EVALUATION OF AGRONOMIC AND NUTRITIONAL TRAITS IN 5×5 HALF-DIALLEL POPULATION OF TOMATO (*Solanum lycopersicum* L.)

MAHBUBA FATEMA

DEPARTMENT OF GENETICS AND PLANT BREEDING

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA -1207

JUNE, 2020

EVALUATION OF AGRONOMIC AND NUTRITIONAL TRAITS IN 5×5 HALF-DIALLEL POPULATION OF TOMATO (*Solanum lycopersicum* L.)

BY

MAHBUBA FATEMA

REGISTRATION NO. 13-05585

A Thesis
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

SEMESTER: JANUARY-JUNE, 2020

Approved by:

Prof. Dr. Jamilur Rahman **Supervisor**	**Prof. Dr. Naheed Zeba** **Co- Supervisor**

Prof. Dr. Kazi Md. Kamrul Huda
Chairman
Examination Committee

Prof. Dr. Jamilur Rahman
Department of Genetics and Plant Breeding
Sher-e-Bangla Agricultural University
Dhaka-1207, Bangladesh
Tel: 88-02-9140770
Mobile: +8801552-323928
E-mail : jamilsau@gmail.com

CERTIFICATE

*This is to certify that the thesis entitled,"**EVALUATION OF AGRONOMIC AND NUTRITIONAL TRAITS IN 5×5 HALF DIALLEL POPULATION OF TOMATO (Solanum lycopersicum L.)"** 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 **MAHBUBA FATEMA,** Registration No. **13-05585** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated: June, 2020
Dhaka, Bangladesh

(Prof. Dr. Jamilur Rahman)
Supervisor

DEDICATED TO MY

BELOVED

MOTHER AND BROTHER

SOME COMMONLY USED ABBREVIATIONS

Abbreviations	Full name	Abbreviation	Full name
AEZ	Agro-Ecological Zone	BBS	Bangladesh Bureau of Statistics
Agric.	Agriculture	*Sci.*	Science
Agril.	Agricultural	Sl.	Serial
Agron.	Agronomy	BARI	Bangladesh Agricultural Research institute
ANOVA	Analysis of Variance		
et al.	and others		
App.	Applied	Applied	App.
@	At a rate	Environment	Environ.
BP	Better parent	mg	miligram
Biol.	Biology	ml	milliliter
Bot.	Botany	MOP	Muriate of Potash
Breed.	Breeding	OM	Organic matter
cm	Centimeter	%	Percentage
CV	Component variance	σ_p^2	phenotypic variance
FAO	Food and Agriculture Organization	RCBD	Randomized Complete Block Design
DAS	Days after sowing	i.e.	That is
ºC	Degree celsius	Society	Soc.
Div	Division	*Res.*	Research
d.f	Degrees of freedom	*Proceedings*	Proc.
etc.	Etcetera	ppm	Parts per million
Viz.	For example	*Rev.*	Review
Genet.	Genetics	wt.	Weight
σ_g^2	Genetic variance	*Soc.*	Society
GCA	General combining ability	SCA	Specific combining ability
g_{ij}	General combining ability effect	s_{ij}	Specific combining ability effect
G	Gram	m^2	Square meter
ha	Hectare	*Inf.*	Information
Hort.	Horticulture	*Exp.*	Experimental
Intl. J.	International Journal	Kg	Kilogram
SAU	Sher-e-Bangla Agricultural University	F_1	The First Generation of a cross between two dissimilar parents
Standard error	SE	Univ.	University
m	Meter	Var.	Variety
stat.	Statistics	Ltd.	Limited

ACKNOWLEDGEMENTS

At first, the author expresses her profound gratitude to Almighty Allah for the never-ending blessing to complete this work successfully. It is a great pleasure to express her reflective gratitude to her respected parents, brother, and teachers who entitled much hardship inspiring for prosecuting her studies, thereby receiving a proper education.

The author would like to express her earnest respect, sincere appreciation, and enormous thankfulness to her reverend supervisor, Professor Dr. Jamilur Rahman, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, for his scholastic supervision, continuous encouragement, constructive suggestion, and unvarying inspiration throughout the research work and for taking immense care just like a family member during whole study period and preparation this manuscript.

The earnest indebtedness to her co-supervisor Professor Dr. Naheed Zeba, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University for her continuous support, guidance, constructive criticism, and valuable suggestions which were very helpful during the final stretch of her thesis writing.

The author expresses her sincere respect to the Chairman of the Department, Professor Dr. Kazi Md. Kamrul Huda, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, for his Valuable knowledge teaching and guidance during her study as well as encouragement, comments, and heartedly cooperation during the whole research period.

The author is highly grateful to Profesor Dr. Kamal Uddin Ahamed, honorable Vice-chancellor, Sher-e-Bangla Agricultural University, Dhaka, and Professor Dr. Parimal Kanti Biswas, Dean, Post Graduate Studies for providing her overall logistic, academic support, valuable suggestions, and cooperation during the whole study period.

The author feels to express her heartfelt thanks and deepest gratitude to her all respectable teachers, Specially honorable Professor Dr. Md. Shahidur Rashid Bhuiyan, Professor Dr. Md. Sarowar Hossain, Professor Dr. Firoz Mahmud, Professor Dr. Mohammad Saiful Islam, Professor Dr. Md. Ashaduzzaman Siddikee, Dr. Md. Harun-Ur-Rashid, Professor Dr. Md. Abdur Rahim, professor Dr. Ms. Shahanaz Parveen, and all other teachers of her department for their excellent guidance, direct and indirect guidance, and continuous warm cooperation during the period of her study.

The author would like to thank Mosammat Rexona Parvin and Shyamol Kumar Roy, academic officers and also grateful to all the staff of her department, the staffs of the SAU library, and the farmworkers for their nice cooperation.

The author feels proud of expressing her sincere appreciation and gratitude to the Ministry of Science and Technology, the Peoples Republic of Bangladesh for selecting her National Science and Technology (NST) fellow and providing adequate funding.

She would like to thank all of her friends and well-wishers who always inspired her during her research especially Imran Ahmed, Md. Kamal Hossain, Asmaul Husna, Abu Bakar Siddique, who helped her with their valuable suggestions and wonderful directions. It was an amazing experience to work with all of them.

Over and above, the author can never repay the debt of her mother and elder brother for their constant encouragement and inspiration, who sacrifice much for her higher education and guided her toward the achievement of his goal.

The author expresses her immense gratefulness to all of them who assisted and inspired her to achieve higher education and regrets her inability not to mention everyone by name.

June 2020 ***The Author***

LIST OF CONTENTS

LIST OF CONTENTS (CONT'D)

LIST OF CONTENTS (CONT'D)

LIST OF CONTENTS (CONT'D)

LIST OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES

EVALUATION OF AGRONOMIC AND NUTRITIONAL TRAITS IN 5×5 HALF-DIALLEL POPULATION OF TOMATO (*Solanum lycopersicum* L.)

BY

MAHBUBA FATEMA

ABSTRACT

The study was conducted through 5×5 diallel cross excluding reciprocals to evaluate the ten F_1 hybrids of tomato for different agronomic traits *viz.* days to 50% flowering, plant height, number of secondary branches, number of fruits per cluster, number of fruits per plant, single fruit weight, fruit diameter, fruit length, days to first harvesting, yield per plant, shelf life, pericarp thickness, number of locules per fruit and nutritional traits *viz.* Vitamin-C content, brix percentage, titrable acidity percentage. To develop the F_1 hybrid lines, five parental genotypes were matted in 5×5 half-diallel fashion during the rabi season 2017-18 and then evaluated for their combining ability and heterosis over check variety, BARI hybrid tomato-4 and corresponding better parent at the research farm of Sher-e-Bangla Agricultural University, Dhaka 1207 during rabi season 2018-19. The experiment on evaluation of F_1 hybrids was laid in RCBD design using three replications. The significant differences among the genotypes were obtained for all of the traits studied in the experiment here. 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 in governing the traits. The values of GCA were higher than the SCA values for all the traits except yield trait indicating the superiority of additive gene effects were more prominent for the inheritance of these traits. The parental lines P2 and P4 were proved to be the best general combiner for dwarf plant height, early flowering and early maturity while the parental lines P2 and P3 were proved to be the best general combiner for yield and yield related traits. The tested crosses P2×P5, P1×P3, and P3×P4 showed best specific combiner for yield and yield related traits. Again, three cross combinations *viz.* P1×P2, P1×P4 and P4×P5 showed best specific combiners for the traits of days to 1st harvesting. Cross combination P2×P5 exhibited highest 49.80% significant heterosis was followed by 40.16% in P1×P2 and 33.80% in P1×P3 over check variety for yield traits. In addition, five cross combinations *viz.* P1×P2, P1×P4, P2×P4, P4×P5, and P1×P3 showed desirable value for days of 1st harvesting followed by yield contributing traits. Furthermore, two cross combinations *viz.* P1×P4 and P4×P5 were best nutritional traits. Considering the performance of SCA effects and heterosis, afore-mentioned crosses could be utilized for developing promising hybrid varieties as well as for exploiting hybrid potency.

INTRODUCTION

CHAPTER I

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a high demanding vegetable crop with an enormous economic value in the world. It is one of the most widely grown vegetables across the globe. Tomato trade and production have particular importance in tropical, subtropical, and mild regions of the world, for both, fresh and processing markets (Meena *et al.,* 2017). In the world, it ranks second in importance after potato but at the top in the list of processed vegetables (Chaudhary, 1996). It is a very good source of income for small and marginal farmers and also contributes to the nutrition of the consumers (Singh *et al.,* 2010).

Tomato (2n=2x=24) belongs to the family Solanaceae and is native to Central and South America (Vavilov, 1951). The Genus *Lycopersicon*is derived from a Greek word meaning "wolfs peach". There are nine species of this genus, among them, only two are cultivated e.g. *Lycopersicon esculentum* (common tomato) and *Lycopersicon pimpinellifolium.*

Tomato contains nutrition fact as vitamins A, C, lycopene, flavonoid, and other minerals like Ca, P, and Fe, that are good for human health (Akhtar and Hazra, 2013; Bhowmik *et al.* 2012). Furthermore, tomatoes are major contributors of antioxidants such as carotenoids (especially, lycopene and β-carotene), phenolics, ascorbic acid (vitamin C), and small amounts of vitamin E in daily diets (Rai *et al.,* 2012). Moreover, tomato is used as a vegetable, table fruit, drinks, raw material for cosmetics and herbs. The ripen fruits are taken as raw or made into salads, soups, preserve, pickles, ketchup, puree, paste, and many other products (Chadha, 2001). The crop plays a pivotal role in improving the nutrition resources of the poor population as compared to meat, milk, fruits, and other high priced fruit items. In many countries, it is considered as "poor man's orange" because of its attractive appearance and nutritive value (Singh *et al.*, 2004). Tomato also flushes out free radicals, protects against inflammation, heart diseases, and prevents DNA damage in the human body.

Tomato is an introduced crop in Bangladesh. Over time, now tomato is one of the most important and popular vegetable crops in Bangladesh for its good taste as well as nutritional value. A wide range of latitude, soil types, and methods of cultivation is suitable for tomato production (Villareal,1980). Winter night temperature of 15°C to 20°C ensures optimum fruit setting (Charles and Harris,1972; Schiable,1962) which makes tomato cultivation preferable in Bangladesh. But its national average yield is 10 tons/ha (Anonymous, 2014) which is very low compared to that other tomato producing countries. According to BBS (2018) tomatoes are grown in 68,366 acres of land with a production of 388725 M. ton in Bangladesh.

The identification of high yielding and stable parental lines and the development of F_1 hybrids will help the farmers for commercial cultivation of tomato. As, F_1 hybrid varieties of tomatoes are generated through the crossing of two genetically diverse parents, which are one of the most leading forms of vegetable varieties all over the world. Apart from high yield potential, the hybrid varieties have specific advantages e.g. early maturity, the higher number of fruits, fruit size, improved quality, uniformity, and adaptation to adverse conditions (Tesi *et al.* 1970).

In general, the observation of the performance of hybrid offsprings is conducted using the diallel crossing approach. This technique was developed and illustrated by Jinks and Hayman (1953). Crossing in a diallel fashion is the only specific and effective approach to estimate the allele transfer capacity, which is genetically designed and widely exploited in breeding programs for numerous species and purposes, including for tomato (Maluf,2001). Since the introduction of combining ability has been also widely adopted in plant breeding to compare the performances of lines in hybrid combinations (Fasahat *et al.,* 2016). Combining ability is especially one of the most effective tools related to the crossing which is widely used for the identification and selection of right and good parents for hybrid development as well as superior genetically recombined potential lines. General combining ability (GCA) and specific combining ability (SCA) are two types of combining ability defined by Sprague (1966).

Utilization of heterosis or hybrid vigor would be one of the most important approaches to meet the growing demand for tomatoes. Being a bisexual self-pollinated crop tomato has a tremendous potentiality for heterosis breeding. It is reported that heterosis in tomatoes resulted in an increased yield of 20 to 50% (Chowdhury *et al.*, 1965). Heterosis in tomato was first observed by Hedrick and Booth (1907) for higher yield and more number of fruits per plant. Since then, heterosis for yield, its components, and quality traits were extensively studied in tomato. Heterosis manifests in tomato in form of greater vigor, faster growth, and development, earliness in maturity, increased productivity, and higher levels of resistance to biotic and abiotic stresses. The best way to utilize heterosis in the crop is to produce F_1 hybrids, which possess maximum heterozygosity.

In Bangladesh Bhuiyan (1982) first time studied the heterosis and combining ability in tomato for yield and yield contributing characters. He reported better parent heterosis in fruit yield per plant up to 124.5% in the cross of Fujuki × World champion lines of tomato.

Many countries have developed high-yielding tomato varieties by exploiting hybrid vigor in tomatoes, but in Bangladesh, such studies are still insufficient. So far Bangladesh Agricultural Research Institute (BARI) and some seed companies have developed some F_1 varieties of tomatoes, but these are not sufficient to fulfill the growing demand for tomatoes. The farmers demand early maturing, high yielding, extended shelf-life hybrid tomato varieties. Unfortunately, there is no mega hybrid variety of tomato developed yet in the county which has both early maturity and high yielding potentials.

Considering the above facts, the present study has been undertaken to generate some pieces of information on breeding so that some potential hybrid varieties of tomato cloud be developed in the future. In that case, the present study has been undertaken with the following objectives.

i. To study the general combining ability (GCA) of the parents and specific combining ability (SCA) of the F_1 hybrids used in the crosses
ii. To estimate the heterosis and hybrid vigor of F_1 hybrids for agronomic and some nutritional traits
iii. To elucidate the nature and magnitude of some gene actions involved in the inheritance of different traits
iv. To select some potential F_1 hybrid lines having high yielding and early maturity traits

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

High production of tomato depends on the yield potential of HYV and hybrid variety improved management and timely supplying of inputs. The nature and magnitude of gene action are important factors in developing an effective breeding program. Many attempts were conducted by the breeders to develop potential varieties of tomatoes. Combining ability analysis is an important tool to select desirable parents together with the information regarding the nature and magnitude of gene effects controlling quantitative traits. The diallel cross technique provided information on gene action and the combining ability of parental lines (Kabir *et al.,* 1993). In this chapter, literature related to the diallel analysis, combining ability, mode of gene action, and heterosis have been reviewed and presented chronologically in this chapter which will provide valuable pieces of information to the researcher to develop the improved variety in near future.

2.1 Diallel analysis

A set of crosses produced by involving the number of lines in all possible combinations is designated as diallel cross and the analysis of such crosses is known as diallel analysis. Baktash (1995). Hayman (1954) and Griffing (1956) proposed the concept of diallel cross as the recombination of genetic variability available in the program, performing crosses among all lines.

Different types of progenies can be produced with the diallel mating design. As a consequence, different analyses can be used. There are four methods of producing progenies:

1. Method I = $n^{2.}$ It includes all possible crosses and parents.
2. Method II = n (n+1) / 2. This method is the most widely used and it includes one set of crosses and the parents (no reciprocals).
3. Method III = n (n−1). It includes two sets of crosses without parents.
4. Method IV = n (n−1) / 2. It only includes one set of crosses with neither reciprocals nor parents.

The two models, where the parents are not included, Griffing termed them as “modified model”.

The contribution of each parent to general combining ability was measured by the estimates of GCA effects (g_i) and the contribution of each parent to hybrids was given by estimates of Sca effects (S_{ij}).

To choose appropriate parents and crosses, and to determine the combining abilities of parents in the early generation, the diallel analysis method has been widely used by plant breeders. This method was applied to improve self- and cross-pollinated plants (Jinks and Hayman, 1953; Hayman, 1954; Jinks, 1956; Griffing, 1956; Hayman, 1960).

Griffing's biometrical analysis has been widely used in plant improvement programs to identify superior parents for crossing and for characterizing general, specific, and reciprocal effects. This analysis is not hindered by the requirements of numerous genetic assumptions and interpretations from this evaluation are usually straightforward. However, several important factors must be considered when using the analysis (Shattuck *et al.,* 1993).

