest number of fruits was found in G10 (166.97) whereas lowest in G5 (33.06) (Table 6). Among the cross population, G7×G10 showed the highest (320.50) and G1×G3 showed lowest (22.28) number fruits per plant (Table 6).

4.1.12 Fruit length (mm)

Genotypes showed significant variation in term of number of fruit length (Appendix IV). Maximum and minimum fruit length was found 82.35 mm and 24.99 mm respectively having a mean of 50.16 mm (Table 6). Parent G5 showed highest fruit length (59.44 mm) and G10 showed lowest (24.99 mm) fruit length (Table 6). Among the crosses, G4×G5 showed highest (82.35 mm) and G2×G10 showed lowest (26.11 mm) fruit length (Table 6).

4.1.13 Fruit diameter (mm)

Genotypes showed significant variation in term of fruit diameter (Appendix IV). Mean fruit diameter was found 51.35 mm with a minimum and maximum 20.32 and 84.37 respectively (Table 6). Parent G4 showed the highest fruit diameter (84.38 mm) and G10 showed the lowest (22.63 mm) fruit diameter (Table 6).

Among the crosses, G10×G4 showed highest (80.92 mm) and G4×G10 showed the lowest (20.32 mm) fruit diameter (Table 6).

4.1.14 Individual fruit weight

Genotypes showed significant variation in term of fruit weight (Appendix IV). Average individual fruit weight was 57.43 g having minimum and maximum of 4.68 g and 165.54 g respectively (Table 6). Among parents, G4 showed highest fruit weight (125.95 g) and G10 showed lowest (5.06 g) fruit weight (Table 6). Among crosses, G4×G1 showed highest fruit weight (165.54 g) whereas G4×G10 showed lowest fruit weight (4.68 g) (Table 6).

4.1.15 Yield per plant

Genotypes showed significant variation in term of yield per plant (Appendix IV). Population mean for yield per plant was 3.66 kg with a maximum of 8.88 kg and minimum of 0.59 kg (Table 6). Among parents, G4 showed highest yield per plant (8.52 kg) and G10 showed lowest (0.80 kg) yield per plant (Table 6). Among crosses, G4×G1 showed highest yield per plant (8.88 kg) and G6 × G2 showed lowest (0.59 kg) yield per plant (Table 6).

4.1.16 Fruit pH

Genotypes showed significant variation in term of fruit pH (Appendix IV). Mean fruit pH was found 4.30 with a maximum of 6.3 and minimum of 3.14 (Table 7). Among parents, G2 showed highest pH (6.3) and lowest in G5 (4.31) (Table 7). Among crosses, G1×G3 showed highest pH (5.08) whereas G4×G5 showed lowest (3.14) pH (Table 7).

4.1.17 Brix %

Genotypes showed significant variation in term of fruit Brix% (Appendix IV). Minimum and maximum population Brix % was found 0.93 and 4.5 respectively with a mean of 2.77 (Table 7). Among parents, G10 showed highest Brix% (4.5) and G3 showed lowest Brix% (1.1) (Table 7). Among crosses, G1×G3 showed highest Brix% (4.5) and G1×G8 showed lowest Brix% (0.93) (Table 7).

4.1.18 Shelf life

Genotypes showed significant variation in term of number of fruit shelf life (Appendix IV). Maximum and minimum population shelf life were 27.33 and 9.08 days respectively with a mean shelf life of 17.50 (Table 7). Among parents, G3 showed longest shelf life (21) and G4 showed shortest (9.08) shelf life (Table 7). Among crosses, G1×G10 showed longest shelf life (27.33 days) and G1×G4 showed shortest shelf life (10.33 days) (Table 7).

4.1.19 Dry matter content (%)

Dry matter content showed non-significant variation among the genotypes (Appendix IV). Mean dry matter content was found 13.28 % with a maximum of 37.5 % and minimum of 8.3 % (Table 7). Among parents, G10 showed highest dry matter content (37.5 %) and G3 showed lowest dry matter content (8.71 %) (Table 7). Among the crosses, G7×G10 showed the highest dry matter content (18.62 %) and G1×G8 showed the lowest dry matter content (8.3 %) (Table 7).

4.1.20 Moisture content (%)

Moisture content showed non-significant variation among the genotypes (Appendix IV). Average moisture content was found 86.72 % with a maximum and minimum of 91.7 and 62.5 % respectively (Table 7). Among parents, G3 showed highest moisture content (91.29 %) and G10 showed the lowest moisture content (62.5 %) (Table 7). Among crosses, G1×G8 showed the highest moisture content (91.7%) and G7×G10 showed the lowest moisture content (81.38 %) (Table 7).

4.1.21 Leaf chlorophyll content

Genotypes showed significant variation in term of leaf chlorophyll content (Appendix IV). Population mean leaf chlorophyll content was found 46.93 with a maximum of 65.03 % and minimum of 28.23 % (Table 7). Among parents, G2 showed highest leaf chlorophyll content (57.65) and G5 showed lowest leaf

chlorophyll content (45.17%) (Table 7). Among crosses, G1×G5 showed highest leaf chlorophyll content (65.03%) and G3×G5 showed lowest leaf chlorophyll content (28.23%).

4.2 Estimation of heterosis over better parent and heterosis over mid parent

Heterosis over better parent and heterosis over mid parent were calculated for 21 agromorphological and qualitative traits which are presented in Table 8-14.

4.2.1 Plant height

G1×G5 showed the lowest better parent heterosis (-32.67) whereas G1×G3 showed lowest heterosis over mid parent (-25.53) for plant height which indicated that these crosses were found shorter compared to their respecting better and mid parent (Table 8). G5×G10 showed the highest heterosis over better parent (30.62) and heterosis over mid parent (37.28) in term of plant height which indicates that these crosses were found higher height compared to their respecting better and mid parent (Table 8).

4.2.2 Number of leaves per plant

G1×G3 showed lowest negative heterosis over better parent (-45.70) and heterosis over mid parent (-45.58) in term of number of leaves per plant which indicates that these crosses had a smaller number of leaves per plant compared to their respecting better and their mid parent (Table 8). G1×G8 showed the highest and positive heterosis over better parent (61.08) and heterosis over mid parent (69.12) in term of number of leaves per plant which indicates that these crosses had higher number of leaves per plant compared to their respecting better and mid parent (Table 8).

4.2.3 Leaf area

G4×G10 showed lowest and negative heterosis over better parent (-35.90) which indicates that its lower leaf area compared to better parent whereas G4×G9 showed the highest and positive heterosis over better parent (50.01) in term of

Table 8. Estimation of heterosis over better parent and heterosis over mid parent for plant height, No. of leaves/plant and leaf area of crosses

Crosses	Plant Height		No. of leaves/plant		Leaf area	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	-32.02	-25.53	-45.70	-45.58	-18.89	-11.66
G1×G4	6.69	7.39	23.97	23.97	12.10	18.07
G1×G5	-32.67	-24.28	-14.48	-11.06	-18.42	-10.21
G1×G6	-16.69	-7.36	-28.51	-21.97	23.00	28.19
G1×G7	15.57	20.55	3.77	7.83	-19.11	-10.95
G1×G8	10.39	11.11	61.08	69.12	35.63	42.19
G1×G9	5.90	10.46	-14.93	-3.84	48.57	53.69
G1×G10	-6.39	0.54	-11.77	10.17	-15.28	4.31
G2×G7	-1.29	4.05	-33.85	-31.07	6.06	38.33
G2×G10	1.62	3.96	-27.69	-4.32	-4.49	1.58
G3×G2	-9.14	-9.01	-13.46	-6.25	-22.72	-0.04
G3×G5	4.48	7.57	1.83	5.67	8.35	9.61
G3×G10	1.78	3.98	31.37	63.74	-0.08	23.35
G4×G1	16.97	21.64	45.69	45.69	-14.56	-10.01
G4×G5	-6.75	4.27	-20.92	-14.06	10.90	16.19
G4×G9	-6.45	-3.03	-42.99	-35.55	50.01	183.11
G4×G10	-12.30	-6.37	-41.18	-26.56	-35.90	22.48
G5×G10	30.62	37.28	14.71	38.88	-20.57	5.21
G6×G2	-7.12	-5.69	-23.08	-9.91	-5.02	18.72
G7×G10	1.45	4.61	-10.88	14.52	-12.94	15.31
G8×G10	0.00	6.76	-38.50	-26.13	6.33	25.99
G9×G10	21.29	25.06	18.23	32.67	-7.92	16.35
G10×G2	-0.28	2.02	-9.23	20.11	48.56	51.88
G10×G4	-1.80	4.84	-1.82	22.59	-20.20	2.21

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 9. Estimation of heterosis over better parent and heterosis over mid parent for days to first flowering, days to first fruit setting and days to maturity of crosses

Crosses	Days to 1st flowering		Days to 1st fruit setting		Days to maturity	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	50.53	56.16	33.10	38.71	9.12	10.05
G1×G4	-17.78	-15.42	-4.78	-2.85	-5.12	-4.79
G1×G5	17.29	29.01	-4.30	14.48	0.32	3.33
G1×G6	-29.49	-10.57	14.42	14.42	-10.66	-5.33
G1×G7	-22.22	-22.22	-28.21	-20.28	-8.86	-5.11
G1×G8	-29.92	-20.77	0.02	4.60	-7.33	-5.92
G1×G9	-25.40	-14.14	-24.84	-17.26	-7.82	-3.44
G1×G10	23.33	33.74	1.55	3.54	-6.53	-2.68
G2×G7	10.10	13.22	0.00	6.12	0.95	2.57
G2×G10	-42.71	-34.07	-7.25	-4.47	-16.67	-11.15
G3×G2	14.57	18.01	34.06	35.04	0.00	1.66
G3×G5	5.47	12.09	-2.15	13.05	-0.65	1.48
G3×G10	-23.70	-14.44	-14.70	-12.77	-15.88	-11.70
G4×G1	-38.89	-37.14	6.42	8.58	-11.95	-11.65
G4×G5	6.38	20.02	-8.06	11.76	3.56	6.31
G4×G9	5.76	24.66	14.61	22.19	8.44	13.21
G4×G10	-1.16	4.36	34.62	40.00	-9.90	-5.88
G5×G10	-25.44	-11.81	-30.65	-18.35	-12.30	-6.07
G6×G2	-23.08	-7.33	-1.69	10.20	-5.18	-1.89
G7×G10	-36.69	-25.40	-26.92	-20.28	-18.67	-11.98
G8×G10	-31.62	-17.09	-1.45	1.13	-12.67	-7.75
G9×G10	-39.33	-25.24	-17.65	-10.95	-19.38	-12.24
G10×G2	-8.73	5.04	-0.72	2.24	0.32	6.97
G10×G4	14.13	20.51	-6.15	-2.40	-4.44	-0.18

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 10. Estimation of heterosis over better parent and heterosis over mid parent for No. of branches / plant, No. of clusters / plant and No. of flowers /Cluster of crosses

Crosses	No. of branches/plant		No. of clusters/plant		No. of flowers /cluster	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	-38.22	-36.33	-43.74	-39.98	3.52	13.00
G1×G4	13.54	21.79	-1.55	0.02	12.51	18.75
G1×G5	-9.32	-6.42	-18.74	-11.86	-12.53	-7.65
G1×G6	-15.57	-6.83	-12.14	-5.78	-14.76	-10.04
G1×G7	18.83	22.62	46.97	49.24	-2.57	0.72
G1×G8	23.57	27.33	56.27	65.30	-9.40	0.93
G1×G9	-6.19	7.18	-31.24	-29.02	-8.72	-7.00
G1×G10	-3.07	21.64	6.56	33.36	11.54	32.01
G2×G7	18.83	22.62	19.70	30.59	28.60	34.02
G2×G10	-3.07	21.64	-36.44	-16.03	15.20	35.42
G3×G2	14.74	18.24	8.97	9.94	1.49	11.62
G3×G5	-11.74	-6.24	-3.54	-1.80	3.50	7.22
G3×G10	23.57	58.55	-14.94	11.68	-19.44	2.35
G4×G1	10.84	18.90	18.77	20.66	-1.15	4.33
G4×G5	-27.01	-19.39	-25.78	-20.68	-31.78	-24.22
G4×G9	-37.82	-24.57	-16.10	-14.74	-14.56	-11.44
G4×G10	-40.53	-21.40	-5.59	19.56	13.70	28.41
G5×G10	26.67	55.14	-9.33	20.51	0.23	23.98
G6×G2	12.57	24.22	-37.82	-28.67	-0.88	6.50
G7×G10	23.33	51.05	15.91	43.37	-0.93	20.48
G8×G10	-38.22	-20.72	-11.20	15.87	1.08	30.54
G9×G10	29.16	44.21	6.56	36.54	-7.48	7.80
G10×G2	15.69	45.18	-28.96	-6.16	-33.45	-21.77
G10×G4	2.73	35.77	-42.98	-27.79	-20.33	-10.02

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 11. Estimation of heterosis over better parent and heterosis over mid parent No. of fruits / cluster, No. of Fruits / plant, and fruit length of crosses