Diallel cross is the prospective technique because it provides a comprehensive evaluation of hybrid combinations from inbred lines crosses (Chukwu *et al.,* 2016). Plant breeders frequently need overall information on the average performance of individual inbred lines in crosses- known as general combining ability, for subsequent choosing the best amongst them for further breeding. For this purpose, diallel crossing techniques are employed (Himadri and Ashish, 2003).

Diallel mating designs provide the breeders with useful genetic information, such as general combining ability GCA and specific combining ability SCA, to help them devise appropriate breeding and selection strategies (Zhang *et al.,* 2005).

The diallel cross method enables to estimate useful genetic parameters to select genitors for hybridization, as the identification of gene action of character control along with it allows to identify the best lineages combination to be used as male or female genitor to provide the maximum heterotic expression for the hybrids (Vencovsky, 1987).

Cruz and Regazzi (1997), Paterniani and Viegas (1987), and Vencovsky (1987) mentioned that the diallel method of analysis allows estimating useful genetic parameters to select parental lines and verify the combining ability effects.

Vencovsky (1987), also mentioned that diallel crosses allow the genetic parameters estimating, thereby increasing information to the breeder and contributing to decision making.

The diallel mating system has proved very effective in genetic research for determining the inheritance of important traits among genotypes, investigating the GCA of the parents, identifying superior parents for hybrid cultivars development and categorizing inbred genotypes into various heterotic groups, and identifying appropriate testers for breeding purpose (Bhatnagar *et al*., 2004, Menkir *et al*., 2003 and Yallou *et al*., 2009).

2.2 Combining Ability

Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits (Ahmad *et al.* 2016).

General combining ability (GCA) effects were due to additive type of gene action and it measures the general mean deviation. Specific combining ability (SCA) effects were due to non-additive (dominant or epistatic) gene action (Poehlman 1979; Falconer 1989).

The variances of general and specific combining ability are related to the type of gene action involved. Variance for GCA includes an additive portion, while that of SCA includes a non-additive portion of total variance arising largely from dominance and epistatic deviations (Rojas and Sprague, 1952). Scientific reviews owned to combining ability of tomatoes that are related to the present study are described here.

Gayosso-Barragán *et al.* (2019), used seven elite tomato lines (*Solamun lycopersicum* L.) of determinate and indeterminate growth with good yield potential and good combining ability for diallel analysis without reciprocals to produce 21 F_1's. General combining ability (GCA) and specific combining ability (SCA) analyses were performed, for assessing the yield and six yield component traits. Results showed highly significant differences ($p \leq 0.01$) among genotypes, as well as in GCA and SCA effects in all the characteristics that were assessed, except for days to first harvesting. The results also revealed that variance contribution to the yield attributed to the crossings had more non-additive effects (SCA) than additive effects (GCA).

Furthermore, line D4 had the greatest effect on yield in terms of GCA, as well as AFW (average fruit weight), NFP (number of fruits per plant), and PD (polar diameter) followed by D3 and K3. These lines were suggested to use as donor parents in the future tomato-breeding program. Hybrids K3×D4, R1×Y53, D3×IR13, and F3×Y53 had the highest level of SCA, with average yields of 93 t ha^{-1}. These potential hybrids could be exploited at the commercial level after critical testing.

Kumar *et. al.* (2018), investigated various quantitative characters in tomato genotypes. Crosses were made to determine general combining ability and specific combining ability of parents and crosses respectively using Line x Tester mating fashion, type of gene action involved for fruit yield and its components and to ascertain the magnitude of heterosis. Development of hybrids and varieties for better yield and quality traits requires identification of good specific and general combiners. Combining ability revealed the predominance of non-additive gene action for all the characters under study. Line H-86 and Kashi Anupam were found as good general combiner for fruit yield per hectare, average fruit weight, fruit diameter, fruit yield per plant, plant height, number of fruits per cluster. High performance with significant SCA effects were expressed by PR x 14/TLCV-3, KA x 15/TLCV-2, H-86 x 14/TLCV-3, KA x 14/TLCV-3, and H-24 x 14/TLCV-1 for higher fruit yield and its contributing traits. Hence, the present study was a framework for improving high yielding genotypes of tomato with desirable traits.

Raj *et al*. (2017), experimented to find out the general and specific combining abilities of ten lines and two testers of tomato. Among the lines, EC-620410 was found good general combiner for days to 50% flowering and fruit shape index (P/E). The lines, BT-1-1 had maximum GCA for the number of fruits per cluster, average fruit weight, fruit yield per plant, and harvest duration. Again, among the testers, FT-5 was a good general combiner for most of the traits except for average fruit weight, the number of locules per fruit, and plant height. The F_1 hybrid from cross combinations, EC-191535 × Solan Lalima was good in terms of earliness, had better fruit shape and fruit yield per plant. The hybrid combination of BT-1-1 × FT-5 was superior in terms of the number of fruits per cluster and per plant, whereas, hybrid of BT-1-1×SolanLalima was found promising for average fruit weight (E-Metawally *et al.*, 1996) also found such an effect in heat tolerance tomato lines. (Natarajan, 1992) reported that additive gene effects appeared more important than non-additive gene effects.

Reddy *et. al.* (2017), used forty hybrids generated from crossing ten lines with four testers were studied along with parents for combining ability in tomato. The general combining ability (GCA) and specific combining ability (SCA) were significant for all the characters, indicating the importance of both additive and non-additive genetic components. But it is found that non-additive genetic components were predominant for the expression of different traits in the present set of materials. Amongst the lines, CO-3, Pant T-3, and Flawery were the best general combiners for yield along with other traits, whereas among the testers H-24 and H- 86 were the best general combiner for yield along with other traits. The most promising specific combiners for yield and other traits were Flawery × Sel-7, Fla-7171 × Azad T-5, GT-20 × Azad T-5, C0-3 × Sel-7, B-S-31-3 × H-24. Hence, the present study was carried out to obtain information on combining ability involved in expressing the different characters in tomato. The high GCA effect of variety CO-3 was associated with its high SCA effect for primary branches per plant, fruits per plant, average fruit weight, and yield per plant. Too good combining ability of line T-3 was due to high fruits per cluster, fruits per plant, and yield per plant. Among the female parents, H-24 and H-86 were the best general combiners for yield per plant along with high GCA for fruits per plant and average fruit weight. It was followed by the number of fruits per plant 'B-S-31-3', 'SEL-7' and 'Pant T-3', for average fruit weight ' H-24', 'CO-3' and 'Punjab Upama' were good general combiners is desired directions. It was observed that a total of 16 crosses exhibited positive and significant SCA for yield per plant. The promising combinations for yield were, 'Flawery × Sel-7' followed by 'Fla-7171 × Azad T-5' and 'GT-20 × Azad T-5,. It is observed that the majority of the crosses with high SCA for yields were involved with high/low or average/low combining parents. The cross combinations showing high negative SCA for days to earliness were Pant T-3× Sel-7, EC521087 × H-24, 'Flawery × H-86' and 'B-S-31-3' × H-86. For plant height, estimates of SCA are desirable and good specific combiners were B-S-31-3'× Azad T-5, 'Flawery × Sel-7', Fla-7171 × Azad T-5' and Kashi Sharad × H-86. The cross combinations *viz.* GT-20× H-86 and T-Local × H-86 were good specific combiners for primary branches per plant. The cross combinations *viz.* T-Local × H-24, Kashi Sharad× Azad T-5 showed higher SCA for fruits per cluster. For the number of fruits per plant, the cross of Pant T-3× H-24, 'Fla-

7171 × Azad T-5', Punjab Upama'× H-86, and B-S-31-3' × H-24 exhibited high specific combining ability for the fruit. Cross GT-20× Azad T-5 and Fla-7171 × H-86 showed high SCA for average fruit weight.

Aisyah *et al.* (2016), conducted a study with a 6×6 full diallel cross set of tomato including reciprocals to estimate the general combining ability, specific combining ability and heterosis for yield per plant (g) and yield components, namely number of fruits per plant, individual fruit weight (g) fruit length (cm), fruit diameter (cm), locule number, and fruit thickness (cm). Data from the F_1 generation and parents were analyzed using Griffing's Method. Significant differences among genotypes were obtained for all the 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 fruit thickness. The parental genotype IPB 78 was the best general combining ability for yield per plant, individual fruit weight, fruit length, and fruit thickness. The tomato genotype IPB T73 × IPB T3 proved to be the best general combiner for yield and number of fruits per plant.

Panchal et al. (2016) carried out combining ability analysis in a field experiment through the line × tester method using a set of 40 genotypes of tomato including seven females, four males, their 28 F_1 hybrids, and one standard check (Abhinav) for ten characters. Among the female parents, JTI-12-04, JTL-12-10, JTL-12-12 were identified as the best general combiners for fruit yield per plant. It also exhibited significant and desirable GCA effects for primary branches per plant, plant height, single fruit weight, and some of its direct components. JT-3 and AT-3 significant and high positive GCA effects for yield per plant and also other characters like primary branches per plant, number of fruits per plant, first flowering node, and other important characters. Parents JTI-12-14 and GT-1 were proved to be poor general combiners for the majority of the traits under study. GCA effects for such characters have also been reported in tomatoes by (Angadi et al., 2012), (Shende et al.,2012), (Kumari and Sharma, 2012).

Yadav *et al*. (2016), estimated combining ability of thirteen lines of tomato for growth, yield, and quality traits through a line × tester analysis. The estimate of variances of GCA and SCA and their ratio indicated that the preponderance of non-additive gene action for most of the traits. Based on the mean performance and GCA effects, male parents, H-86 and NDT-4 were found as good general combiner for fruit yield per plant and number of fruits per plant, while female parents, ArkaAhuti, ArkaAbha, and Azad T-6 were better for fruit yield per plant.

Baban *et al.* (2015), conducted, eight nearly homozygous, horticulturally superior, and optimally divergent lines of tomato carrying out half diallel design to study general combining ability (GCA) and specific combining ability (SCA) estimates for fruit weight, polar and equatorial diameter. The variances due to both GCA and SCA were significant, suggesting that both additive and non-additive genetic variance were involved for genetic control of the characters, fruit polar and equatorial diameter, and locules number in F_1 and F_2 generations. However, the variance due to GCA was more pronounced for fruit weight, pericarp thickness, and firmness as a result of additive gene action.

Zengin *et al.* (2015) investigated the genetic structure of 30 F_1 hybrid tomato combinations obtained from 15 female lines and two male testers to determine the parents showed superior general combining ability (GCA). GCA was the highest in parental line, BH-135 for yield per plant and days to first flowering and BH-28 for early yield per plant; BH-93 for days to first fruit ripening; G-8 for plant height and plant stem diameter at 60 days after transplantation and fruit weight. They found non-additive genetic variance was predominant in controlling the eight characters. Based on GCA, lines BH-4, BH-28, BH-37, BH-135, BH-53, BH-102, G-8, and Tester 2 were recommended as potential lines for further hybrid breeding studies.

Agarwal *et. al.* (2014), experimented with eight parental lines of diverse origin of tomato which were crossed in an 8 × 8 diallel mating design excluding reciprocals. The 28 F_1 hybrids along with their parents were evaluated in a randomized block design with three replications. In the present study, significant and highest general combining ability effect for fruit yield and average fruit weight was recorded in CLN 5915-206 (49.06 and 8.23 respectively). Genetic components H1, H2 were highly significant for all the traits exhibiting the importance of both additive and dominant gene effects in regulating these traits.

Bhavna *et al.* (2014), experimented on diallel analysis to study the combining ability in tomato for fourteen characters including fruit yield and its component characters and found that both additive and non- additive variances were significant for fruit yield its related components indicating their improvements in the expression of various traits. The magnitude of non-additive variance was higher for fruit yield and its contributing traits indicating the predominant role of non-additive gene action in the inheritance of the traits.

In a study with thirteen parental lines were crossed in line x tester fashion comprising 10 lines and 3 testers by Kumar *et al.* (2013). The analysis of components of genetic variance for yield components showed that the main part of genetic variance was due to the additive effect. Estimation of general combining ability (GCA) for yield and earliness showed that Pant T-3 had the highest GCA for both earliness and average fruit weight. Cross combination CO-3 x Azad T-5 exhibit significant specific combining ability (SCA) for the most desirable traits among all cross combination. An overall appraisal of GCA effects revealed that among parents H 24 emerged out as a good general combiner for plant height, days of 50% flowering, fruits per cluster, and total yield per plant, whereas, DT-2 traced out good general combiner for days of 50% flowering, average fruit weight. Among the parents, Punjab Upma was found to be a good general combiner for plant height, days of 50% flowering, and yield per plant. Pant T-3 for days of 50% flowering and total yield per plant, whereas H-86 for plant height. Significant SCA effects in a favorable direction as observed in many crosses for, plant height, days of 50% flowering, no. of fruits per plant, etc. This result getting support from the findings of (Singh *et al.*, 2010), (Saleem *et al.*, 2009), (Hannan *et al.,* 2007), (Premalakshme *et al*., 2006), (Duhan *et al.,* 2005), and (Dhaliwal *et al.,* 2004).

Farzane *et al*. (2012) conducted a study 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 the traits. The variances for general combining ability (GCA) and specific combining ability (SCA) were highly significant indicating the presence of an 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 as the best general combiner for yield and number of fruits per plant. Bhuiyan (1982) and Natarajan (1992) reported a result of some good general combiners for the number of fruits per plant. Wang *et al.* (1998 a) also reported the important role of additive gene action.

Izge *et al.* (2012), performed combining ability studies for yield and yield components in a set of 6 lines and 2 testers during the 2009 and 2010 dry seasons under irrigation. The results showed that both general combining ability (GCA) and specific combining ability (SCA) were influenced by the environment. Out of the 12 hybrids studied, 4 each was found to be good specific combiners for the number of flower clusters and plant height, and 5 for the number of fruits per plant over both the environment combined. Cherry × Hong Large and Cherry × Roma VF were the best specific combiners for the number of fruits per plant and incidentally having the high number of trichome count.

Souza *et al.* (2012) studied general combining ability (GCA) and specific combining ability (SCA) in a complete diallel cross among fresh market tomato breeding lines excluding reciprocals. Fifteen genotypes (five parents and ten hybrids) were tested using a randomized complete block design. The data for each trait was first subjected to analysis of variance. Griffing's method 2, model 1 was employed to estimate the general (GCA) and specific (SCA) combining abilities. For plant fruit yield, IAC-2 was the best parental line with the highest GCA followed by IAC-4 and IAC-1 lines. The hybrids IAC-1 x IAC-2, IAC-1 x IAC-4 and IAC-2 x IAC-4 showed the highest effects of SCA. From twenty-five varieties of tomato Peter *et al.* (2012) in the same way, reported that component characters locules per fruit and plant height were found to be important for the expression of genetic divergence.

Ahmad *et. al.* (2009), estimated combining ability effects for yield, yield components, and plant height in 8× 8 diallel analysis excluding reciprocals. 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 in the traits studied. The relative magnitude of these variances indicated that additive gene effects were more prominent for all the characters. The tomato genotype P1 proved to be the best general combiner for yield followed by P2. In general, the cross P1 × P3 followed by cross P4 × P6 proved better for yield per plant and also for the number of fruits per plant, individual fruit weight, and days to 50% flowering.

Solieman *et al*. (2009), conducted an experiment using five commercial tomatoes (L*ycopersicon esculentum*, Mill) cultivars and their ten F_1 hybrids, in a diallel cross-system without reciprocals, were used in this study to detect the general performance, relative to general and specific- combining ability. The obtained results reflected also that both additive and non-additive gene effects contributed, with different degrees, to the basic genetic mechanisms involved in the inheritance of all studied characters. However, the best general combiner parental cultivar "Super Marmand" (for the characters plant height, number of branches per plant and total soluble solids), cultivar "Peto-86" (for the characters plant height to the first flower, number of flowers per cluster, number of fruits per plant and fruit shape index), cultivar "Edkawy" (for the characters fruit weight, fruit diameter, fruit length, and fruit locules number), and cultivar "Super Strain-B" (for the character total fruits weight per plant). The results indicated also that the best hybrid combinations were C x M (for the plant height), S x E (for the four characters number of branches per plant, plant height to the first flower, number of fruits per plant, and total fruits weight per plant), C x P (for the characters number of flowers per cluster and fruit shape index), M x E (for fruit weight), S x M (for the fruit length character), P x S(for fruit diameter and number of locules per fruit characters), and the cross P x M (for total soluble solids). Bhuiyan (1982); (Chadha *et al.*, 1997) and Ahmed (2002) also reported some good general combiners for single fruit weight.