Crosses	No. of Fruits /cluster		No. of Fruits/plant		Fruit length	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	15.48	27.05	-71.17	-64.96	-9.69	-6.71
G1×G4	31.23	37.76	17.86	20.20	-1.50	1.49
G1×G5	48.76	63.39	-66.42	-52.96	1.21	7.63
G1×G6	32.78	36.45	-2.26	19.89	-6.86	-6.62
G1×G7	-19.07	-0.34	28.39	31.12	-9.03	-6.89
G1×G8	-7.48	6.72	-10.14	0.88	-10.89	-8.81
G1×G9	6.37	26.36	-16.46	-11.33	3.66	8.69
G1×G10	15.74	69.55	51.52	107.16	-48.62	-48.62
G2×G7	39.33	59.54	-27.02	-21.32	-9.02	-6.07
G2×G10	1.44	41.18	87.29	171.58	-55.38	-37.47
G3×G2	36.55	38.03	7.63	20.40	1.79	4.10
G3×G5	-9.64	8.12	1.50	22.10	11.91	15.33
G3×G10	-23.66	5.55	176.83	176.83	-34.84	-9.94
G4×G1	-32.41	-29.05	-0.48	1.50	-8.48	-5.70
G4×G5	-24.51	-13.38	-26.09	4.76	38.55	43.15
G4×G9	14.63	30.61	-7.57	-0.07	-10.64	-9.02
G4×G10	17.38	67.27	30.03	75.52	-49.97	-30.96
G5×G10	7.44	65.32	91.55	219.78	-33.38	-6.19
G6×G2	19.95	27.39	-17.37	-6.60	14.46	20.54
G7×G10	5.58	33.20	91.95	165.94	-38.92	-16.08
G8×G10	16.85	56.05	6.41	56.29	-36.40	-12.62
G9×G10	7.66	40.33	28.28	82.05	-39.74	-15.91
G10×G2	-48.11	-27.78	-63.20	-46.64	-0.87	38.93
G10×G4	-53.00	-33.03	-54.38	-38.42	1.62	40.24

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 12. Estimation of heterosis over better parent and heterosis over mid parent fruit diameter, fruit weight and yield per plant of crosses

Crosses	Fruit diameter		Fruit weight		Yield/plant	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	-11.09	-8.84	-18.80	-17.31	-78.19	-72.91
G1×G4	-15.10	-7.19	5.41	20.92	-85.33	-84.44
G1×G5	-35.52	-20.11	-31.21	-12.37	-79.42	-66.97
G1×G6	-10.78	-6.25	-32.54	-28.87	-36.53	-17.66
G1×G7	-10.30	5.50	-30.55	-11.76	-13.43	13.87
G1×G8	-7.22	-5.25	-84.87	-83.45	-86.70	-83.59
G1×G9	0.20	4.44	-1.35	-0.87	-20.32	-13.63
G1×G10	-65.03	-47.14	-94.35	-89.28	-80.64	-64.98
G2×G7	-14.21	3.32	1.59	36.09	-26.69	0.56
G2×G10	-33.51	-21.71	-80.21	-66.79	-21.61	8.54
G3×G2	-24.95	4.25	-46.50	-17.16	-25.86	6.65
G3×G5	-37.30	-20.82	-32.06	18.39	-31.08	-1.79
G3×G10	-45.48	-16.58	-78.61	-59.48	-40.65	1.15
G4×G1	-5.42	3.40	31.43	50.78	4.23	10.52
G4×G5	-36.08	-15.30	-49.58	-8.80	-57.08	-29.54
G4×G9	-23.96	-13.69	-31.04	-20.56	-22.92	-11.85
G4×G10	-75.92	-62.02	-96.28	-92.86	-88.56	-79.08
G5×G10	-23.16	0.69	-75.03	-54.38	138.39	233.38
G6×G2	-42.25	-23.63	-86.75	-79.82	-85.50	-79.86
G7×G10	-31.68	-6.50	-73.75	-52.02	17.76	95.69
G8×G10	-65.17	-46.82	-93.89	-88.53	-81.90	-69.07
G9×G10	-41.13	-12.90	-94.22	-89.04	-81.90	-67.83
G10×G2	-6.88	9.65	73.56	191.14	53.72	112.85
G10×G4	-4.09	51.27	-16.18	61.16	-6.34	71.24

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 13. Estimation of heterosis over better parent and heterosis over mid parent for fruit pH, fruit Brix % and fruit shelf life of crosses

Crosses	Fruit pH		Fruit Brix %		Fruit shelf life	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	-17.75	-8.74	52.03	121.67	-24.20	-21.71
G1×G4	-30.91	-21.36	-56.08	-52.38	-47.44	-28.09
G1×G5	-26.70	-13.63	-25.00	-13.79	-35.57	-12.61
G1×G6	-34.90	-24.80	36.26	62.63	1.31	8.19
G1×G7	-30.04	-19.34	-38.38	-35.04	-5.48	0.69
G1×G8	-32.20	-23.26	-68.47	-56.49	-5.05	-4.66
G1×G9	-34.20	-25.86	-49.32	-41.06	0.04	2.65
G1×G10	-36.41	-27.22	-21.48	-5.27	39.03	45.81
G2×G7	-37.04	-26.81	20.20	25.93	8.21	17.08
G2×G10	-34.92	-24.91	-51.11	-41.33	-14.74	-9.16
G3×G2	-34.13	-26.29	-65.56	-49.60	-23.01	-21.77
G3×G5	-15.86	-9.96	-3.33	51.64	-29.37	-2.19
G3×G10	-25.14	-22.48	-14.07	38.10	-28.57	-22.74
G4×G1	-42.83	-34.93	48.65	61.17	-5.05	29.90
G4×G5	-32.91	-30.14	-63.33	-54.87	85.78	88.30
G4×G9	-17.89	-16.93	4.00	12.31	-1.75	32.18
G4×G10	-16.88	-16.34	-16.30	7.62	-10.26	18.91
G5×G10	-11.11	-8.02	-44.44	-41.18	0.49	31.94
G6×G2	-38.62	-28.53	-13.33	4.00	-11.87	-4.42
G7×G10	-13.85	-13.10	-55.56	-48.72	2.82	4.52
G8×G10	-16.67	-15.60	-37.78	-3.95	-5.98	-1.78
G9×G10	-15.66	-14.13	-33.33	-9.50	-14.26	-12.30
G10×G2	-39.58	-30.28	-43.70	-32.45	-13.92	-8.28
G10×G4	-17.66	-17.13	-11.85	13.33	10.30	46.17

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

Table 14. Estimation of heterosis over better parent and heterosis over mid parent for fruit dry matter content, fruit moisture content and leaf chlorophyll content of crosses

Crosses	Fruit dry matter content		Fruit moisture content		Leaf chlorophyll content	
	HBP	HMP	HBP	HMP	HBP	HMP
G1×G3	-1.70	10.55	-2.50	-1.16	-2.36	2.70
G1×G4	3.13	14.94	-2.90	-1.66	7.97	8.10
G1×G5	-3.18	2.44	-1.09	-0.32	28.45	35.78
G1×G6	-9.52	-1.49	-1.01	0.22	-0.18	1.65
G1×G7	-18.17	-17.58	2.11	2.20	1.43	2.23
G1×G8	-25.83	-16.62	0.46	1.84	-27.84	-25.74
G1×G9	6.76	11.55	-1.90	-1.37	-14.86	-12.10
G1×G10	-54.93	-30.58	-6.42	9.85	-27.38	-23.96
G2×G7	3.45	6.05	-1.09	-0.77	-26.11	-21.89
G2×G10	-55.17	-31.53	-5.88	10.27	-20.73	-19.31
G3×G2	42.04	62.26	-8.50	-7.03	-24.31	-15.51
G3×G5	-6.63	10.31	-3.31	-1.22	-38.14	-37.81
G3×G10	-68.03	-48.12	-3.58	14.47	-27.44	-20.28
G4×G1	-2.26	8.93	-2.24	-0.99	-20.60	-20.51
G4×G5	-26.15	-13.49	-0.42	1.63	-20.08	-15.61
G4×G9	20.56	29.01	-3.77	-3.06	-10.79	-7.79
G4×G10	-53.63	-25.03	-9.32	7.57	-15.87	-11.81
G5×G10	-53.95	-31.03	-5.37	10.36	-15.33	-10.50
G6×G2	32.18	41.55	-6.86	-5.92	-31.14	-27.94
G7×G10	-50.34	-23.25	-8.53	7.45	-28.52	-25.71
G8×G10	-60.05	-35.17	-6.86	10.57	-25.64	-19.98
G9×G10	-57.09	-32.57	-6.52	10.22	-32.35	-31.36
G10×G2	-69.78	-53.84	0.31	17.53	-8.64	-7.01
G10×G4	-74.13	-58.18	-0.88	17.58	3.78	8.79

Here, G = Genotype; HBP = Heterosis over better parent and HMP = Heterosis over mid parent

leaf area which indicates that it produced larger leaf area compared to its better parent (Table 8). G1×G3 showed negative lowest heterosis over mid parent (-11.66) whereas G4×G9 showed highest positive heterosis over mid parent (183.11) which indicates that this cross produced smaller leaf compared to mid parent (Table 8). G4×G9 showed highest heterosis in term of mid parent and better parents for leaf area.

4.2.4 Days to first flowering

G1×G3 showed positive and highest heterosis over better parent (50.53) and heterosis over mid parent (56.16) in term of days to first flowering which indicates that G1×G3 needed the longer time for days required for first flowering (Table 8). G2×G10 showed the lowest and negative heterosis over better parent (-42.71) which indicates that G2×G10 takes lower time compared to its better parent for first flower setting and G4×G1 showed the lowest and negative heterosis over mid parent (-37.14) which indicates that G4×G1 takes lower time compared to its mid parent for first flower setting (Table 9). The morphological comparison for flowers between F_1 offspring and their related parent is shown in Plate 5.

4.2.5 Days to first fruit setting

G4×G10 showed highest positive heterosis over better parent (34.62) and heterosis over mid parent (40.00) which indicates that it takes the more days to set the first fruit setting (Table 9). G5×G10 showed the lowest and negative heterosis over better parent (-30.65) which indicates that it took lower days compared to its better parent for first fruit setting (Table 9). G1×G7 and G7×G10 showed the lowest and negative heterosis over mid parent (-20.28) which indicates that it took lower number of days for fruit setting compared to mid parent (Table 9). The morphological comparison for fruits between F_1 offspring and their related parent is shown in Plate 6.

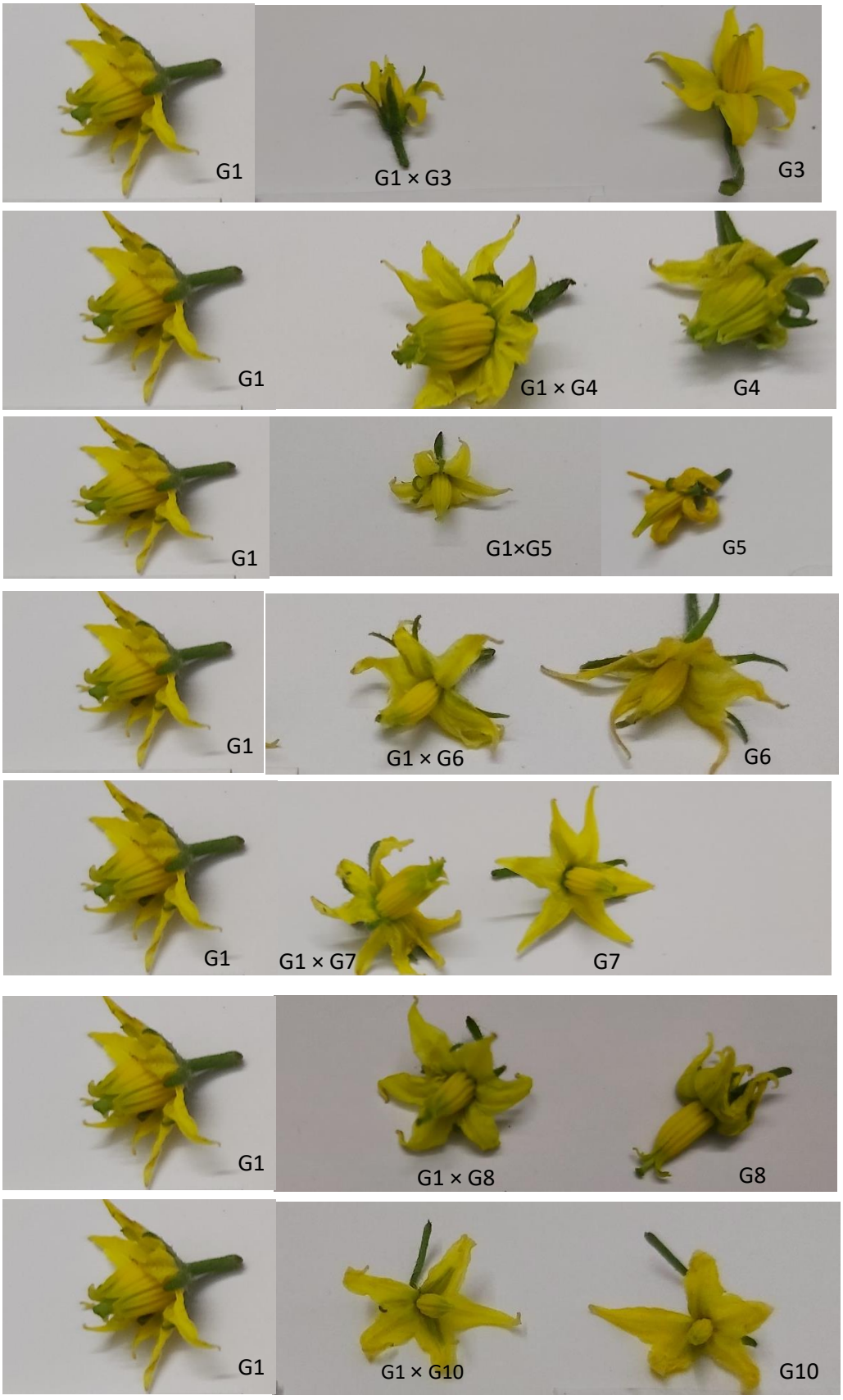

Plate 5: **Morphological comparison for flowers between F_1 offspring and their related parent**

Plate 5. Continued.