Chada *et al.* (1997) reported the lines 'BWR-5(HR)', 'LB79-5(W)' and 'EC 129156' as good combiners for marketable fruits per plant. They also found that four hybrids showed significant positive SCA effects and lines 'BT-1Q', 'BWR-5(HR)' and 'EC 191540' as good general combiners for average fruit weight. Five F_1's showed significant positive SCA effects for average fruit weight. Similarly, Vidyasagar *et al.* (1997) in a line (8) × tester (3) analysis observed the superiority of 3 F_1's to their respective better parents for fruit weight. Again, (Chandrasekar and Rao, 1989), evaluated progenies and parental genotypes reported significant variations of GCA and SCA. SCA effects were significant and 29 positive in 6 crosses for plant height, fruit weight, and yield. 'Pusa Early Dwarf' was the best general combiner.

2.3 Heterosis

Nowadays, applications and effects of heterosis in early fruit development and enhancement of yield potential have been identified as breeding targets in tomato breeding programs (Hannan *et al.*, 2007). The reproductive biology and production of an appreciable quantity of seeds per fruit provide plentiful opportunity for manifestation of heterosis in tomato (Singh and Singh, 1993). The improvement in different quantitative and qualitative traits in tomato through heterosis breeding was observed by (Tiwari and Lal, 2004), who reported significant heterosis ranging from 23.8% to 71.71% for total yield. The exploitation of heterosis is a quick and convenient way of combining desirable characters and hence, assumed greater significance in the production of hybrids. Estimates of heterosis may help in deciding whether the hybrids are of economic value and worth exploiting.

Dhilon *et al.* (2019), conducted an experiment to assess the yield and quality attributes of tomato hybrids under a protected environment. The experiment was consisting of ten hybrids of tomato and one standard check variety. Here, 12-1 × Palam Pride and 12-1 × BT-20-3 (Yellow Egg Shape) are good performing hybrids for yield-related characters taken under study.12-1 × Palam Pride had maximum fruit yield per plant, the number of fruits per plant, plant height, and minimum days took to 50% flowering and first picking followed by 12-1 × BT-20-3 (Yellow Egg Shape). Singh and Singh (1993), (Kumar *et al.,* 1995a), (E-Metwally *et al.*, 1996), (Vedyasagar *et al.*, 1997), and (Ahmad *et al.*, 2011) also reported negative heterosis for days to 50% flowering.

Gautam *et al.* (2018), studied that 6×6 diallel cross excluding reciprocal in tomato to evaluate heterotic manifestation of yield and yield attributing characters. The heterosis over better parent (BP) to the extent of -14.64, -7.70, 15.84, 21.29, 15.30, and 38.91 percent was recorded for days to first flowering, average fruit weight, number of fruit per plant, harvesting duration, yield per hectare, and plant height, respectively. The heterosis for yield was generally accompanied by heterosis for yield components. Agarwal *et. al*. (2014), studied the highest significant heterosis over better and standard parent was recorded for average fruit weight (74.69 and 117.27). The range of heterosis for fruit yield over better parent was 6.63- 35.90% and a cross between CLN 5915-206 × CLN 1314G recorded the maximum heterosis over both better (35.90) and standard parent (56.32%) for the trait.

Sharma *et al.* (2018) carried out 6×6 diallel crosses of tomato excluding reciprocals and evaluated along with their six parents. The observations were recorded on days to 50% flowering (days), days to marketable maturity (days), number of flowers per cluster, number of fruits per cluster, fruit length (cm), fruit diameter (cm), average fruit weight (g), number of fruits per plant and yield per plant (kg). The experimental outcome revealed that based on heterosis (better parent) F_1 TOINDVAR-1 × TOINDVAR-5 was found the best test hybrids best for earliness and hybrid TOINDVAR-2 × TOINDVAR-4 for yield per plant.

Kumar *et al.* (2017), studied heterosis for yield components and yield per plant using 8× 8 half diallel cross in tomato (*Solanum lycopersicum* L.) The heterosis for yield was generally accompanied by heterosis for yield components. Heterosis for yield per plant ranged from 25.57% (P7 ×P8) - to 43.81% (P6 × P8) over better parent and heterosis over standard variety NDTP-4 (SV-1) varied from -52.19% (P1 × P6) to 60.80% (P4 × P7) and heterosis over standard variety NDTP-7 (SV-2) varied from -59.23% (P1 × P6) to 37.13% (P4 × P7), respectively. Significant heterosis over better and standard varieties was observed for all the traits. Five crosses P4 × P7, P5 × P7, P1 × P7, P2 × P7, P3× P7 showed standard heterosis for fruit yield per plant, also found significant over better parents with the different magnitude. Out of the top three heterotic F_1 with the attractive fruit shape crosses P4 × P7, and P1× P7 and P5 × P7 which also found maximum fruit weight and the high number of fruits per plant, and also identified for developing high-yielding F_1 hybrids of tomato. The heterosis for fruit per plant was also reported by several workers like Vidyasagar *et al.* (1997), Bhatt *et al.* (1999), and Sekar (2001).

Ahmad *et al.* (2015), conducted the present study to evaluate the performance of different cross combinations of tomatoes for better parent heterosis regarding yield and yield-related traits. Significant better-parent heterosis was observed in some cross-combinations for the parameters *viz.* no of fruits per cluster, no of fruits per plant, and yield per plant. While, no significant positive heterosis was observed for the parameters like fruit-length, fruit diameter, fruit size, and fruit weight. For fruit length and fruit diameter, all the combinations showed the negative value of heterosis. Significant positive heterosis for yield per plant is a great achievement in the study as yield per plant is the ultimate goal of tomato growers.

Hybrids had a significantly higher number of fruits cluster and number of fruits per cluster over both mid and better parental values, while for the other traits, hybrids expressed average heterosis in both the orders determined by Pemba *et al*. (2014). The maximum degree of heterobeltiosis for the number of fruits per cluster (32.59%) and fruit yield per plant (31.77%). Heterosis for yield and other traits, maximum significant heterosis in favorable direction was observed for yield, fruit number, plant height and fruits per cluster work out by Kumari *et al.* (2011). Gul *et al.* (2010) studied tomato for the degree of heterosis in yield and its five yield attributing components, *viz., the* number of fruits set per cluster, fruit length, fruit width, fruit weight, and fruit yield per plant.

Sharma *et al.* (2014), experimented with thirty crosses that were evolved in a line x tester mating design with 10 genotypes as female parents (lines) and 3 genotypes as male parents (testers). The hybrids, PT-11 x PT-3 and PT-20 x Punjab Chhuhara were most promising for earliness exhibiting the highest negative heterosis. Concerning plant height, hybrids, PT-09-06 x PT-3 and PT-20 x Roma were most promising for tallness and dwarfness, respectively. Hybrid combination, PT-09-06 x PT-3 exhibited the most promising results for heterosis for fruit yield per plant and total fruit yield per hectare. The best hybrids for heterosis were PT-2009-02 x PT-3 for average fruit weight, PT-09-06 x Punjab Chhuhara for the number of fruits per plant. Singh *et al* (1996), Bhatt *et al.* (1999), and Bhatt (2001 a) also reported heterobeltiosis for yield trait.

Kumar *et al.* (2013), used six diverse parental lines of tomato were crossed in a 6×6 diallel mating design excluding reciprocals. The 15 F_1 hybrids and two standard checks (HYB- Roop-666 and TS-15) along with their parents. The top three cross combinations for fruit yield per plant as per their performance, ArkaAbha× Punjab Chhuhara, ArkaMeghali × Punjab Chhuhara, Punjab Chhuhara ×Best of all came out to be expressing significantly positive standard heterosis. Most of the crosses manifested highly significant heterosis over both check varieties, for fruit length and fruit breadth that reflect that hybrids have a better chance of having bigger fruits in case of tomato. For average fruit weight, ArkaAbha× Punjab Chhuhara, ArkaMeghali × Punjab Chhuhara to be the best hybrids which have expressed significant positive results for all types of heterosis including over checks. Overall, hybrids have reported greater plant heights as compared to check and mid parents which indicates that heterosis can be exploited for further improving the plant heights. ArkaMeghali ×

Punjab Chhuhara was found to be the best cross combination which has significant heterosis, of all three types, for vital yield attributing traits i.e. number of fruits per cluster and number of fruit clusters per plant.

Patwary *et al*. (2013), conducted at an experiment at BARI, Gazipur to study heterosis using eight parents. Most of the combinations showed better parent heterosis for earliness. The highest heterotic effect for fruit set (%) was found in the cross P6 × P7 (62.59%) followed by that in P7 × P8 (60.49%) and P1 × P7 (40.00%). For fruits per plant, 8 crosses provided more than 15 % heterosis over the better parent. Considering fruit yield per plant, the higher degree of heterosis was manifested by 24 hybrids over better parent ranging from 13.58 to 282.63%. Cross combination P4×P7 showed the maximum significant positive heterosis followed by P6 × P7 (187.84 %), P4 × P8 (166.97 %), P3 × P7 (146.08 %), P3 ×P6 (103.92 %), and P1 × P7 (100.45 %) and the minimum in P4 × P6 (13.58 %).

Chattopadhay *et al.* (2012) a total of 25 entries consisting of 13 diversified genotypes of tomato along with their 12 F_1 hybrids were evaluated during two consecutive rabi seasons which showed that pronounced heterosis over better-parent was observed for the number of locules per fruit, fruit length, etc. Heterosis over mid parent and better parent, however, for most of the characters were in the negative direction. Some of the parents having good potentiality for generating high cross combination for most of the quality traits under study were identified. Singh *et al.* (2012) in a complete 7×7 half diallel cross of tomato evaluate with parents for the heterotic manifestation of yield and yield attributing characters. The crosses showing heterosis for yield per plant were not heterotic for all the characters under study. Five promising crosses *viz.,* Ox-heart× Sutton Roma, Marglobe Supreme× Sutton Roma, Moneymaker ×Pusa Early Dwarf, Marglobe Supreme× Moneymaker, and Sutton Roma ×Pusa Early Dwarf were identified for developing high yielding F_1 hybrids/varieties f tomato with many desirable traits.

An investigation was carried out at the Research Farm of Olericulture Division of Horticulture Research Centre of Bangladesh Agricultural Research Institute (BARI) to evaluate the heterotic performance in F_1 hybrids of tomato by Islam *et al*. (2012). The hybrids showed significant variation in heterosis. The highest heterobeltiotic effects were observed in the cross P3 × P8 (-18.46%) for earliness, P1 × P6 (8.57 %) for flowers per cluster, P2 × P6 (21.73%) for fruits per cluster, P6 × P7 (75.54%) for plant height, P5 × P6 (67.44%) for fruits per plant, P9 × P10 (54.82 %) for yield per plant, P2 × P8 (21.21 %) for individual fruit weight, P7× P8 (3.09 %) for fruit length and P3 × P8 (14.11 %) for fruit diameter. Considering all the characters the crosses P1 × P8, P2 × P6, P2 × P7, P2 × P8, P3 × P8, and P5 × P6 were found suitable for further studies to variety selection. Bhatt *et al.* (1999) also found appreciable heterosis for fruits per cluster in tomatoes. Heterosis for fruit diameter was also reported by Chaudhury and Khanna (1972), Susie (1998), and Wang *et al*. (1998 b).

Kumar *et al*. (2012) studied heterosis on 15 hybrids and 8 parental lines in a randomized block design with three replications during winter 2010-11 at Vegetable Research Farm, Banaras Hindu University, Varanasi, India. Heterosis was estimated in fifteen single experimental cross hybrids, obtained by five parental lines namely H-24, DT-2, CO-3, Punjab Upma, Pant T-3, and three testers of tomato *viz.* Floradade, Kashi Sharad, Azad T-5 for yield and yield-related traits; plant height, days to 50% flowering, number of fruits per plant, average fruit weight, fruit diameter, number of fruits per cluster, and total yield per plant. Significant differences among genotypes were observed for all the traits positive and highly significant heterosis was found for the number of fruits per plant 25.27%, 25.13%, and 21.13% over better parent and 29.95%, 25.27%, and 24.46% over standard parent and total yield per plant 32.06%, 18.34%, 13.36% and 11.27% over better parent and 31.83%, 31.14%,30.10% and 25.26% over standard check 'Azad T-5'. The hybrid also showed a significantly high percentage of positive heterosis over better and standard parent for the number of fruits per cluster, average fruit weight and the hybrids showed negative heterosis for plant height and day to 50% flowering which are desirable characters. Heterosis over better parent and negative heterosis for days to flowering over the better parent in many of the hybrids vigor in their diallel progenies reported by Singh (1993) and Ahmed *et al.* (1988). Heterosis for plant height was also studied by Dod *et al*. (1992) from the diallel cross.

Souza *et al.* (2012) studied heterosis in a complete diallel cross among fresh market tomato breeding lines excluding reciprocals in terms of fruit yield per plant, fruit number per plant, average fruit weight, no. of cluster per plant, fruit number per cluster, and some quality components. High heterotic responses were found for fruit yield and plant fruit number with values up to 49.72% and 47.19%, respectively. The best hybrids for fruit yield and plant fruit number were IAC-1 × IAC-2, IAC-1 × IAC-4, and IAC-2 × IAC-5, for fruit yield and plant fruit number which are the main yield components.

Ahmad *et al.* (2011) conducted a study to estimate heterosis of 21 tomato cross combinations involving seven parents at the experimental field of Olericulture Division of HRC, BARI. Analysis of variance indicated highly significant differences for all the characters suggesting the presence of genetic variability among the studied materials. Three combinations (P2 × P3, P3 × P4, P3 × P5) showed significant early flowering, while two P1 ×P7 (16.67%) and P1 × P2 (12.44%) for individual fruit weight. In the study, the cross combinations P4 × P7 (62.31%), P2 × P6 (37.44%), P4 × P6 (34.77%), P2 × P7 (33.67%), P3 × P7 (32.09%), and P3 × P4 (29.82%) manifested higher heterosis over better parent for yield per plant.

Ramana *et al.* (2018) estimated heterosis in tomato (*Solanum lycopersicum* L) for yield attributing traits and yield. Ten parents were crossed in diallel mating design (without reciprocals). The resultant 45 F_1's were evaluated along with their parents and two standard check variety (Siri and US-618) for six characters *viz.,* plant height (cm), number of primary branches per plant, days to 50% flowering, number of fruits per cluster, average fruit weight (g) and fruit yield per plant (kg). Calculation of heterosis revealed that the majority of the hybrids exhibited relative heterosis, heterobeltiosis, and standard heterosis in the desirable direction. The potential crosses *viz.,* LE-64 × LE-66, LE-56 × LE-68, EC-157568 × LE-68, and EC-164838 × LE-66, exhibited high standard heterosis and high performance for fruit yield per plant, which offers scope for commercial exploitation through heterosis breeding. Chadha *et al.* (1997), also selected some hybrids for individual fruit weight.

MATERIALS AND METHODS

CHAPTER III
MATERIALS AND METHODS

The field and lab experiments were carried out in the research field and laboratory of the Dept. of Genetics and Plant Breeding of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207, during the Rabi season of 2018-19 to study the combining ability and heterosis in tomato. Before this, the F_1 hybrid lines were developed during the Rabi season of 2017-18 through 5×5 half diallel cross. The details of material and methods and the experimental procedure including the location of experimental site, planting materials, climate and soil, preparation of soil pots for seedlings raising, experimental design and layout, plot preparation, transplanting of seedlings, fertilizing, intercultural operations, harvesting, data recording procedure, nutritional and statistical analyzing procedure implemented during research are described below.

3.1 Experimental site

The study was carried out at the research farm and laboratory of the Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from mid-October 2018 to March 2019. The diallel crossing pattern among the five (5) selected parents of tomato varieties had performed during the rabi season of 2017-18. The location is situated at the sub-tropical climate and AEZ No. 28 called "Madhupur Tract". It is located at 23°4’ N latitude and 90°22’ E longitude with an elevation of 8.6 meters from the sea level (Appendix-I). It is categorized by high temperature supplemented by moderate high rainfall during Kharif season (April to September) and low temperature in the Rabi season (October to March).

3.2 Climate and soil

The geographical situation of the experimental site was under the subtropical climate, characterized by three distinct seasons, the post-monsoon period or winter season from November to February, the pre-monsoon period or hot season from March to April, and the monsoon period or rainy season from May to October (Edris *et al.,* 1979) and also categorized by heavy precipitation during May to August and scanty precipitation during the period from October to March. The record of air, temperature, humidity, and rainfall during the period of the experiment was recorded from the Bangladesh Metrological Department, Agargaon, Dhaka (Appendix III-IV). The experimental site was located in the subtropical zone. The soil is categorized under the Agroecological region of Madhupur Tract (AEZ no. 28). The soil was loamy in texture. The experimental site was medium high land and the pH was 5.6 to 5.8 and organic carbon content was 0.82%. The physical and chemical characteristics of the soil have been presented in (Appendix-II).

3.3 Experimental materials

The experimental materials consisted of five (5) varieties of tomato (BARI tomato -8, BARI tomato -15, BARI tomato -14, BARI tomato -11, and BARI tomato -3) which were crossed in a diallel fashion excluding the reciprocals, shown in (Table 1a). The resulting ten (10) F1 hybrid lines evaluated along with their five (5) parents and one (1) check variety (BARI Hybrid tomato -4) are presented in (Table 1 b).