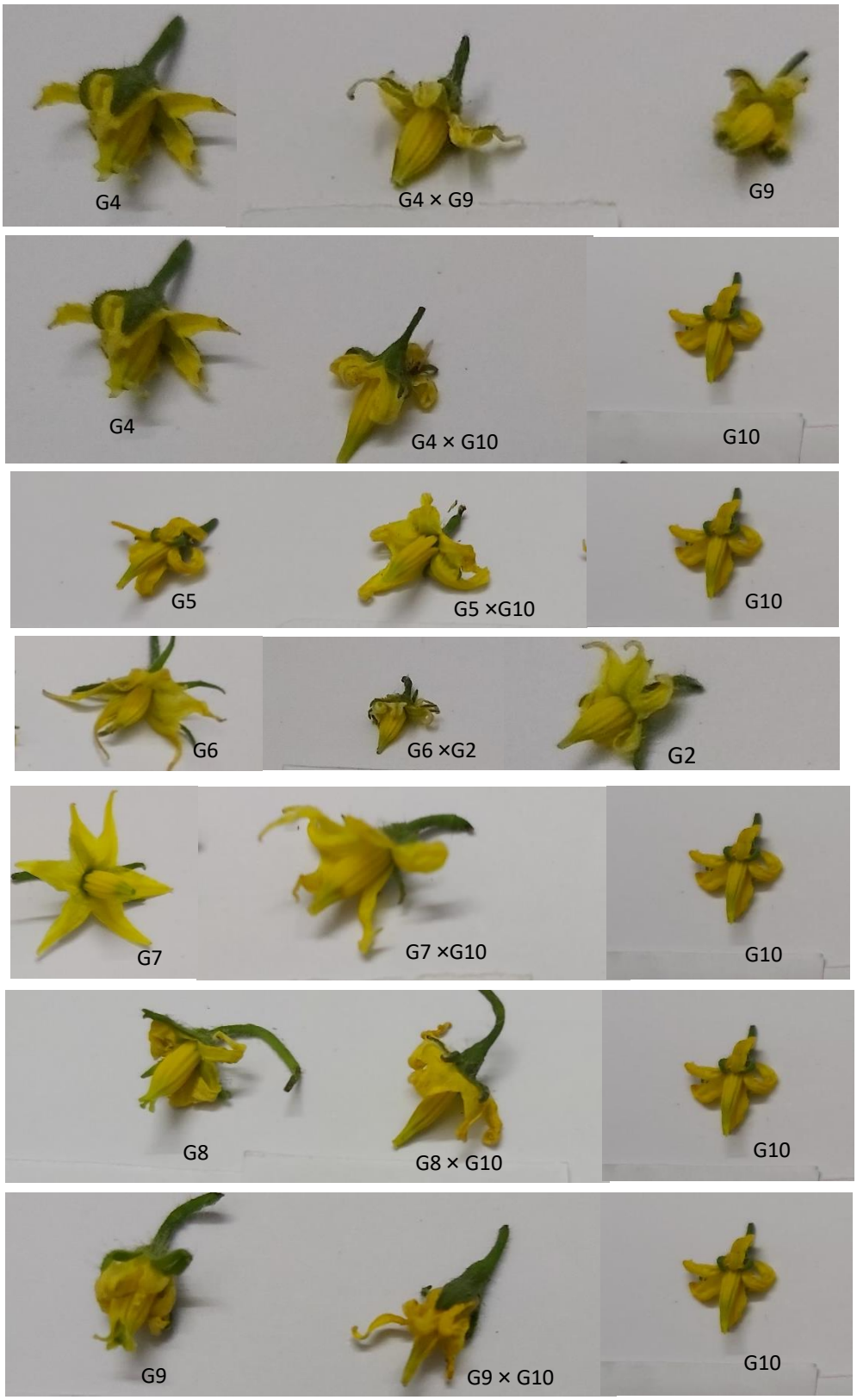

Plate 5. Continued.

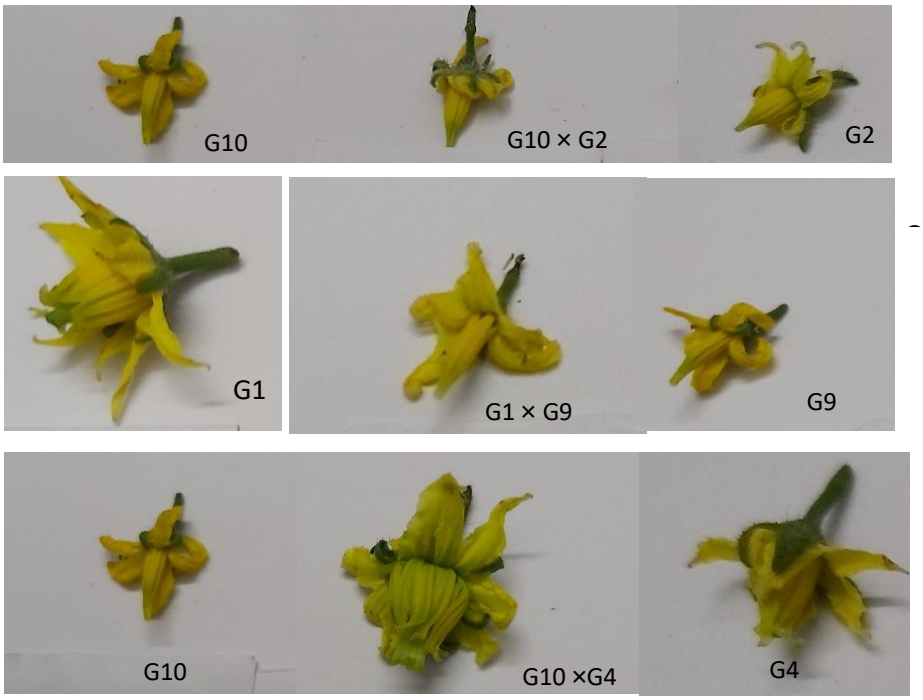

Plate 5. Continued.