Table 1. List of name and source of experimental materials of tomato used in the experiment

Table 1(a). List of five parental lines used in 5×5 diallel cross experiment

Sl. no.	Name of tomato varieties	Origin
1	BARI tomato-8	BARI, Gazipur
2	BARI tomato-15	BARI, Gazipur
3	BARI tomato-14	BARI, Gazipur
4	BARI tomato-11	BARI, Gazipur
5	BARI tomato-3	BARI, Gazipur

Table 1(b). List of ten F_1 hybrid lines developed from 5×5 diallel cross with one check variety

Sl. no.	Cross combinations of F_1 hybrid lines of tomato
1	P1×P2
2	P1×P3
3	P1×P4
4	P1×P5
5	P2×P3
6	P2×P4
7	P2×P5
8	P3×P4
9	P3×P5
10	P4×P5
11	Check variety (BARI hybrid tomato-4)

3.4 Soil pots preparation and raising of the tomato seedlings

The experiments were conducted during the Rabi seasons of 2017-18 and 2018-19. In the 1st season (Rabi 2017-18) the five selected tomato varieties were crossed in half diallel fashion to develop ten (10) F_1 lines and in the 2nd season (Rabi 2018-19) the developed ten (10) F_1 hybrid liens were evaluated along with five parents and one check hybrid variety. Seeds were sown on 10th November 2017 in the 1st season and 25th October 2018 for the 2nd season in the soil pots for each variety separately. Before the showing, seeds were treated with Austin 50 WDG for five minutes. Seedlings of all tomato genotypes (parents) and F_1 hybrids were raised in the soil pots at the roof of the Dept. of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka-1207. Seedlings were raised following the regular nursery practices. Recommended cultural practices were taken up before and after sowing the seeds including watered regularly. When the seedlings become 25 days old, those were transplanted in the main field with proper labeling. The pots preparation and raising of the good seedlings are shown in plate 1(A).

3.5 Design and layout of the experiment

The experiment on the evaluation of combing ability and heterosis of the developed F_1 hybrid lines was carried out in the main field through a Randomized Complete Block Design (RCBD) with three replications. The total experimental area was 210 m^2 and each replication area was 70 m^2. The plant spacing between rows was 60 cm and between plants of the same row was 40 cm. The whole plot was surrounded by two major tunnels and each replication having 1.0 meter wide beds with a 30 cm drain in between rows, which serves as an irrigation channel. The tunnels were used to protect the plants from high rainfall. The date of transplanting of the F_1 hybrid lines was 20th November 2018. The experimental land design and layout is shown in plate 1(B).

3.6 Land preparation

The field experimental plots were ploughed after the first week of November, with a power tiller, applied the recommended dose of fertilizers with cow dung and farmyard manure (FYM). The land was equipped by several ploughing and cross ploughing followed by laddering and harrowing with power tiller to bring about good tilth. This was done to manage weeds, ensured good soil aeration, and obtain good seedling emergence and root penetration. Weeds and other stubbles were eliminated carefully from the experimental plot and leveled properly. Slight watering was done frequently to keep the soil moist till transplanting. The final land preparation was done on 15th November 2018. Special care was taken to remove the rhizomes of mutha grass. Pits were prepared for transplanting the seedling. Some pictorial views of the experimental tomato field are shown in plate 3.

3.7 Manure and fertilizers application

Total cow dung and the entire amount of Triple Super Phosphate (TSP) were applied in the field during final land preparation. Half Urea and half Muriate of Potash (MOP) were applied in the plot after three weeks of transplanting. The remaining Urea and Muriate of Potash (MOP) were applied at the 5th week of transplanting. Doses of manure and fertilizers used in the study are presented in Table 2.

Table 2. Doses of manures and fertilizers used in the study

Sl. No.	Fertilizers/ Manures	Dose	
		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

3.8 Transplanting of tomato seedlings in the main field

The seedlings were raised in the seedbed and 25 days old seedlings were transplanted in the main field on 20th November 2018. The transplanted seedlings were watered regularly to make a firm relation with roots and soil to stand along. Transplanting of seedlings and watering in the field are presented in plate 1(C).

3.9 Intercultural operations

When the seedlings were well established, first weeding was done uniformly in all the plots. The second wedding was done after 20 days of the first one. Mechanical support was provided to the growing plants by jute sticks as well as bamboo sticks to keep them erect in such a way that necessary data could be taken from an individual plant without much difficulty. Stem Pruning was done by removing some of the lateral branches by pruning shear during the early stage of growth to allow the plants to get more sunlight and to reduce the self-shading and incidence of increased insect infestation. The field was weeded and mulched when necessary. Insecticide such as Diazinon was sprayed to prevent the damage of the plants by the fruit borer and whitefly, the vector of TYLCV. Thinning and gap filling, staking, irrigation, and after-care were also done as per requirement which is shown in Plate 1(D, E, and F).

Plate 1. Seedlings transplanting and intercultural operations A. Soil pots preparation and raising of the seedlings **B.** Design and layout of the main tomato field **C**. Tomato seedlings transplanting in the main field **D.** Irrigation in the tomato field after fertilization **E.** Removing of the lateral branches through stem pruning **F.** Staking and roping of the tomato plants

3.10 Emasculation and hybridization to developed the F_1 hybrids line

For developing the F_1 hybrid lines of tomatoes, hybridizations among the five parents through 5×5 half diallel cross were performed in the middle of January 2018. For preparing the female (five) parents, the day before hybridization, the selected bisexual flowers were emasculated at the evening time and then bagged with paper for the prevention of undesirable pollination. Emasculation was done with flourishing flowers which were almost yellowish colored but remained closed, using small tweezers. Calyx and petals were removed very carefully so that only stigmas of the female flowers remained bare.

For preparing the pollen grains, the anthers, which were collected from the selected tomato parental lines, were kept in an incubator at 30°C for 14-16 hours for facilitating of releasing the pollen grains from the collected anthers. In the next early morning (9-10 am) the pollen grains from each parental line were collected in a casket cap bottle. These pollens were then dusted onto the stigma of emasculated female flowers.

Each genotype was once counted as a female parent or male parent, thus, half diallel crosses were performed. To ensure 100% success in cross-product same crossing combination was done several times in several flowers. In a single cluster, almost all the flowers were hybridized which was at the pollen receptive stage of the same genotype. After crossing, the flowers were bagged again with papers, and proper labeling was done. Different colored threads and scotch tapes were used carefully for labeling the parental lines. Some emasculated flowers and hybridized fruits are shown in plate 2.

3.11 Harvesting and processing

Different lines of tomato were matured at different times because of its indeterminate type flowering. So harvesting of tomatoes was continued for about one and half months because fruits of different lines matured progressively at different dates. The fruits per entry were allowed to ripe properly. After collection, some fruits were used for nutritional analysis, and then seeds were collected from some fruits and stored at 4^{o}C for future use. The harvesting of the tomatoes was started from 26th January 2019 to mid of March 2019. The harvesting procedure is shown in plate 4.

Plate 2. Emasculation and hybridization procedure of tomato A. Emasculation of female flowers **B.** Successful crossings **C**. Fruits setting in the crossed flowers

Plate 3. Some pictorial views of the experimental tomato field A. Photograph showing the field view of diallel crossing experiment during rabi season of 2017-18 **B.** Photograph showing the field view of the evaluation of F_1 hybrids during rabi season of 2018-19. **C.** Photograph showing the visiting of the experiment by supervisor and guest (a professor from japan)

Plate 4. Harvesting procedure A. Harvesting of tomato hybrids **B.** Harvested fruits

3.12 Observation and collection of data

Five plants from each entry of each replication were randomly selected. Data including yield and yield contributing and nutritional traits on the following parameters were recorded.

3.12.1 Agronomic traits

Data for some phenotypic parameters related to yield and yield contributing traits were recorded during the experiment. These traits are as follows.

3.12.1.1 Days to 50% flowering

The number of days required from seedling transplanting to flowering in 50% of the plants of each replication.

3.12 .1.2 Plant heights (cm)

The average length of the main stem from the ground level to the tip leaf, measured in centimeters at the reproductive stage of the 5 selected plants from each genotype.

3.12.1.3 Number of secondary branches

The average value of the number of secondary branches was measured by counting the whole secondary branches from 5 selected plants of each genotype.

3.12.1.4 Number of fruits per cluster

The average value of the total number of fruits in the fruit-bearing 5 clusters which randomly selected and then counted as fruits per cluster.

3.12.1.5 Number of fruits per plant

The average value of the number of mature fruits harvested from the 5 selected plants from each genotype from each plot.

3.12.1.6 Single fruit weight (g)

Individual fruit weight in grams was calculated as mean value based on the ten representative fruits by electric precision balance.

3.12.1.7 Fruit diameter (mm)

Fruit breadth was measured along the equatorial part of the same ten representative fruits from each genotype of 3 plants and their average value was calculated in mm for fruit breadth by digital slide calipers.

3.12.1.8 Fruit length (mm)

Fruit length was measured with a digital slide caliper from the neck of the fruit to the bottom of the same fruit from ten representative fruits from each genotype of 3 plants and their average value was calculated in mm as the length of the fruit.

3.12.1.9 Days to first harvesting

The number of days required to mature from transplanting date to first picking date of fruits from each replication.

3.12.1.10 Fruit yield per plant (kg)

The total weight of fruits (kg) of selected 5 plants from each genotype was recorded and yield per plant was calculated from the average value.

3.12.1.11 Shelf life (days)

Picking of enough ripens fruits that were eatable and suitable for market value and after that were kept at room temperature. Then the average number of days was counted till the fruits were rotten.

3.12.1.12 Pericarp thickness (mm)

Reliable ripen fruits were taken and sliced out for taking skin thickness with a digital slide caliper and the average value was taken from some representative fruits.

3.12.1.13 Number of locules per fruit

The total number of locules present in fruit was counted by cutting five mature fruits and their average was taken as locules per fruit.

3.12.2 Nutritional traits

Different parameters of tomato named Brix (%), Vitamin-C content (mg/100g), Titrable acidity percentage (%) were recorded. Different steps of data recording are presented in the following plate 5.

Plate 5. Data collection for nutritional traits A. Brix determination machine (Portable Refractometer) and Estimation of Brix (%) content of tomato lines in the laboratory **B.** Juice preparation for vitamin-C content analysis & Vitamin- C determination after titration **C.** Juice of tomato for titrable acidity (%) determination

3.12.2.1 Determination of Brix (%)

Total soluble solid content or Brix percentages were measured by Portable Refractometer (ERMA, Tokyo, Japan) at room temperature. Single fruit was blended from each genotype and juice was collected to measure Brix percentage. Determination of Brix percentage is shown in plate 5(A).

3.12.2.2 Determination of Vitamin-C content (mg/100g fruit)

Vitamin-C was measured by Oxidation Reduction Titration Method (Tee *et al*., 1988). Determination of vitamin C is shown in plate 5(B).

3.12.2.2.1 Dye preparation

260 mg 2, 6-dichloro indophenols with 210 mg sodium bicarbonate were mixed with one liter of distilled water. It was used in a burette.

3.12.2.2.2 5% oxalic acid preparation

50 mg oxalic acid was mixed with one liter of distilled water and it was used for washing the fruit and for the preparation of fruit juice preparation.

3.12.2.2.3 L-ascorbic acid preparation

10 mg of granular L-ascorbic acid was mixed with 100 ml oxalic acid solution. Then, 5 ml solution was taken in another volumetric flask, and volume was made up to 100 ml. From this solution, 5 ml was taken for titration against 2,6-dichloro indophenol from burette for 3 times, and their mean was recorded as the required amount of dye for titrating L-ascorbic acid.

3.12.2.2.4 Preparation of tomato solution

Single fruit was weighted and was blended with few drops of oxalic acid solution. It was filtered through Whatman filter paper and the juice was collected. Volume was made up to 100 ml with the oxalic acid solution. 5 ml was taken from that solution and titrated against dye solution which was kept in the burette. The required amount of dye was recorded for titrating tomato solution.

The amount of vitamin C was determined by the following formula;

$$\text{Vit-C} = \frac{(0.5 \times dye\ required\ for\ tomto\ juice \times 100 \times 100}{\text{dye required for L}-\text{ascorbic acid} \times 5 \times \text{weight of fruit)}}$$

3.12.2.3 Determination of titrable acidity (%):

Four (4) gm of NaOH pellet was mixed into 1000 ml distilled water and 0.1 N NaOH solution was prepared. It was poured in a burette. After weighing, a single fruit was pressed and blended and fruit juice was collected by passing it through Whatman filter paper. The volume was made up to 100ml with distilled water. From that, 10 ml solution was separated and 2 drops of phenolphthalein were added to it. It was titrated against the former prepared 0.1N NaOH and the amount of NaOH required was noted. Determination of titrable acidity (%) is shown in plate 5 (C). Finally, titrable acidity was determined using the following formula;

$$\text{Acidity \%} = \frac{(titrate \times Normality\ of\ alkali \times Volume\ made\ up \times Equivalent\ wt.of\ acid \times 100)}{(Volume\ of\ sample \times weight\ of\ sample \times 100)}$$

3.13 Statistical analysis

All the collected data were statistically analyzed using Statistix 10 (trial version) and OPSTAT computer package program. The mean value for each trait was calculated and analysis of variance was performed by F-test (variance ratio). The difference between treatments was assessed by the least significant difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

3.13.1 Analysis of variance (ANOVA)

The collected data for various characters were statistically analyzed using Statistix10 (trial version) program to find out the variation among the different genotypes by F-test as it was a single factor experiment. The variances of each character were partitioned into replication, genotype, and error differences. Treatment means were compared by Duncan's Multiple Range Test (DMRT) and coefficient of variation (CV %) were also estimated as suggested by Gomez and Gomez (1984). As the purpose of the experiment was to evaluate the performance of the hybrids and their parents, data were recorded for all the (16) genotypes.

3.13.2 Combining Ability Analysis

Combining ability analysis of the traits with significant genotypic differences was done according to model 1 (fixed genotypic effects) and method 2 (half diallel) of Griffing (1956a,b). The fixed-effect model was more appropriate in the present case since the parent selected was self-pollinated lines and the parents and F_1's were considered as population. This analysis portioned the variation due to genotypic differences in general combining ability (GCA) and specific combining ability (SCA) effects.

Grilling's analysis indicates the performance of the parents and their relative contribution to the F_1's expressed as general and specific combining abilities. In Griffing's approach, GCA represents additive variance, while SCA represents non-additive effects.

The mathematical model used in this analysis was as follows:

$_lY_{ij} = m + g_i + g_j + S_{ij} + l/bc\sum_k\sum_l e_{ij}kl$

Where,

ij = 1, 2,………………., p

k = 1,2, ..., b

l =1,2, ... c

p =Number of parents

b = Number of blocks or replications

c = Number of observations in each plant

Y_{ij} = the mean of y_{ij}^{th} genotype over k and l

m = population mean

g_i = The general combining ability (GCA) effect of the i^{th} parent

g_j = The GCA effect of j^{th} parent

$e_{ij}kl$ = environmental effects particular to the $ijkl^{th}$ individual observation

S_{ij} =The SCA effect such that $S_{ij} = S_{ji}$

l/bc ∑∑ kl eijkl =The mean error effect

The restrictions imposed are :

$\sum g_i = 0$ and $\sum S_{ij}+S_{ji} = 0$ (for each i)

The significant differences within each of the component effects were tested by F- test. Diallel tables were prepared by computing the averages over the 3 replications of all the parents and F_1's in the appropriate cells. The row sums, column sums, the sums of the squares of GCA, SCA were all computed from this table. The GCA of any parent is estimated as the difference between its array mean and the overall mean. The analysis of variance of combining ability and expectation of mean squares using Griffing's (1956) method II model I.

Table 3. Analysis of variance for the diallel cross as combining ability according to Griffing's (1956) method II model I (Parents, one set of F_1's)

Item	d.f	MSS(Mean squares)	Sum of squares
gca	n-1	Mg	$\frac{1}{n+2}\sum_i(\text{Yi.}+\text{Yii})2 - \frac{4}{n}\ Y^2.....$
sca	n(n-1)/2	Ms	$\sum_i \sum_j Y_{ij}^2 - \frac{1}{n+2}\sum (Y_i + Y_{ij})^2 + \frac{2}{(n+1)(n+2)} Y^2......$
Error	(r-1) (t-1)	Me	SSE

Where,

gca = general combining ability

sca = specific combining ability

n = number of parents

r = number of blocks or replications

t = number of treatments

$Y_{i.}$ = Array total of the i^{th} parent

Y_{ii}= Mean value of i^{th} parent

Y.. = Grand total of the ½ [n(n-l)] crosses and parental lines

Y_{ij} = Progeny mean values in the diallel table

SSE = Sum of square due to error (obtained from preliminary ANOVA after dividing by the number of replications)

$$\text{Mg} = \frac{1}{(n+2)}\left[\sum i(\text{Yi} + \text{Yii}) - \frac{4}{n}\ \right]\text{Y}^2\text{..}$$

$$\text{Ms} = \sum_i \sum_j \text{Y}_{ij}^2 \frac{1}{(n+2)} \sum(\text{Y}_i+\text{Y}_{ij})^2 + \frac{2}{(n+1)(n+2)}\text{Y}^2\text{..}$$

The gca and sca effects of each character were calculated as follows:

$$g_i = \frac{1}{(n+2)}\left[\sum(Y_{i+}\text{Y}_{ij})^2 - \frac{2}{n}\text{Y..}\right]$$

$$S_{ij} = \text{Y}_{ij} - \frac{1}{(n+2)}\sum(y_{i.}+y_{ii}+y_{.j}+y_{ji}) + \frac{2}{(n+1)(n+2)}\text{y..}$$

The standard error (S.E.) was calculated as the square root of the variance of concerned estimate eg.

$$\text{Var}\ (g_i) = \frac{(n-1)}{n\ (n+2)}\sigma_e^2$$

$$\text{Var}\ (S_{ij}) = \frac{n(n-1)}{(n+1)(n+2)}\sigma_e^2 (i \neq j)$$

3.13.3 Estimation of heterosis:

For estimation of heterosis in each trait, the mean values of the 10 F_1's have been compared with better parent (BP) for heterobeltosis and with check variety for standard heterosis.

Percent heterosis was calculated as

$$\text{Heterosis over better parent (\%)} = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$$

Here,

$\overline{F1}$ = Mean of F_1 hybrid

$\overline{BP}$ = Mean of the Better parent

$$\text{Standard heterosis (\%)} = \frac{\overline{F1} - \overline{CV}}{\overline{CV}} \times 100$$

Where, $\overline{F1}$ and $\overline{CV}$ represented the mean performance of hybrid and standard check variety.

The significance test for heterosis was done using the standard error of the value of check variety

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to perform the half diallel analysis of different genotypes of tomato (*Solanum lycopersicum* L.) using agronomic traits. Besides, some nutritional traits are also evaluated of those genotypes. This chapter comprises the presentation and discussion of the findings obtained from the experiment. The data about ten traits have been presented and statistically analyzed with the possible interpretations. On the other hand, nutritional traits showing results through mean performance.

The corresponding analysis of variance (ANOVA) is presented in (Table 4a) and (Table 4b). Highly significant ($p<0.001$) differences were observed among the genotypes studied here (Table 4a) for all the agronomic traits under study *viz.* days of 50% flowering, plant height, number of secondary branches, number of fruits per cluster, number of fruits per plant, single fruit weight, fruit diameter, fruit length, days of first harvesting, yield per plant, shelf life, pericarp thickness, and the number of locules per fruit. Again, highly significant ($p<0.001$) differences due to genotypes were also observed (Table 4b) for nutritional traits *viz.* Brix %. vitamin- C, and titrable acidity %.

4.1 Mean Performance Analysis

The mean values of tomato yield and yield-related traits of parental genotypes and their F_1 progenies are presented in (Table 5).

4.1.1 Agronomic traits

4.1.1.1 Days to 50% flowering

Mean values showed that days of 50% flowering came early in the parental genotype P5 (27.67) followed by P3 (27.00). Among the F_1 hybrids, the cross combinations P2×P4 (20.00) and P1×P4 (21.67) showed earliness in flowering, and on the contrary, the F_1 lines P3×P4 (28.00) and P3×P5 (27.00) showed the latest 50% of flowering habit. While 25.67 mean performances were exhibited by check variety (Table 5). A pictorial view of the flowering stage is shown in Plate 6.

Table 4. Analysis of variances (ANOVA)

Table 4(a). Analysis of variances (MS values) of agronomic traits of 10 F_1 hybrid lines derived from 5×5 diallel cross in tomato

Source	d.f	D50% F	PH	NSB P	NFC	NFP	SFW	FD	FL	DFH	YPP	SL	PT	NLF
Replication	2	2.69	2.83	0.010	0.13	2.34	2.28	11.89	7.35	1.58	0.001	14.65	0.07	1.90
Genotype	15	19.42**	381.83**	8.06**	10.86**	8968.69**	3181.72**	589.35**	355.24**	202.92**	1.02**	137.71**	4.53**	3.51**
Error	30	1.29	4.75	0.02	0.14	12.62	10.53	8.40	4.08	6.58	0.02	2.20	0.03	0.65

Note: D 50%F = Days to 50% flowering; PH = Plant height; NSB = Number of secondary branches; NFC = Number of fruits per cluster; NFP = Number of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL = Fruit length; DFH = Days to first harvesting; YPP = Yield per plant; of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL = Fruit length; DFH = Days to first harvesting; YPP = Yield per plant; SL= Shelf life; PT= Pericarp thickness; NLF= Number of locules per fruit; *p>0.05,**p>0.01

Table 4(b). Analysis of variances (MS values) of nutritional traits of 10 F_1 hybrid lines derived from 5×5 diallel cross in tomato

		Nutritional traits		
Source	**d.f**	**Vit-C (mg/100g)**	**BRIX %**	**TA %**
Replication	2	164.66	0.15	0.01
Genotype	15	516.11**	1.54**	0.03**
Error	30	1.65	0.02	0.01

Note: Vit-C = Vitamin C; Brix % = Brix percentage; TA% = Titrable Acidity percentage; *P>0.05, **P >0.01

Table 5. Mean performance of agronomic traits of five parents and their 10 F_1 hybrid lines derived from 5×5 diallel cross in tomato

Genotype	D50%F	PH	NSBP	NFC	NFP	SFW	FD	FL	DFH	YPP (kg/p)
P1	25.67 b	92.40 ef	7.67 g	4.98 fgh	27.00 h	91.74 cd	63.60 ab	56.83 ab	83.00 c	1.34 f
P2	23.00 cd	89.40 fg	6.07 h	5.84 d	27.27 h	100.18 a	53.68 ef	59.34 a	76.67 d	1.92 e
P3	27.00 ab	117.47 a	5.64 i	5.61 de	32.68 gh	89.56 cde	54.96 def	49.89 cd	82.67 c	2.16 cde
P4	21.33 de	97.66 c	7.67 g	11.67 a	217.25 a	8.00 k	21.40 i	25.25 f	72.00 e	1.08 g
P5	27.67 a	90.27 efg	8.74 c	5.17 efgh	31.20 gh	92.08 cd	56.25 def	49.92 cd	84.00 c	2.30 c
C1 (P1×P2)	22.33 cd	96.80 cd	8.50 d	4.87 gh	47.87 f	67.55 g	52.78 f	47.06 d	66.33 f	2.97 ab
C2 (P1×P3)	23.67 c	111.53 b	7.70 g	5.55 def	62.47 d	84.17 ef	67.35 a	57.79 ab	80.33 cd	2.84 b
C3 (P1×P4)	21.67 de	87.93 g	9.10 b	8.50 b	155.95 b	18.70 ij	33.12 g	32.73 e	66.33 f	2.16 cde
C4 (P1×P5)	26.33 ab	87.67 g	9.00 b	5.32 defg	29.96 h	55.55 h	53.82 ef	51.50 c	80.67 cd	1.20 fg
C5 (P2×P3)	22.67 cd	111.73 b	7.93 f	5.31 defg	36.13 g	97.70 ab	59.61 bcd	55.81 b	82.00 c	2.24 cd
C6 (P2×P4)	20.00 e	98.33 c	11.00 a	7.63 c	114.43 c	17.60 j	26.53 h	31.28 e	66.33 f	2.07 cde
C7 (P2×P5)	23.00 cd	93.60 de	7.93 f	4.58 h	48.97 f	83.48 f	59.43 bcd	50.57 c	88.33 b	3.18 a
C8 (P3×P4)	28.00 a	111.30 b	8.24 e	5.54 def	43.60 f	93.62 bc	63.20 abc	60.12 a	92.67 a	2.31 c
C9 (P3×P5)	27.00 ab	120.32 a	5.61 i	5.07 efgh	36.53 g	87.30 def	58.41 cde	50.86 c	81.00 c	2.29 c
C10 (P4×P5)	22.00 cd	98.87 c	11.03 a	8.61 b	109.77 c	23.04 i	34.81 g	33.62 e	67.00 f	1.99 de
CV(BARI HY-4)	25.67 b	86.67 g	6.12 h	5.80 d	55.67 e	56.45 h	58.32 de	48.62 cd	80.33 cd	2.12 cde
Mean	24.19	99.48	7.80	6.25	67.30	66.67	51.08	47.51	78.10	2.14
Maximum	28.00	120.32	11.03	8.50	217.25	100.18	67.35	60.12	92.67	3.18
Minimum	20.00	86.67	5.61	4.58	27.00	8.00	21.40	25.25	66.33	1.08
LSD	1.8921	3.6336	0.2086	0.6149	5.9239	5.4102	4.8334	3.3679	4.2785	0.2593
CV%	4.69	2.19	1.56	5.90	5.28	4.87	5.67	4.25	3.29	7.28
SE(±)	0.6551	1.2581	0.0722	0.2129	2.0511	1.8732	1.6735	1.1661	1.4814	0.0898

Note: D50%F = Days of 50% flowering; PH = Plant height; NSB = Number of secondary branches, NFC = Number of fruits per cluster; NFP = Number of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL = Fruit length; DFH = Days of first harvesting; YPP = Yield per plant; SL = Shelf life; PT = Pericarp thickness and NLF = Number of locules per fruit; CV = Check variety BARI hybrid tomato-4; *P>0.05, **P >0.01

Plate 6. The photograph showing the 10 F_1 tomato hybrid lines at the flowering stage

4.1.1.2 Plant height (cm)

The lowest plant height was found in the parental genotype P2 (89.40) followed by P5 (90.27), while the parental genotype P3 (117.47) showed the highest plant height. Among the F_1 hybrids, the cross combination P1×P5 (87.67) showed the lowest plant height which followed by P1×P4 (87.93). While, the F_1 lines P3×P5 (120.32), P2×P3 (11.73), P1×P3 (11.53), and P3×P4 (11.30) showed the highest plant height. While check variety had a mean performance of 86.67 cm (Table 5).

4.1.1.3 Number of secondary branches per plant

Among the parents, the maximum number of secondary branches were found in genotype P5 (8.74) followed by both genotypes P1 and P3 (7.68). On the other hand, among the hybrids, the cross combination P4×P5 (11.03) exhibited the highest number of secondary branches followed by cross combination P2×P4 (11.01). Again,6.12 mean performance was exhibited by check variety (Table 5).

4.1.1.4 Number of fruits per cluster

Among the parental genotypes, the maximum number of fruit per cluster observed in genotype P4 (11.67), followed by P2 (5.84) and P3 (5.61). Again among the F_1 hybrids, the crosses P4×P5 (8.61), P1×P4 (8.50) showed the maximum fruit per cluster and contrariwise, the cross combination P1×P2 (4.87) and P2×P5 (4.58) showed the minimum number of fruits per cluster. While 5.80 mean performance was exhibited by check variety (Table 5). A pictorial view of fruits in the clusters is illustrated in Plate 7.

4.1.1.5 Number of fruits per plant

The parental genotype P4 (217.25) exhibited the maximum number of fruit per plant while the genotype P1 (27.00) showed the minimum number of fruit per plant. Among all the hybrids, the cross combination P1×P4 (155.95) showed the maximum fruit per plant followed by P2×P4 (114.43) and P4×P5 (109.77). On the other side, the cross combination P1×P5 (29.96) followed by P2×P3 (36.13) P3×P5 (36.53) showed the minimum number of fruit per plant. While mean performance 55.87 was exhibited by check variety (Table 5).

plate 7. The photograph showing the 10 F_1 tomato hybrid lines at the fruiting stage

4.1.1.6 Single fruit weight (g)

Among all parental genotypes, the genotype P2 (100.18g) showed the highest fruit weight, on the contrary P4 (8.00g) had the lowest fruit weight. In cross combinations two crosses *viz.* P2×P3 (97.70g) and P3×P4 (93.62g) showed the highest fruit weight. On the other hand, the cross combinations P1×P4 (18.70g) and P2×P4 (17.60g) showed the lowest fruit weight. Again, a mean performance of 56.45 g was exhibited by check variety (Table 5).

4.1.1.7 Fruit diameter (mm)

Among the genotypes, the genotype P1 (63.60 mm) and P5 (56.25 mm) showed the highest fruit diameter. On the contrary, the parent P4 (21.40 mm) exhibited the lowest fruit diameter. Out of all F_1 hybrid lines, the cross combinations P1×P3 (67.35mm) and P3×P4 (63.20 mm) showed the highest fruit diameter, while the crosses P2×P4 (26.53 mm), P1×P4 (33.12 mm), and P4×P5 (34.81 mm) showed the lowest fruit diameter. Again, the mean performance of 58.32 mm was exhibited by check variety (Table 5).

4.1.1.8 Fruit length (mm)

The highest fruit length was found in two parental genotypes *viz*. P2 (59.34 mm) and P1 (56.83 mm) and the lowest fruit length found in genotype P4 (25.25 mm). Among the F_1 hybrid lines, the three crosses such as P3×P4 (60.12 mm), P1×P3 (57.79 mm), P2×P3 (55.81 mm) showed the highest fruit length, while the cross combinations P2×P4 (31.28 mm), P1×P4 (32.73 mm) & P4×P5 (33.62 mm) had the lowest fruit length. However, the mean performance of 48.62 mm was exhibited in check variety (Table 5).

4.1.1.9 Days to first harvesting

Days to first as well as early harvesting was observed in parental genotype P4 (72) and P2 (76.67), while late harvesting was observed in P5 (84). Out of the 10 F_1 hybrid lines, three crosses *viz*. P1×P2, P1×P4, and P2×P4 showed the same value (66.33) for early maturity, while P3×P4 (92.67) showed the late maturity. Again, a mean performance of 80.33 days was performed by check variety (Table 5).

4. 1.1.10 Fruit yield per plant (kg)

The parental genotype P5 (2.30 kg) and P3 (2.16 kg) showed the maximum yield per plant, while the parent, P4 (1.08 kg) showed the minimum yield per plant. Among the F_1 hybrid lines, the cross combination, P2×P5 (3.18 kg) followed by P1×P2 (2.97 kg) and P1×P3 (2.84 kg) observed the maximum yield per plant, while the cross P1×P5 (1.20 kg) showed the minimum yield per plant. Moreover, a mean performance of 2.12 kg was observed in check variety (Table 5).

4.1.1.11 Shelf life (days)

The highest shelf life was observed in the parental genotype P1 (22.00) and P4 (14.67). Again, among the F_1 hybrids, the cross, P1×P2 (27.67) followed by P1×P5 (24.67) and P1×P3 (22.67) showed the highest shelf life as these lines took maximum days for rotten. While a mean performance of 4.45 days was exhibited by check variety (Table 5).

4.1.1.12 Pericarp thickness(mm)

The parental genotypes P2 (4.62 mm) and P1 (4.28 mm) showed the highest pericarp thickness, on the contrary, the parent P4 (0.72 mm) showed the thinnest pericarp thickness. Among the F_1 hybrids, the two crosses, P3×P4 (5.52 mm) and P1×P2 (5.45 mm) showed the highest pericarp thickness. On the other hand, the cross P4×P5 (2.09 mm) showed the thinnest pericarp thickness. While the mean performance of 8.00 mm was observed by check variety (Table 5).

4.1.1.13 Number of locules per fruit

The maximum number of locules per fruit observed in parental genotype P1 (5.00) and P3 (4.67). Among the F_1 hybrids, the two crosses P2×P3 (6.00) and P3×P5 (5.00) showed the maximum number of locules per fruit, while both crosses P2×P4 and P4×P5 showed the same minimum number (2.33) of locules. Again, mean performance 3.33 was performed by check variety (Table 5).

Table 5 cont[n]. Mean performance of agronomic traits for shelf life, perimeter thickness and number of locules per fruit of five parents and their 10 F_1 lines derived from 5×5 diallel cross in tomato

Genotype	Agronomic traits		
	SL	PT	NLF
P1	22.00 c	4.28 cd	5.00 ab
P2	8.67 ghi	4.62 b	3.00 def
P3	10.0 gh	3.72 f	4.67 abc
P4	14.67 f	0.72 k	2.00 f
P5	7.00 i	3.26 g	3.33 cdef
C1 (P1×P2)	27.67 a	5.45 a	3.67 bcde
C2 (P1× P3)	22.67bc	2.59 i	4.00 bcd
C3 (P1×P4)	10.67 g	2.78 hi	3.33 cdef
C4 (P1×P5)	24.67 b	4.06 de	4.00 bcd
C5 (P2×P3)	17.00 ef	3.86 ef	6.00 a
C6 (P2×P4)	18.33de	2.94 h	2.33 ef
C7 (P2×P5)	21.33 c	4.08 de	3.33 cdef
C8 (P3×P4)	15.67 f	5.52a	4.00 bcd
C9 (P3×P5)	7.33 i	3.58 f	5.00 ab
C10 (P4×P5)	20.7 cd	2.09 j	2.33 ef
CV 1 (HY-4)	4.45 bc	8.00 hi	3.33 cdef
Mean	16.02	3.62	3.71
Maximum	27.67	5.52	6.00
Minimum	7.00	0.72	2.00
LSD	2.4741	0.2997	1.3458
CV%	9.26	4.96	21.76
SE(±)	0.8566	0.1037	0.4660

Note: SL= Shelf life; PT= Pericarp Thickness; NLF= Number of locules per fruit; **P >0.01

4.1.2 Nutritional traits

The mean values of nutritional traits of five parental genotypes of tomato and their F_1 progenies are presented in (Table 6).