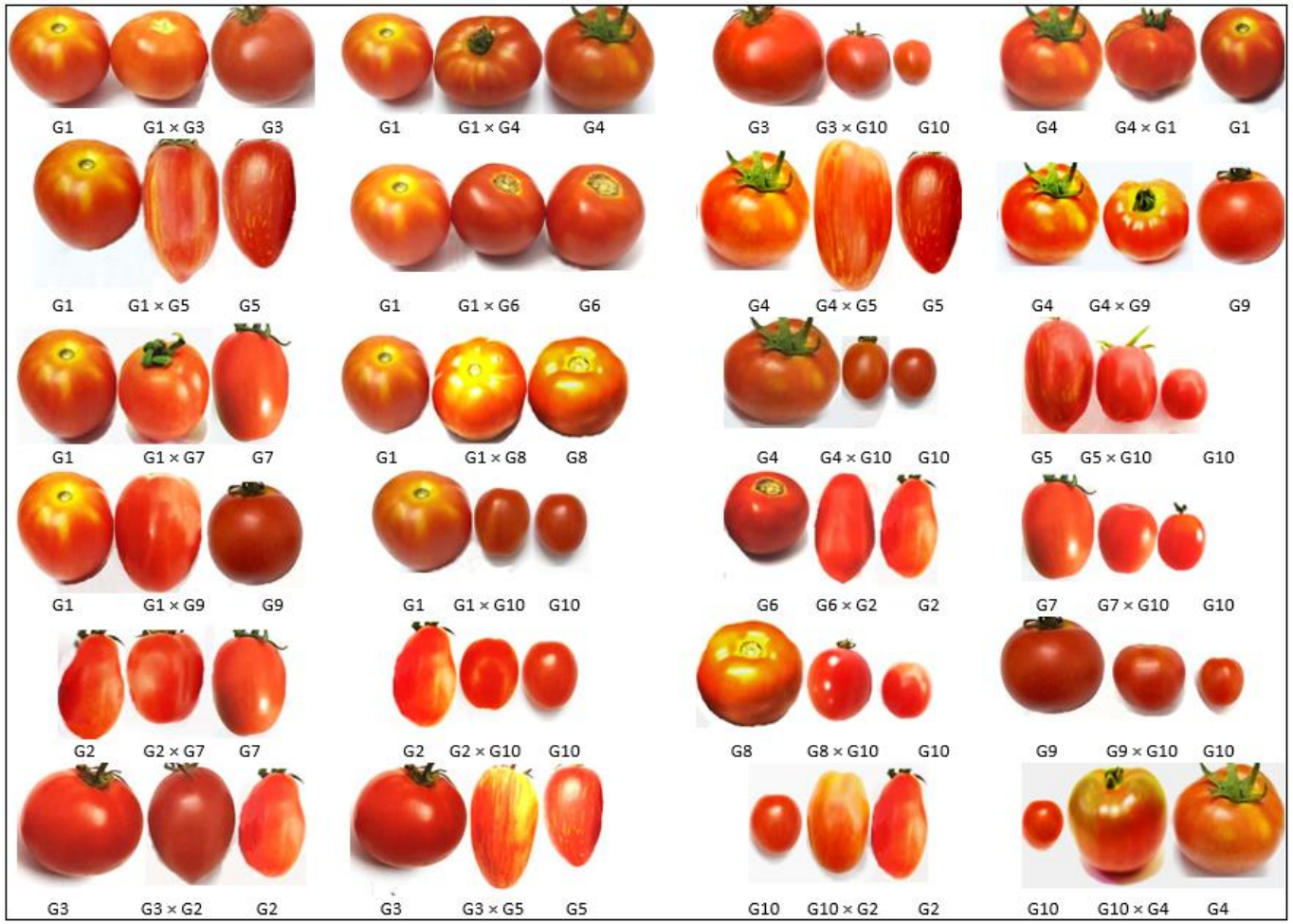

Plate 6. Morphological comparison for fruits between F_1 offspring and their related parent

Plate 5 and plate 6 show the morphological comparison among F_1 and their respective parents which proved the presence of heterosis in terms of flower and fruit morphology respectively. Most of the F_1s showed the presence of variation among the F_1 compared to their parent. Sepal number and length, petal length and number and characters of male and female flower showed increase or decrease which indicates the genetic control of flower morphology.

4.2.6 Days to maturity

G9×G10 showed the lowest negative heterosis over better parent (-19.38) which indicated it took lower days for maturity whereas G1×G3 showed highest and positive heterosis over better parent (9.12) which indicates that it took longer days for maturity compared to better parent (Table 9). G4×G9 showed the highest positive heterosis over mid parent (13.21) which indicates that it took longer days for maturity whereas G9×G10 showed the lowest negative (-12.24 which indicated that it took shorter days for maturity compared to mid parent (Table 9).

4.2.7 Number of branches per plant

G4×G10 showed the lowest negative heterosis over better parent (-40.53) which indicates that it had lower number of branches per plant whereas G9×G10 showed highest positive heterosis over better parent (29.16) which indicates that it had higher number of branches per plant compared to its better parent (Table 10). G1×G3 showed lowest and negative heterosis over mid parent (-36.33) which indicates that it had lower number of branches per plant compared to mid parent whereas G3×G10 showed the highest positive (58.55) heterosis over mid parent which indicates that it had higher number of branches per plant compared to its mid parent (Table 10).

4.2.8 Number of clusters per plant

G1×G8 showed the positive and highest heterosis over better parent (56.27) and heterosis over mid parent (65.30) which indicates that this cross had higher number of clusters per plant compared to its better and mid parent (Table 10).

G1×G3 showed lowest and negative heterosis over better parent (-43.74) and lowest heterosis over mid parent (-39.98) which indicates that this cross had lower number of clusters per plant compared to its better and mid parent (Table 10).

4.2.9 Number of flowers per cluster

G2×G7 showed highest heterosis over better parent (28.60) and G2×G10 showed highest heterosis over mid parent (35.42) which indicates that these crosses had higher number of flowers per cluster compared to their better parent and mid parent respectively (Table 10). G10×G2 showed lowest and negative heterosis over better parent (-33.45) and G4×G5 showed the lowest and negative heterosis over mid parent (-24.22) which indicates that these crosses had lower number of flowers per cluster compared to their respective better and mid parent (Table 10).

4.2.10 Number of fruits per cluster

G1×G5 showed the highest and positive heterosis over better parent (48.76) and G1×G10 showed highest and positive heterosis over mid parent (69.55) which indicates that these crosses had higher number of fruits per cluster compared to their better and mid parent respectively (Table 11). G10×G4 showed the lowest and negative heterosis over better parent (-53.00) and G10×G4 showed negative and lowest heterosis over mid parent (-33.03) which indicates that these crosses had lower number of fruits per cluster compared to better parent and mid parent respectively (Table 11).

4.2.11 Number of fruits per plant

G3×G10 showed the highest positive heterosis over better parent (176.83) and G5×G10 showed the highest positive heterosis over mid parent (219.78) which indicates that this cross produced a greater number of fruits per plant compared to their better and mid parent (Table 11). G1×G3 showed the lowest and negative heterosis over better parent (-71.17) and negative lowest heterosis over mid parent (-64.96) which indicates that this cross combination produced lower number of fruits per plant (Table 11).

4.2.12 Fruit length

In most of the crosses, the fruit length in both term of heterosis over better parent and heterosis over mid parent showed negative result (Table 12). Among cross combinations, G4×G5 showed highest and positive heterosis over better parent (38.55) heterosis over mid parent (43.15) which indicates that this cross performed well in term of fruit length compared to their better and mid parent. G2×G10 showed the lowest and negative heterosis over better parent (-55.38) and G1×G10 showed lowest and negative heterosis over mid parent (-48.62) which indicates that these crosses had smaller fruits compared to their better and mid parent (Table 12).

4.2.13 Fruit diameter

In most of the cross combinations, it produced smaller fruit in term of fruit diameter compared to their better and mid parent (Table 12). G1×G9 showed the positive and highest heterosis over better parent (0.20) and G10×G4 showed the positive and highest heterosis over mid parent (51.27) which indicates that these cross combinations produced larger fruit in diameter. G4×G10 showed the lowest and negative heterosis over better parent (-75.92) and heterosis over mid parent (-62.02) which indicates that fruit diameter was found lower in these cross combinations. Fruit length and diameter shows variation depending on the parental matting which is presented in Plate 6. Fruit length and size showed highest morphologically positive deviation in case of G4 × G1 and G10 × G2 whereas G1 × G10 showed the negative deviation (Plate 6).