4.1.2.1 Vitamin-C content (mg/100g fruit)

The highest Vitamin-C content was observed in parental genotypes P4 (77.32 mg) and P5 (35.52 mg), while the lowest Vitamin-C content was observed in P3 (4.24 mg). Among the F_1 hybrids, the crosses P1× P4 (38.83 mg) followed by P4×P5 (31.74 mg) and P2×P4 (30.85 mg) showed the highest Vitamin-C content while the cross P1×P5 (7.88 mg) showed the lowest Vitamin-C. Again, a mean performance of 7.39 mg was exhibited by check variety (Table 6).

4.1.2.2 Brix percentage (%)

Among the five parental genotypes, the parents P4 (6.00%) followed by P2 (4.90%) and P1 (4.80%) showed the highest brix percentage content. On the other hand, the crosses, P1×P4 (5.03%) followed by P3×P4, P1×P5, and P2×P4 showed the same lowest brix percentage 5.00%. While mean performance 4.90% was exhibited by check variety (Table 6).

4.1.2.3 Titrable Acidity (%)

The parental genotype P4 (0.27%) and P5 (0.15%) showed the highest titrable acidity percentage. Among the F_1 hybrids, the cross combinations, P4×P5 **(**0.35%) showed the highest titrable acidity percentage while the cross P1×P4 (0.37%) and P4×P5 0.35%) showed the lowest titrable acidity percentage. Again, a mean performance of 0.15 was exhibited by check variety (Table 6).

4.2 Combining Ability

To conduct a sound basis for any breeding programs, breeders must-have information on combining ability (Chawla and Gupta, 1984). The nature of combining ability of parents, their behavior, and performance in hybrid combinations combining ability is indispensable for the selection of suitable parents for hybridization and identification of promising hybrids for the development of improved varieties for a diverse agro-ecology (Alabi *et al.,* 1987).

Table 6. Mean performance of nutritional traits of five parents and their 10 F_1 lines derived from 5×5 diallel cross in tomato

Genotype	Nutritional traits		
	Vit-C content (mg/100g)	BRIX%	TA %
P1	9.67 ef	4.80 b	0.05 c
P2	11.83 def	4.90 b	0.08 c
P3	4.24 f	3.90 d	0.06 c
P4	77.32 a	6.00 a	0.27 ab
P5	35.52 bc	3.50 e	0.15 bc
C1 (P1×P2)	16.46 cdef	4.00d	0.06 c
C2 (P1× P3)	10.77 def	4.90 b	0.07 c
C3 (P1×P4)	38.83 b	5.03 b	0.37 a
C4 (P1×P5)	7.88 f	5.00 b	0.08 c
C5 (P2×P3)	15.42 cdef	4.93 b	0.05 c
C6 (P2×P4)	30.85 bcde	5.00 b	0.16 bc
C7 (P2×P5)	16.81 cdef	3.00 f	0.08 c
C8 (P3×P4)	8.27 f	5.00 b	0.07 c
C9 (P3×P5)	12.49 def	4.50 c	0.07 c
C10 (P4×P5)	31.74 bcd	4.87 b	0.35 a
CV 1 (HY-4)	7.39 f	4.90 b	0.15 bc
Mean	20.97	0.13	4.64
Maximum	773.15	6.00	0.37
Minimum	4.24	0.15	0.05
LSD	2.1461	0.2468	0.1702
CV%	4.73	3.19	77.03
SE(±)	0.4305	0.0854	0.0589

Note: Vit-C = Vitamin C; Brix % = Brix percentage; TA% = Titrable Acidity percentage; *P>0.05, **P >0.01

The analysis of variances for general combining ability (GCA) and specific combining ability (SCA) was found significant for all the characters studied (Table 7) indicating both additive and non-additive gene actions for the expression of these characters. Chisti *et al.* (2018) also found that GCA and SCA were significant for all characters.

The general combining ability (GCA) variances for all the characters studied higher in magnitude than the specific combining ability variances indicating the predominance of the additive effect for these characters. The general combining ability (GCA) variances for the characters *viz.* days of 50% flowering, plant height, number of secondary branches, number of fruits per cluster, number of fruits per plant, individual fruit weight, fruit diameter, fruit length, days to first harvesting were higher in the magnitude than the specific combining ability (SCA) variances indicating that additive gene effect is predominant for these characters. Bhuiyan (1982) and Wang *et al.* (1998a) also reported that additive gene action appears more important than non-additive gene effects for the fruits per plant, average fruit weight, and fruit breadth in tomato.

4.2.1 General Combining Ability (GCA)

The GCA component is primarily a function of the additive genetic variance. GCA variances with each parent play a significant role in the choice of parents. A parent with higher positive significant GCA effects is considered as a good general combiner. The magnitude and direction of the significant effects for the seven parents provide meaningful comparisons and would give indications to the future breeding program. The results of GCA effects for ten different agronomic traits (Table 8).

4.2.1.1 Days to 50% flowering

The estimate of GCA effects for this trait is given in (Table 8). Among the five parent studies, here the parent P2 (-1.51) showed the highest negative GCA effect followed by the parent P4 (-1.46) for days to 50% flowering. On the other hand, three parents P3, P5, P1 showed positive GCA values (1.54, 1.31, and 0.11 respectively). So the parent P2 was the best general combiner for the earliness trait. (Table 8). E-Metawally *et al.* (1996) also found such an effect in heat tolerance tomato lines.

Table 7. Analysis of variances (MS values) for GCA and SCA for ten yield and yield contributing characters in 5×5 diallel cross of tomato

Source	d.f	D 50%F	PH	NSBP	NFC	NFP	SFW	FD	FL	DFH	YPP(kg)
GCA	4	44.54**	1,055.27**	11.49**	34.12**	27,713.89**	8,474.54**	1,589.03**	867.06**	279.44**	1.00**
SCA	10	10.62**	98.39**	6.33**	2.58**	2,324.20**	1,349.34**	231.65**	185.64**	191.02**	1.13**
Error	28	1.35	4.90	0.01	0.14	12.62	10.73	8.03	3.63	6.45	0.02
GCA: SCA		4.195	10.725	1.815	13.230	11.924	6.281	6.860	4.671	1.463	0.891

Note: D50%F = Days of 50% flowering; PH = Plant height; NSB = Number of secondary branches; NFC = Number of fruits per cluster; NFP = Number of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL= Fruit length; DFH = Days to first harvesting; YPP = Yield per plant; *P>0.05, **P >0.01

Table 8: Estimates of general combining ability (GCA) for ten yield and yield contributing characters in 5×5 diallel cross analysis in tomato

Genotype	D50%F	PH	NSB	NFC	NFP	SFW	FD	FL	DFH	YPP(kg)
P1	0.11	-4.74**	0.13	-0.50	-8.31**	0.76	4.38*	2.59	-1.15	-0.14
P2	-1.51	-3.24*	-0.18	-0.52	-15.21**	8.94**	0.31	2.68	-1.63	0.21
P3	1.54	12.52**	-1.14	-0.72	-23.48**	19.68**	7.84**	5.68**	-4.80**	0.17
P4	-1.46	-1.55	0.86	2.28	64.26**	-33.59**	-14.73**	10.91**	-4.49*	-0.31
P5	1.31	-2.99*	0.33	-0.54	-17.26**	4.20*	2.20	-0.04	2.47	0.06
SE g_i	0.23	0.43	0.02	0.07	0.69	0.64	0.55	-7.93	0.50	0.03
SE (g_i-g_j)	0.36	0.68	0.04	0.11	1.10	1.01	0.88	0.59	0.78	0.05

Note: D50%F = Days of 50% flowering; PH = Plant height; NSB = Number of secondary branches; NFC = Number of fruits per cluster; NFP = Number of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL= Fruit length; DFH = Days to first harvesting; YPP = Yield per plant.*P>0.05, **P >0.01

Natarajan (1992) reported that additive gene effects appeared more important than non-additive gene effects. Zengin *et al.* (2015) and Raj *et al.* (2017) reported that some parental genotypes having maximum GCA effects as a good general combiner for early flowering in tomatoes.

4.2.1. 2 Plant height (cm)

Among the five parent studies here, the parent P1 (-4.74**) showed the highest negative significant value followed by parents P2 (-3.24*), and P5 (-2.99*) which showed a highly significant negative GCA effect. So the parents P1 with P2 and P5 were the good general combiners for short plant height trait (Table 8). On the other hand, the parent P3 (12.52**) showed a highly positive significant value which indicated poor general combiner for short plant height trait. On the other hand, Bhuiyan (1982), Solieman *et al.*(2009), Zengin *et al.* (2015), and Kumar *et al.* (2018) reported a predominance type of additive gene action.

4.2.1. 3 Number of secondary branches per plant

Among five parents, the parent P4 showed the highest positive GCA effect (0.86) followed by P5 (0.33) and P1 (0.13) while the rest of the parents showed a non-significant GCA value. So all the parents were poor combiner except parents P4 and P5 for increasing number of fruits per branch (Table 8). Solieman *et al.*(2009), reported two parents as good general combiners for this trait.

4.2.1. 4 Number of fruits per cluster

Among the five parents, only the parents P4 (2.28) showed positive GCA effects but non-significant while all other parents showed negative GCA effects. Thus none of the parents was found as a good general combiner for fruits per cluster trait (Table 8).

4.2.1.5 Number of fruits per Plant

Among five parents, only the parents P4 showed highly significant positive GCA effects (64.26**). On the contrary, the highest significant negative value was obtained by the parent P3 (-23.48**) followed by P5 (-17.26**) and P1 (-8.31*). Thus the parent P4 was the best general combiner in this trait for increasing the number of fruits per plant (Table 8). Bhuiyan (1982) and Natarajan (1992) reported a result of some good general combiners for the number of fruits per plant. Wang *et al.* (1998a) also reported the important role of additive gene action. Ahmad *et al.* (2009), Farzane *et al.* (2012), Yadav *et al.* (2016), and Gayosso-Barragán *et al.* (2019) found also two parental genotypes as good general combiners for fruit per plant.

4.2.1.6 Single fruit weight (g)

Among five parents, the parents P3 (19.68**) showed significant positive GCA followed by P2 (8.94**) for single fruit weight trait. The result indicated that the parents P3 and P2 were the best general combiners, so these parents could be used in hybridization program for the improvement of single fruit weight as indicated by the significance and higher GCA effect. On the other hand, the parent P4 (- 33.59**) showed a significant negative GCA effect for single fruit weight (Table 8). Bhuiyan (1982); Chadha *et al.* (1997) and Ahmad (2002) also reported some good general combiners for single fruit weight. Ahmad *et al.* (2009), Solieman *et al.*(2009), Agarwal et. al. (2014), Baban *et al.* (2015), Aisyah *et al.* (2016), Raj *et al.* (2017) Kumar *et al.* (2018), and Gayosso-Barragán *et al.* (2019) reported that some parental lines showed the experimental result as a best general combiner for single fruit weight.

4.2.1.7 Fruit diameter (mm)

Among the five parents, the highest GCA effects for fruit diameter exhibited by the parent P3 (7.84**) followed by P1 (4.38*). The result indicated that the parent P3 and P1 were the good general combiners for fruit diameter. The highest significant negative GCA effect was obtained from P4 (-14.73**) in (Table 8). Susie (1998), Ahmad (2002), Solieman *et al.*(2009), Baban *et al.* (2015), Kumar *et al.* (2018), and Gayosso-Barragán *et al.* (2019) also reported some good general combiners for this trait in tomato.

4.2.1.8 Fruit length (mm)

Among the five parental genotypes, only the two parents showed significant positive GCA effects. The highest significant positive GCA value was observed in parent P4 (10.91**) followed by P3 (5.68**). Therefore, the parent P4 and P3 were good general combiner for fruit length trait. While the parents P1 (2.59) and P2 (2.68) showed positive GCA effects but non-significant (Table 8). Susie (1998), Ahmed (2002) and Solieman *et al.*(2009), and Aisyah *et al.* (2016) reported some good general combiners for fruit length.

4.2.1.9 Days to first harvesting

Among the five parents the highest negatively significant GCA effects for days to first harvesting was exhibited by the parent P3 (-4.80**) followed by P4 (-4.49*). So, the result indicated that parent P3 and P4 were the good general combiner for early maturity and early harvesting. Two parents P1 (-1.15) and P2 (-1.63) showed negative GCA effects but non-significant. On the other hand, only the parent P5 (2.47) showed a positive non-significant GCA effect (Table 8). Zengin *et al.* (2015) and Raj *et al.* (2017) found some parental genotypes as best general combiners for early maturity or harvesting which assists early ripening of fruits.

4.2.1.10 Yield per plant (kg)

Among the five parents, three parents showed positive GCA effects and two parents showed non-significant negative effects (Table 8). The highest positive and non-significant GCA effects were obtained in the parents P2 (0.21) followed by P3 (0.17) and P5 (0.06). Thus, the result indicated that none of the parents was a good general combiner for yield per plant. Again non-significant negative GCA value was found in parents P1 (-0.14) followed by P4 (-0.31) in (Table 8).

4.2.2 Specific combining ability (SCA)

The specific combining ability SCA effects signify the role of non-additive gene action in the expression of the characters. It indicates the highly specific combining ability leading to the highest performance of some specific cross combinations. That is why SCA is related to a particular cross combination. High GCA may arise not only in crosses involving high combiners but also in those involving low combiners. Thus in practice, some of the low combiners should also be accommodated in hybridization programs. The results of SCA effects for ten different agronomic traits are shown below (Table 9).

Table 9. Estimates of specific combining ability (SCA) for ten yield and yield contributing characters in 5×5 diallel cross analysis in tomato

Crosses	D 50%F	PH	NSBP	NFC	NFP	SFW	FD	FL	DFH	YPP
C1 (P1×P2)	-0.37	4.46**	0.42	-0.40	3.32**	-9.51**	-2.50**	-5.65**	-8.84**	0.05
C2 (P1×P3)	-2.08	3.44**	0.59	0.49	26.18**	-3.63**	4.53**	2.09	-1.27	0.67
C3 (P1×P4)	-1.08	-6.10**	-0.01	0.44	31.93**	-15.82**	-7.13**	-6.38**	-5.98**	0.47
C4 (P1×P5)	0.83	-4.92**	0.42	0.07	-12.54**	-16.77**	-3.36**	1.51	1.40	-0.86
C5 (P2×P3)	-1.46	2.13	1.13	0.26	-12.54**	1.72	0.86	0.01	0.87	-0.28
C6 (P2×P4)	-1.13	2.80	2.21	-0.41	-2.68	-25.10**	-9.64**	-7.93**	-5.51**	0.03
C7 (P2×P5)	-0.89	-0.49	-0.35	-0.65	13.37**	2.98**	6.33**	0.48	9.54**	0.77
C8 (P3×P4)	3.83**	0.01	0.40	-2.30	-65.26**	40.18**	19.49**	17.92**	14.40**	0.31
C9 (P3×P5)	0.06	10.47**	-1.71	0.04	9.20**	-3.94**	-2.23	-2.22	-4.22**	-0.08
C10(P4×P5)	-1.94	3.08*	1.73	0.60	-5.31**	-14.92**	-3.26**	-2.87	-8.94**	0.09
Max	3.83	10.47	2.21	0.60	31.93	40.18	19.49	17.92	14.40	0.77
Min	-2.08	-6.10	-0.01	-0.41	-65.26	-25.10	-9.64	-7.93	-8.94	-0.08
SE (sij)	0.59	1.12	0.06	0.19	1.79	1.65	1.43	0.96	1.28	0.08
SE (sij-skl)	0.80	1.53	0.08	0.26	2.451	2.26	1.96	1.32	1.75	0.11

Note: D50%F = Days of 50% flowering; PH = Plant height; NSB = Number of secondary branches; NFC = Number of fruits per cluster; NFP = Number of fruits per plant; SFW = Single fruit weight; FD = Fruit diameter; FL = Fruit length; DFH = Days to first harvesting; YPP = Yield per plant, *P>0.05, **P >0.01

4.2.2.1 Days of 50% flowering

Among F_1 hybrids, cross combinations three crosses *viz.* P1×P3 (-2.08) followed by P4×P5 (-1.94) and P2 × P3 (-1.46) showed non-significant negative SCA effects. On the other hand one cross combination P3× P4 (3.825**) showed significant positive SCA. The result suggested that none of the F_1's were good specific combiner for earliness in 50% flowering trait (Table 9).