4.2.14 Individual fruit weight

Most of the cross combinations showed lower in fruit weight compared to their mid and better parent (Table 12). G10×G2 showed the positive and highest heterosis over better parent (73.56) and heterosis over mid parent (191.14) that indicates this cross combination had highest fruit compared to their better and mid parent. G4×G10 showed the lowest and negative heterosis over better parent

(-96.28) and heterosis over mid parent (-92.86) which indicates that this cross had fruits with lower weight compared to their better and mid parent (Table 12).

4.2.15 Yield per plant

G5×G10 showed highest and positive heterosis over better parent (138.39) and heterosis over mid parent (233.38) which indicates that this cross combination had better yield compared to its better and mid parent (Table 12). G4×G10 and G1×G4 showed lowest as well as negative heterosis over better parent (-88.56) and heterosis over mid parent (-84.44) respectively which indicates that this cross produced lower yield compared to their better and mid parent. Most of the cross failed to produce higher yield compared to better and mid parent.

4.2.16 Fruit pH

All the cross combinations produced fruits with lower fruit pH compared to the respecting better and mid parent (Table 13). All crosses showed negative heterosis in both better and mid parent heterosis. G4×G1 showed the lowest negative heterosis over better parent (-42.83) and lowest negative heterosis over mid parent (-34.93) (Table 13). This result showed that fruit pH trait could not be improved by crossing the parents which were used in this experiment.

4.2.17 Fruit Brix%

G1×G3 showed highest and positive heterosis over better parent (52.03) and highest positive heterosis over mid parent (121.67) which indicates that this cross had fruits with higher Brix % compared to better and mid parent (Table 13). G1×G8 showed the lowest negative heterosis over better parent (-68.47) and lowest negative heterosis over mid parent (-56.49) which indicates that these cross combinations produced fruits with lower brix content.

4.2.18 Fruit shelf life

G4×G5 showed the highest and positive heterosis over better parent (85.78) and heterosis over mid parent (88.30) which indicates that this cross combination produced fruits with longer shelf life then its respecting better and mid parent

(Table 13). G1×G4 showed lowest and negative heterosis over better parent (-47.44) and heterosis over mid parent (-28.09) which indicates that this cross-produce fruits with shorter shelf life.

4.2.19 Fruit dry matter

G3×G2 showed highest and positive heterosis over better parent (42.04) and heterosis over mid parent (62.26) which indicates that this cross produced fruits with higher dry matter content compared to their better and mid parent (Table 14). G10×G4 showed the lowest and negative heterosis over better parent (-74.13) and heterosis over mid parent (-58.18) which indicates that this cross had fruits with lower dry matter content compared to its better and mid parent.

4.2.20 Fruit moisture content

All the crosses showed lower heterosis over mid parent and better parent (Table 14). G1×G7 showed higher and positive heterosis over better parent (2.11) and G10×G4 showed the highest positive heterosis over mid parent (17.58) which indicates that these crosses produced fruits with higher moisture content (Table 14). G4×G10 showed lowest and negative heterosis over better parent (-9.32) and G3×G2 showed the lowest negative heterosis over mid parent (-7.03) which indicates that these crosses combinations produced fruits with lower moisture content compared with their mid and better parent.

4.2.21 Leaf chlorophyll content

G1×G5 showed highest and positive heterosis over better parent (28.45) and heterosis over mid parent (35.78) which indicates that this cross had leaves with higher leaf chlorophyll content compared to its better and mid parent (Table 14). G3×G5 showed the lowest and negative heterosis over better and mid parent (-38.14, -37.81 respectively) which indicates that this cross produced leaf with lower leaf chlorophyll content compared to their better and mid parent (Table 14).

Chapter V

Summary and Conclusion

CHAPTER V
SUMMARY AND CONCLUSION

This experiment was conducted entitled in 2018-2019 and 2019-2020 at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. Estimation of heterosis along with mean performance for fifteen agromorphological and six qualitative traits of ten parental lines and twenty-four F_1 genotypes.

Plant height, days to first flowering, days to first fruit setting, days to maturity, number of clusters per plant, number of fruits and number of flowers per cluster, number of fruits per plant, fruit length and fruit diameter and individual fruit weight, yield per plant, fruit pH, Brix content, shelf life and leaf chlorophyll content showed significant in term of genotypes at 5 % level. The following can be summarised from the mean performance of ten parental lines and twenty-four crossed progeny. Highest plant height was found in G1 × G7, higher number of leaves in G1 × G3, highest leaf area in G4 × G9, late flowering in G1 × G3 and early flowering in G4 × G1, late fruit setting in G3 × G2 and early fruit setting in G1 × G7, early maturity in G3 × G10 and late maturity in G4 × G9, higher number of clusters per plant in G7 × G10, highest number of flowers per plant in G4 × G5, highest number of fruits per plant in G7 × G10, highest fruit length in G4 × G5, highest fruit diameter in G10 × G4, highest yield in G4 × G1 and lowest yield in G6 × G2. In case of qualitative traits, highest fruit pH and fruit Brix % were found in G1 × G3, longer shelf life in G1 × G10, highest dry matter in G7 × G10 and highest moisture content in G1 × G8.

Heterosis over mid parent and heterosis over better parent for fifteen agromorphological and six qualitative traits were estimated. G5×G10 showed the highest heterosis over better parent and heterosis over mid parent in term of plant height; G1×G8 showed the highest and positive heterosis over better parent and heterosis over mid parent in term of number of leaves per plant; G1×G3 showed positive and highest heterosis over better parent in term of days to first

flowering; G4×G10 showed highest positive heterosis over better parent and heterosis over mid parent in term of days to first fruit setting; G1×G8 showed the positive and highest heterosis over better parent and heterosis over mid parent for number of clusters per plant; G2×G7 showed highest heterosis over better parent and G2×G10 showed highest heterosis over mid parent for number of flowers per cluster; G1×G5 showed the highest and positive heterosis over better parent and G1×G10 showed highest and positive heterosis over mid parent for number of fruits per cluster; G3×G10 showed the highest positive heterosis over better parent and G5×G10 showed the highest positive heterosis over mid parent for number of fruits per plant; G5×G10 showed highest and positive heterosis over better parent and heterosis over mid parent for yield per plant. G4×G1 showed the lowest negative heterosis over better parent in term of fruit pH, G1×G3 showed highest and positive heterosis over better parent and highest positive heterosis over mid parent for fruit Brix content; G4×G5 showed the highest and positive heterosis over better parent and heterosis over mid parent for fruit shelf life; All the crosses showed lower heterosis over mid parent and better parent.

From this current experiment, G5 × G10 can be suggested for higher yield per plant; G1 × G3 can be suggested for highest Brix content and G4 × G5 can be suggested for longer shelf life. Suggested F_1 can be experimented in several locations as well as several years. Besides, parental lines can be used again for crossing with a target of full diallel analysis to find out highest heterotic as well as best specific and general combiner.

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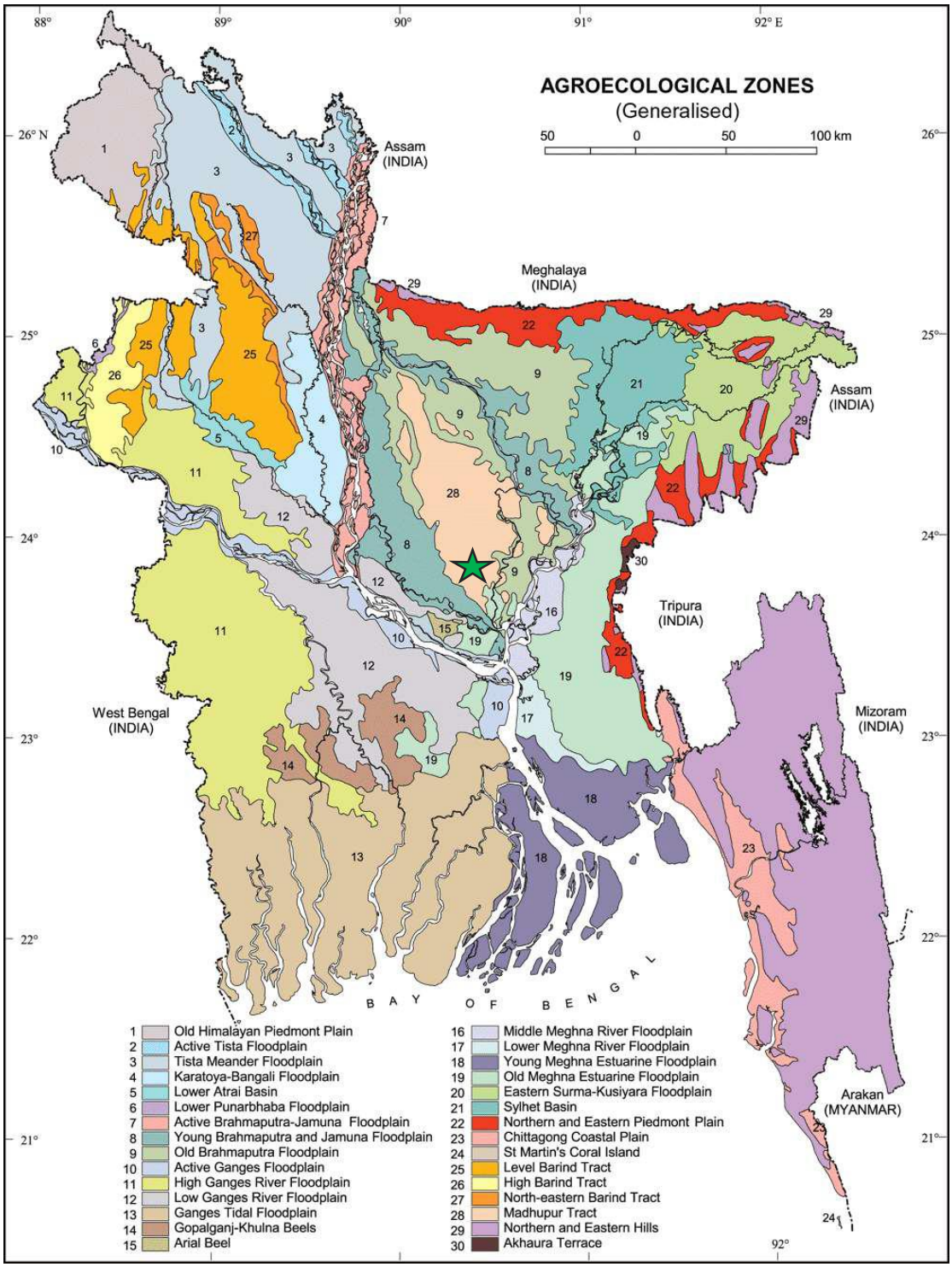
Appendices

APPENDICES

Appendix I. Map showing the experimental site under the study



★ The experimental site under the study

Appendix II. Weather parameters of experimental site during November 2018-March 2019 and November 2019-April 2020.

1st Experimental year (November, 2018-April, 2019)					
Year	**Month**	**Average Temperature**	**Rainfall**	**Humidity**	**Sunshine hours**
2018	November	24	Trace	63	216.4
2018	December	19.34	Trace	61	212.5
2019	January	20.2	1	59	212.5
2019	February	22	115	63	195
2019	March	26	39	61	225
2019	April	28.3	212	69	235

2nd Experimental year (November, 2019-April, 2020)

Year	**Month**	**Average Temperature**	**Rainfall**	**Humidity**	**Sunshine hours**
2019	November	24.9	37	74	214.4
2019	December	19.3	5	72	210.5
2020	January	18.5	21	76	209.5
2020	February	21.6	1	59	194
2020	March	26.4	30	57	224
2020	April	27.9	127	72	234

Appendix III. Morphological, physical, and chemical characteristics of soils from experimental site

A. Morphological characteristics of the experimental field

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 leveled

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**
1	Organic carbon (%)	0.45	Walkley and Black, 1947
2	Total N (%)	0.03	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (ppm)	20.54	Olsen and Dean, 1965
7	Exchangeable K (me/100 g soil)	0.10	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	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 IV. Analysis of variance (ANOVA) for 21 different characters of *Solanum lycopersicum* L.

Source of Variation	Degree of freedom	Mean Sum of Square (MS) value.						
		Plant height	**No. of leaves / plant**	**Leaf area**	**Days to 1st flowering**	**Days to 1st fruit setting**	**Days to maturity**	**No. of branches / plant**
Replication	2	609.59	90.30	98581	63.88	264.19	74.24	127.68
Genotypes	33	611.62*	953.62^{NS}	128302^{NS}	198.87**	188.77*	206.76**	14.57^{NS}
Error	66	146.52	583.52	53828	36.75	49.89	32.71	9.48

*Significant at 0.05 level; **Significant at 0.01; ^{NS} Non-significant.

Appendix IV. Continued.

Source of Variation	Degree of freedom	Mean Sum of Square (MS) value.						
		No. of clusters / plant	No. of flowers / cluster	No. of fruits / cluster	No. of fruit / plant	Fruit length	Fruit diameter	Individual fruit weight
Replication	2	176.78	7.68	0.86	123.9	603.28	320.77	223.49
Genotypes	33	178.57*	6.99**	9.29**	22076**	512.41**	1123.41**	5654.87**
Error	66	60.14	0.67	0.74	823.5	1.97	1.11	11.65

*Significant at 0.05 level; **Significant at 0.01; ^{NS} Non-significant.

Appendix IV. Continued.

Source of Variation	Degree of freedom	Mean Sum of Square (MS) value.						
		Yield / plant	Fruit pH	Fruit Brix%	Shelf life	% Dry matter content	% Moisture content	Leaf chlorophyll content
Replication	2	0.47	0.04	0.43	112.21	168.82	168.82	719.50
Genotypes	33	41.59**	1.23**	3.50**	36.99**	81.44^{NS}	81.44^{NS}	166.26**
Error	66	1.31	0.003	0.01	5.32	60.79	60.79	1.85

*Significant at 0.05 level; **Significant at 0.01; ^{NS} Non-significant.

Appendix V. Visit of research supervisor in the experimental field.