4.2.2.2 Plant height (cm)

For plant height the cross combinations P1×P4 (-6.10**) and P1×P5 (-4.92**) showed the highest significant negative SCA effects. Thus the result indicated that these two crosses were good specific combiner for plant height trait. The cross combination P1×P4 (-6.10**) was the best specific combiner found in the present investigation. On the other hand, three cross combinations such as P1×P2 (4.46**), P1×P3 (3.44**), and P3×P5 (10.47**) showed the highest significant positive SCA effects indicates poor performer for developing short stature tomato variety development (Table 9). Solieman *et al*. (2009) reported some hybrids as good specific combiner for plant height.

4.2.2.3 Number of secondary branches per plant

For the number of secondary branches per plant three cross combinations out of ten showed positive but non-significant SCA effect. These cross combinations were P2×P4 (2.21), P4×P5 (1.73), and P2×P3 (1.13) respectively but non-significant. The crosses with the highest positive SCA are generally considered as the best specific combiners for this trait, suggesting none of the parents are good combiners for this character (Table 9).

4.2.2.4 Number of fruits per cluster

For the number of fruits per cluster three cross combinations out of ten showed positive but non-significant SCA effect and these crosses were P4×P5 (0.60), P1×P3 (0.49), and P1×P4 (0.44). The crosses with the highest positive SCA had generally considered were the best specific combiners for this trait, but here, suggesting that none of the crosses is a good combiner for the number of fruits per cluster in the present investigation (Table 9).

4.2.2.5 Number of fruits per plant

For the number of fruits per plant**,** out of ten cross combinations, five crosses showed the highest significant positive SCA effects and these cross combinations were P1×P4 (31.931**) followed by P1×P3 (26.183**), P2×P5 (13.367**), P3×P5 (9.195**) and P1×P2 (3.321**). The result indicated that these crosses were the best specific combiner for increasing fruits per plant. The cross between P1 and P4 was the best specific combiner for this trait. Significant negative SCA effects were observed in cross combinations P3×P4 (-65.26**) followed by P1×P5 (-12.54**) and P2×P3 (-12.54**) (Table 9). Bhuiyan (1982) also found some hybrids showed significant positive SCA in tomato. Aisyah *et al.* (2016) and Raj et al. (2017) found some hybrids which showed predominance non-additive gene action for the number of fruits per plant.

4.2.2.6 Single fruit weight (g)

For single fruit weight among the ten cross combinations two crosses *viz*. P3×P4 (40.18**) and P2×P5 (2.98**) showed the highest significant positive SCA effects. The result indicated that these cross combinations produced heavier fruit weight compared to the mean of their parents. The highest significant negative SCA effect was obtained in the cross P2×P4 (-25.009**) followed by P1×P5 (-16.77**), P1×P4 (-15.82**) and P4×P5 (-14.92). So this result indicated that cross P3×P4 was the best specific combiner for single fruit weight (Table 9). Chadha *et al.* (1997), Solieman *et al*.(2009), and Raj *et al.* (2017) selected some hybrids for individual fruit weight.

4.2.2.7 Fruit diameter (mm)

Three cross combinations showed a significant positive SCA effect for fruit diameter. The highest significant positive SCA was obtained in the cross combination P3×P4 (19.49**) followed by P2×P5 (6.33**) and P1×P3 (4.53). So, the cross P3×P4 was found as the best specific combiners for this trait (Table 9). While the rest of the five cross combinations showed significant negative SCA effects, Susie (1998) and Ahmad (2002) and Solieman *et al*. (2009) reported some superior hybrids for fruit diameter.

4.2.2.8 Fruit length (mm)

The cross combination P3×P4 (17.92**) showed the highest significant positive SCA effects for fruit length. Again three crosses *viz*. P2×P4 (-7.93) followed by P1×P4 (-6.38) and P1×P2 (-5.65) showed significant negative SCA effects. The result indicated that the cross P3×P4 was the best specific combiner for fruit length (Table 9). But Susie (1998) reported a good specific combiner for fruit lengthy in tomato. Superior hybrids for fruit length were also reported by Ahmad (2002) and Solieman *et al*. (2009).

4.2.2.9 Days to first harvesting

For days of first harvesting five crosses showed the highest significant negative SCA effects found in such in the combinations P4×P5 (-8.94**) followed by P1×P2 (-8.84**), P1×P4 (-5.98**), P2×P4 (-5.51**) and P3×P5(-4.22**). So, the result indicated that these crosses were the best specific combiner for increasing fruits per plant. Significant positive SCA effects were observed in cross P3×P4 (14.40**) followed by P2×P5 (9.54**) (Table 9).

4.2.2.10 Yield per plant (kg)

For yield per plant seven cross combinations showed positive SCA effects. For this trait, the positive but non-significant SCA was obtained by the cross P2×P5 (0.77) followed by P1×P3 (0.67), P1×P4 (0.47), P3×P4 (0.31), P4×P5 (0.09), P1×P2 (0.05), and P2×P4 (0.03). The result indicated that none of the cross combinations was the best general combiner for increasing fruit yield per plant. Furthermore, three crosses showed negative non-significant SCA effects (Table 9). Two pictorial views of fruit yield of 10 F_1 hybrids are illustrated in plate 8 and plate 9 respectively.

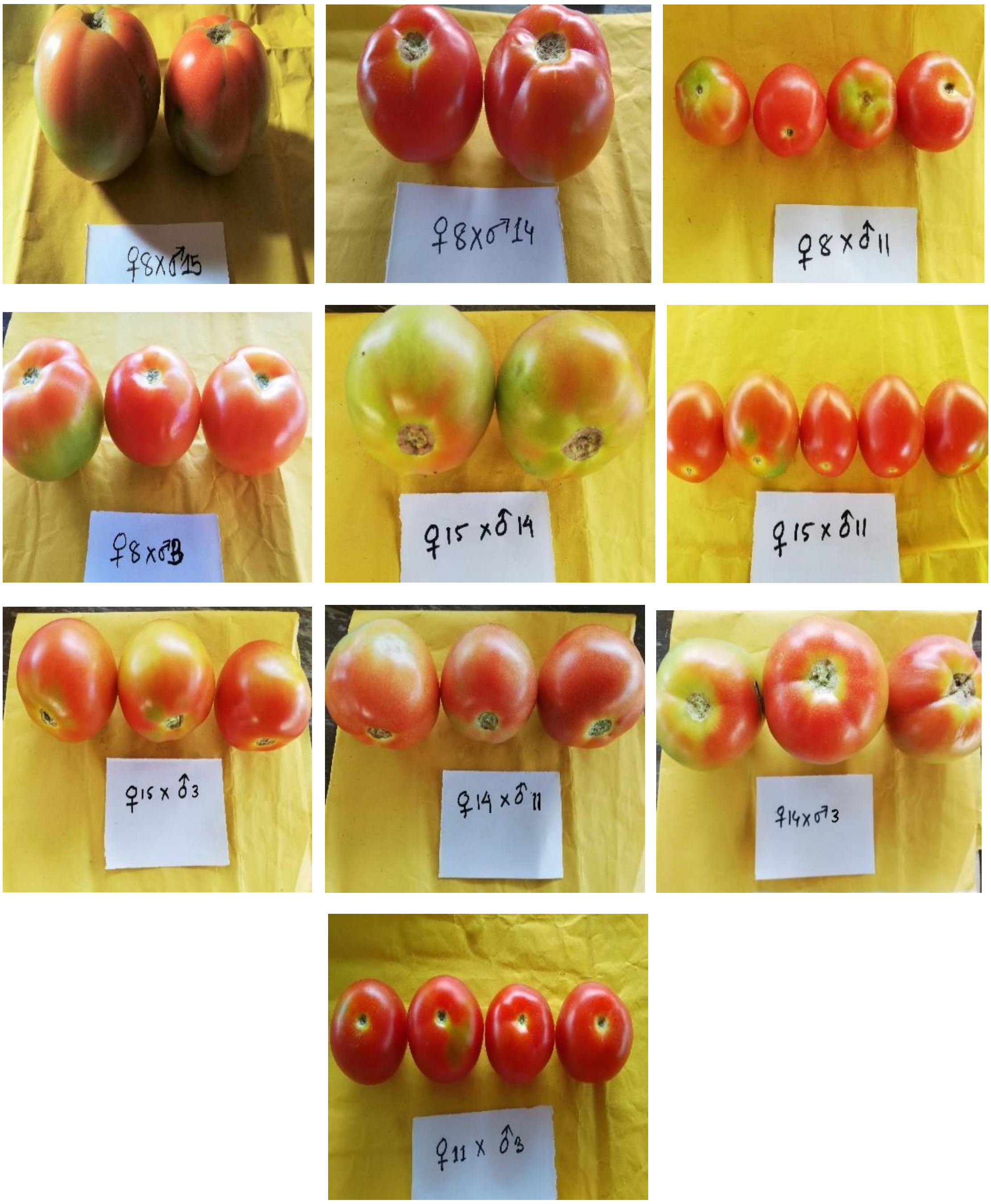


Plate 8. The photograph showing the tomato fruits of 10 F_1 hybrid lines at the maturity stage

Plate 9. The photograph showing the transverse section of tomato fruits of 10 F_1 hybrid lines

4.3 Estimation of heterosis

The magnitude of heterosis provides information on the extent of genetic diversity of parents in developing superior F_1 to exploit hybrid. Usually, standard heterosis is measured over a commercially cultivated popular variety or hybrid variety. In this experiment, one standard check variety BARI hybrid tomato-4 (CV1) was included as check variety for a better comparison of ten yield contributing traits of the ten experimental F_1 hybrids. Percent heterosis for different traits of the F_1 hybrids over better parent (BP) and standard check value are shown in (Table 10). The results of percent of heterosis in crosses were varied from trait to trait or from the cross to cross.

4.3.1 Days of 50% flowering

For developing the early maturity variety negative heterosis is desirable for days of 50% flowering. Seven hybrids manifested significant heterosis over the better parent (Table 9). Highly negative significant heterosis (-20.48%) was found in the hybrid of P4×P5 (C10) for days to 50% flowering over their better parent P5. In the case of standard heterosis six F_1 hybrid lines, *viz*. P1×P2 (C1), P1×P4 (C3), P2×P3 (C5), P2×P4 (C6), P2×P5 (C7), and P4×P5 (C10) manifested the desirable significant negative heterosis over check variety BARI hybrid-4. Among them, the cross combination P2×P4 (C6) manifested the highest negative significant heterosis -22.08% over check variety (Table 10) and Appendix VI (a). Singh and Singh (1993), Kumar *et al.* (1995a), E-Metwally *et al.* (1996), Vedyasagar *et al.* (1997), Ahmad *et al.* (2011), Kumar *et al*. (2012), Gautam *et al.* (2018), and Dhilon *et al.* (2019) also reported negative heterosis for days to 50% flowering.

4.3.2 Plant height (cm)

In the case of plant height, negative heterosis is also desirable which helps to develop dwarf type plant. The estimated heterosis value ranged from -9.66% to 4.76% over better parent and 11.69% to 38.83% heterosis was obtained over check variety. Four hybrids *viz*. P1×P3, P1×P4, P2×P3, and P3×P4 manifested highly negative significant heterosis over the better parent, and these four hybrids expressed positive but non-significant heterosis over the better parent. Among ten hybrids seven hybrids *viz*. P3×P5 (C9), P2×P3 (C5), P1×P3 (C2), P3×P4 (C8), P4×P5 (C10), P2×P4 (C6), and P1×P2 (C1) manifested standard highly significant heterosis in the positive direction in respect

Table 10. Estimation of heterosis over better parent (BP) and Check variety CV (BARI hybrid tomato-4) for D 50% F, PH, NSB, NFC and NFP in ten (10) F_1 hybrids derived from 5×5 diallel cross in tomato

Crosses	D50%F		PH		NSBP		NFP		NFC	
	BP	CV	BP	CV	BP	CV	BP	CV	BP	CV
C1 (P1×P2)	-12.99**	-12.99**	4.76*	11.69**	10.77**	38.81**	-16.67**	-16.04**	75.55**	-14.01*
C2 (P1×P3)	-12.35**	-7.79*	-5.05**	28.69**	0.30	25.69**	-0.95	-4.20	91.13**	12.22*
C3 (P1×P4)	-15.58**	-15.58**	-9.66**	1.46	18.55**	48.56**	-27.14**	46.64**	-28.22**	180.15**
C4 (P1×P5)	-4.82	2.60	-5.12*	1.15	2.97*	46.98**	2.77	-8.28	-3.97	-46.18**
C5 (P2×P3)	-16.05**	-11.69**	-4.88**	28.92**	30.77**	29.56**	-9.13	-8.45	10.56	-35.09**
C6 (P2×P4)	-13.04**	-22.08**	1.03	13.46**	43.44**	79.75**	-34.57**	31.68**	-47.33**	105.57**
C7 (P2×P5)	-16.87**	-10.39**	3.69	8.00**	-9.23**	29.56**	-21.63**	-21.05**	56.94**	-12.04*
C8 (P3×P4)	3.70	9.09*	-5.25**	28.42**	7.34**	34.51**	-52.49**	-4.37	-79.93**	-21.68**
C9 (P3×P5)	-2.41	5.19	2.43	38.83**	-35.85**	-8.44**	-9.63	-12.59*	11.78	-34.37**
C10 (P4×P5)	-20.48**	-14.29**	1.58	14.08**	26.24**	80.19**	-26.17**	48.59**	-49.47**	97.19**

Note: D50% = Days of 50% flowering; PH = Plant height; NSB = Number of secondary branches, NFC = Number of fruits per cluster; NFP= Number of fruits per plant; BP = Better parent, CV = Check variety (BARI hybrid tomato-4); *P>0.05, **P >0.01

of plant height over check variety BARI hybrid tomato- 4 (Table 10) and Appendix VI (a). Dhilon *et al.* (2019) reported maximum heterosis for plant height. Kumar *et al*. (2012) reported negative heterosis for plant height.

4.3.3 Number of secondary branches per plant

In the case of secondary branches, positive heterosis is desirable which helps to develop more tomatoes in a plant. The estimated heterosis value ranged from -35.85 % to 43.44% over better parent and -8.44% to 80.19% heterosis were found over the check variety. Five hybrids *viz.* P2×P4 (C6), P2×P3 (C5), P4×P5 (C10), P1×P4 (C3), and P1×P2 (C1) manifested highly positive significant heterosis over the better parent, while two hybrids *viz*. P3×P5 (C9) and P2×P5 (C7) manifested highly negative significant heterosis over the better parent. On the other hand, nine hybrids *viz* P1×P2 (C1), P1×P3 (C2), P1×P4 (C3), P1×P5 (C4), P2×P3 (C5), P2×P4 (C6), P2×P5 (C7), P3×P4 (C8) and P4×P5 (C10) showed highly positive significant heterosis over check variety and only one hybrid showed negative significant heterosis (Table 10) and Appendix VI (a).

4.3.4 Number of fruits per cluster

Among the ten (10) cross combinations six crosses manifested negative significant heterosis over the better parent. The heterosis over better parent ranges from -52.49% to 2.77 (Table 10). The highest significant positive heterosis was observed in the cross P4×P5 (48.59%) followed by P1×P4 (46.64%) and P2×P4 (31.68%) over the check variety BARI hybrid tomato-4. The highest significant negative heterosis was manifested in the cross P2×P5 (-21.05%) followed by P1×P2 (-16.04%) and P3×P5 (-12.59%) (Appendix VI b). Bhatt *et al.* (1999), Kumar *et al.* (2012), and Islam *et al.* (2012) also found appreciable heterosis for fruits per cluster in tomatoes.

4.3.5 Number of fruits per plant

For the number of fruits per plant, three crosses manifested positive significant heterosis over the better parent, and out of all four crosses showed significant negative significant heterosis (Table 10). The highest significant positive heterosis was manifested in the cross P1×P3 (91.13%) followed by P1×P2 (75.55%) and P2×P5 (56.94%) over the better parent. The estimate of heterosis ranges from - 46.18% to 180.15% over the check variety. Three crosses manifested the positive significant heterosis over the check variety; these were P1×P4 (180.15%) followed by P2×P4 (105.57%) and P4×P5 (97.19%) (Appendix VI b). The heterosis for fruit per plant was also reported by several workers like Vidyasagar *et al.* (1997), Bhatt *et al.* (1999), Sekar (2001), Kumar *et al.* (2012), Islam *et al*. (2012), Souza *et al.* (2012), Sharma *et al.* (2014), Kumar *et al.* (2017), Gautam *et al.* (2018) and Dhilon *et al.* (2019).

4.3.6 Single fruit weight (g)

Seven crosses manifested negative heterosis over better parent for single fruit weight (g). The heterosis over better parent ranges from -82.43 % to 4.53 (Table 10). The highest significant positive heterosis was observed in six cross combinations *viz* P2×P3 (73.07%), P3×P4 (65.84%), P3×P5 (54.64%), P1×P3 (49.10%), P2×P5 (47.88%) and P1×P2 (19.60%) over the check variety BARI hybrid tomato-4. The highest significant negative heterosis was observed in the cross P2×P4 (-68.82%) followed by P1×P4 (-66.87%) and P4×P5 (-59.19%) (Appendix VI b). Singh *et al.* (1995), Kumar *et al.* (1995 a), Kumar *et al.* (1995 b), Vidyasagar *et al.* (1997), Ahmad *et al.* (2011), Islam *et al*. (2012), Kumar *et al*. (2012), Sharma *et al.* (2014), Kumar *et al.* (2017) and Gautam *et al.* (2018) reported heterosis for this trait.

4.3.7 Fruit diameter (mm)

In the case of fruit diameter, positive significant heterosis was desirable for yield contributing trait. The F_1 hybrid line P3×P4 (15.00%) manifested significant positive heterosis over better parent (Table 10). However, the other five crosses *viz.* P2×P4 (-50.57%), P1×P4 (-47.93%), P4×P5 (-38.12%), P1×P2 (-17.01%), P1×P5 (-15.38%) manifested negative significant heterosis and the highest one among the crosses was P2×P4 (-50.57%) over better parent. Two-hybrid crosses *viz.* P1×P3 (15.49%) and P3×P4 (8.37%) showed positive significant heterosis over the over check variety and four crosses *viz.* P2×P4 (-54.50%), P1×P4 (-43.21%), P4×P5 (-40.31%) and P1×P2 (-9.49%) manifested negative significant heterosis (Appendix VI c). Heterosis for fruit diameter was also reported by Chaudhury and Khanna (1972), Susie (1998), Wang *et al* (1998 b), Islam *et al*. (2012), and Kumar *et al.* (2013).

Table 10 (cont^n). Estimation of heterosis over better parent (BP) and Check variety CV (BARI hybrid tomato-4) for SFW, FD, FL, DFH and YPP in ten (10) F_1 hybrids derived from 5×5 diallel cross in tomato

Crosses	SFW		FD		FL		DFH		YPP (Kg)	
	BP	CV	BP	CV	BP	CV	BP	CV	BP	CV
C1 (P1×P2)	-32.60**	19.60**	-17.01**	-9.49*	-20.69**	-3.20	-20.08**	-17.43**	54.56**	40.16**
C2 (P1×P3)	-8.26**	49.10**	5.90	15.49**	1.68	18.86**	-3.21	0.00	31.24**	33.80**
C3 (P1×P4)	-79.61**	-66.87**	-47.93**	-43.21**	-42.40**	-32.67**	-20.08**	-17.43**	61.22**	1.65
C4 (P1×P5)	-39.67**	-1.59	-15.38**	-7.72	-9.38**	5.93	-3.97	0.41	-47.85**	-43.34**
C5 (P2×P3)	-2.48	73.07**	8.46	2.21	-5.95*	14.79**	-0.81	2.07	3.69	5.72
C6 (P2×P4)	-82.43**	-68.82**	-50.57**	-54.50**	-47.29**	-35.67**	-13.48**	-17.43**	7.80	-2.24
C7 (P2×P5)	-16.67**	47.88**	5.66	1.91	-14.78**	4.01	5.16*	9.96**	37.88**	49.80**
C8 (P3×P4)	4.53	65.84**	15.00**	8.37*	20.50**	23.65**	12.10**	15.35**	6.94**	9.03
C9 (P3×P5)	-5.19	54.64**	3.83	0.15	1.94	4.61	-2.02	0.83	-0.52	8.10
C10 (P4×P5)	-74.98**	-59.19**	-38.12**	-40.31**	-31.28**	-30.85**	-25.37**	-16.60**	-13.71*	-6.25

Note: SFW **=** Single fruit weight; FD = Fruit diameter; FL= Fruit length; DFH = Days to first harvesting; YPP = Yield per plant; BP = Better parent, CV = Check Variety (BARI hybrid tomato-4); *P>0.05, **P >0.01

4.3.8 Fruit length (mm)

Significant positive heterosis was desirable for the trait of fruit length for developing long length fruit trait. In the present investigation, only one hybrid manifested positive significant heterosis over the better parent (BP). The highest heterosis over the better parent was found 20.50 % heterosis in the cross combination of P3×P4. On the other hand, six crosses *viz*. P2×P4 (-47.29%), P1×P4 (-42.40%), P4×P5 (-31.28%), P1×P2 (-20.69%), P2×P5 (-14.78%) and P1×P5 (-9.38%) manifested negative significant heterosis over the better parent and among them the cross combination P2×P4 showed the highest -47.29% heterosis over the better parent (Table 10). The results of standard heterosis computed relative to check variety showed that three tested hybrids *viz.* P1×P3, P2×P3, and P3×P4 manifested 18.86%, 14.79%, and 23.65% significant positive heterosis respectively. Among the crosses three F_1 hybrids *viz.* P2×P4 (-35.67%), P1×P4 (-32.67%), and P4×P5 (-30.85%) manifested significant negative heterosis over check variety BARI hybrid tomato-4 hybrid variety (Appendix VI c). Islam *et al*. (2012) reported the highest heterobeltiosis for fruit length in P7× P8 (3.09 %).

4.3.9 Days to first harvesting

In the case of days to first harvesting negative heterosis is also desirable for developing early maturity hybrid variety. In the present investigation, four (4) F_1 hybrids manifested significant negative heterosis over the better parent (BP) along with the check variety. The highest negative significant heterosis (-25.37%) was provided by the hybrid combination P4×P5 for days to first harvesting over the better parent. In the case of standard heterosis, the highest significant negative heterosis (-17.43%) over the check variety was obtained in test hybrid lines P1×P2, P1×P4 and P2×P4 respectively (Table 10). Again the hybrid line P4×P5 showed -16.60% the negative heterosis over the check variety BARI hybrid tomato-4 hybrid variety (Appendix VI c). Islam *et al.* (2012), Sharma *et al.* (2014), Dhilon *et al.* (2019), and Sharma *et al.* (2018) reported that, minimum days taken to first picking as early ripening followed by 12-1 × BT-20-3 (Yellow Egg Shape) hybrid over check variety as well as F_1 TOINDVAR-1 × TOINDVAR-5 hybrid and cross P3 × P8 (-18.46%) over the better parent.

4.3.10 Yield per plant (kg)

For yield per plant trait, five crosses manifested positive significant heterosis over the better parent and two of crosses manifested significant negative heterosis over the better parent (Table 10). The highest significant positive heterosis was observed in the cross P1×P4 (61.22%) followed by P1×P2 (54.56%), P2×P5 (37.88%), P1×P3 (31.24%), and P3×P4 (6.94%) over the better parent. The highest significant positive heterosis observed in crosses P2×P5 (49.80%) followed by P1×P2 (40.16%) and P1×P3 (33.80%) respectively over the hybrid check variety BARI hybrid -4, while the hybrid line P1×P5 (-43.34%) showed the negative significant heterosis over the hybrid check variety (Appendix VI c). Singh *et al* (1996), Bhatt *et al.* (1999), Bhatt (2001 a), Ahmad *et al.* (2011), Ramana *et al.* (2011), Patwary *et al*. (2013), Kumar *et al.* (2013), Sharma *et al.* (2014) and Dhilon *et al.* (2019) also reported heterobeltiosis for this trait.

SUMMARY AND CONCLUSION

CHAPTER V
SUMMARY AND CONCLUSION

The study was conducted on 5×5 diallel cross to evaluate the ten F_1 hybrids of tomato for different agronomic and nutritional traits. To develop the F_1 hybrid lines, five parental genotypes were matted in 5×5 half-diallel fashion during the rabi season 2017-18. And then the developed ten F_1 hybrids including their five parents were evaluated for their combining ability and heterosis over check variety BARI hybrid tomato-4 and corresponding better parent at the research farm of Sher-e-Bangla Agricultural University, Dhaka 1207 during rabi season 2018-19. The experiment on the evaluation of F_1 hybrids was laid in RCBD design using three replications. All the required intercultural operations were done during the experiment. On the other hand, some nutritional traits of that developed ten F_1 hybrids including their parents were also evaluated in our departmental laboratory.

Highly significant ($p<0.001$) differences were observed among the genotypes studied in the experiment for almost all the agronomic traits under study *viz.* days of 50% flowering, plant height, number of secondary branches, number of fruits per cluster, number of fruits per plant, single fruit weight, fruit diameter, fruit length, days of first harvesting, yield per plant, pericarp thickness, shelf life, and the number of locules per fruit Again, highly significant ($p<0.001$) differences due to genotypes were also observed for all nutritional traits *viz.* Brix %, vitamin- C content, and titrable acidity %.

On the other hand, the mean data of parental genotypes and F_1 hybrids overall showed some valuable experimental information for further research. Among five parents, P2 proved the best one for some agronomic traits such as dwarf plant height (89.40 cm), earliness in 50% flowering (23) days, fruit length (59.34 mm), number of fruits per cluster (5.84), and single fruit weight (100.18 g). Among all cross combinations *viz.* P1×P3, P1×P4, P2×P4, and P4×P5 were proved best F_1 hybrids for some yield contributing traits such as fruit diameter, fruit length, number of fruits per plant and number of fruits per cluster, etc.

Besides, two cross combinations *viz.* P1×P4 and P2×P4 were also proved for dwarf plant height, early flowering, and early maturity. Furthermore, three cross combinations *viz.* P2×P5 (3.18 kg), P1×P2 (2.97 kg), and P1×P3 (2.84 kg) were proved best F_1 hybrids for higher yield per plant over the check variety BARI hybrid tomato-4.

Furthermore, two cross combinations *viz.* P1×P2 and P1×P5 were the best for longer shelf life, maximum pericarp thickness, and the number of locules traits. The three cross combinations *viz.* P1×P4, P2×P4, and P4×P5 were best for vitamin-C content, Brix percentage, and titrable acidity percentage.

In the present study, the result showed that 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 in governing the traits to the next generation. Also, the ratio of components expressed that the values of GCA were higher than the SCA values for all the traits *viz*. days of 50% flowering, plant height, number of secondary branches, fruit diameter, fruit length, number of fruits per cluster, number of fruits per plant, single fruit weight, days to first harvesting and yield per plant which indicated that additive gene effects were more prominent for all of the traits and the superiority of additive gene effects for the inheritance of these traits. On the contrary, combining ability analysis also exposed that estimates of SCA variance were higher than GCA for only one trait which is the yield per plant suggesting predominance of non-additive or dominant gene action.

The study considering the general combining ability towards desirable direction among five parental lines revealed that P2 and P4 were proved to be the best general combiner for plant height, days to 50% flowering and days to first harvesting, while the parental lines P2 and P3 were proved to be the best general combiner for yield and yield-related traits.

In the present study, cross combination P1×P2 (C1), P1×P4 (C3), and P1×P5 (C4) showed the best specific combiners for the traits of plant height and days to 1st harvesting because of expressing considerable negative significant SCA effects and crosses P2×P5 (C7) and P1×P3 (C2) showed positive significant SCA effect for yield trait. Again, cross combination P2×P5 (C7) showed a positive significant SCA effect as well as expressed as the best specific combiner for the traits *viz*. fruit diameter, the number of fruit per plant, and single fruit weight. Moreover, P3×P4 (C8) showed the best specific combiner for *viz*. single fruit weight, fruit diameter, and fruit length traits because of expressing considerable positive significant SCA effect.

Besides, three F_1's *viz.* P1×P3 (C2), P1×P4 (C3), and P2×P5 (C7) showed the best specific combiners for the number of fruit per plant as expressing highly significant SCA effects. Among them, P1×P4 (C3) showed the highest specific combining ability for this trait. Thus the overall result showed that the tested cross-combinations P2×P5 (C7), P1×P3 (C2), and P3×P4 (C8) showed the best specific combiners for yield and yield-related traits.

P1×P2 (C1), P1×P4 (C3), P2×P4 (C6), and P4×P5 (C10) manifested the negative significant heterosis over check variety for both traits of days to 50% flowering and days to first harvesting and also manifested desirable positive significant heterosis for the number of secondary branches and number of fruits per plant trait. None of the crosses showed desirable negative heterosis over check variety for plant height. Cross combinations *viz.* P1×P2 (C1), P1×P3 (C2) and P2×P5 (C7) showed highly significant positive standard heterosis 40.16%, 33.80%, and 40.16% respectively over check variety BARI hybrid tomato-4 for yield and yield contributing traits.

Recommendations

- Considering the combining ability and standard heterosis for yield and yield-related traits two tested hybrids *viz*. P1×P3 (C2) and P2×P5 (C7) might be recommended as superior tomato hybrids for further trial.
- F_1 hybrid lines *viz.* P1×P2 (C1), P1×P4 (C3), and P4×P5 (C10) might be selected for early maturity trait based on the best specific combiner and standard heterosis over check variety and also higher nutritional traits.

REFERENCES

REFERENCES

Agarwal. A., Arya, D.N., Ranjan, R. and Ahmed, Z. (2014). Heterosis, combining ability and gene action for yield and quality traits in tomato. *Helix* **2**: 511-515.

Ahmad, M., Gul, Z., Khan, Z.U., Iqbal, M., Khan, B., Saleem, M. and Ullah (2011) , I. Study of heterosis in different cross combinations of tomato for yield and yield components. *Int. J. Biosci.* **7** (2): 12-18.

Ahmad, M., Iqbal, M., Gul, Z., Khan, B.A., Shahid, M., Saleem, M. and Khan, N.I. (2016). Genetic analysis of F_2 population of tomato for studying quantitative traits in the cross between Bushbeef × Nagina. *J. Res. Biol.***6** (1):1922-1927.

Ahmad, S. (2002). Genetics of fruit set and related traits in tomato under hot- humid conditions. Ph.D. Thesis. BSMRAU, Gazipur, Bangladesh. pp. 236.

Ahmad, S., Quamruzzaman, A.K.M. and Nazim Uddin, M. (2009). Combining ability estimates of tomato (*Solanum lycopersicum)* in late summer. *SAARC J. Agri.,* **7** (1): 43-56.

Ahmad, S., Quamruzzaman, A.K.M. and Islam, M.R. (2011). Estimate of heterosis in tomato (*Solanum lycopersicum* L.). *Bangladesh J. Agril. Res.* **36** (3): 521-527.

Aisyah, S.I., Wahyuni, S., Syukur, M. and Witono, J.R. (2016). The Estimation of combining ability and heterosis effect for yield and yield components in tomato (*Solanum lycopersicum* Mill.) at Lowland. *J. Crop Breed. and Genet*. **2 (**1):23-29.

Akhtar, S. and Hazra, P. (2013). Nature of gene action for fruit quality characters of tomato (*Solanum lycopersicum*). *African J. Biotech* **12** (20):2869-2875.

Alabi, S.O., Obilana, A.B. and Nwasike, C.C.(1987). Gene action and combining ability for quantitative characters in upland cotton. *Samaru Agric. Res*. **5** (1-2): 59-64.

Angadi, A., Dharmatti, P.R. And Angadi, P.K. (2012). Combining ability studies for productivity-related traits in tomato (*Lycopersicon esculentum* Mill.). *Asian J. Hort.* **7** (1): 17-20.

Baban, D.S., Nasibhai, N.J., Krishna, H., Mulshankar, B.V., Keshavbhai, D.L. and Virsanbhai, B.A. (2015). Estimating the combining ability effect of the Indian and exotic lines of tomatoes by partial diallel analysis. *Turkish J. Agril*. **3**(9): 715-720.

Baktash, F.U. (1995). An experimental program to develop single hybrids in maize. *Iraqi J. Agric.* **26** (1): 131-139.

BBS (2018). Yearbook of Agricultural Statistics of Bangladesh. Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's of the Republic of Bangladesh, Dhaka.

Bhatnagar, S., Betran, F.J. and Rooney, L.W. (2004). Combining abilities of quality protein maize inbreeds. *Crop Sci. J.* **44**: 1997–2005.

Bhatt, R.P., Biswas, V.R. and Kumar, N. (2001b). Combining ability studies in tomato (*Lycopersicon esculentum* Mill.) under mid-hill conditions of Central Himalaya. *Indian J. Genet. Plant Breed*. **61**(1): 74-75.

Bhatt, R.P., V.R. Biswas and N, Kumar. (1999). Studies of heterosis for certain characters in tomato *(Lycopersicon esculentum* L.) under mid-hill condition. *Progressive Hort*. **31**(1-2): 41-43.

Bhatt, R.P., V.R. Biswas and N, Kumar. (2001a). Heterosis, combining ability and genetics for vitamin C, total soluble solids, and yield in tomato *(Lycopersicon esculentum)* at 1700m altitude. *J. Agric. Sci*. **137** (1): 71-75.

Bhavna, M. and Patel, A.I. (2014). Combining ability study in tomato (*Lycopersicon esculentum* Mill.). *Trends Biosci.* **7**: 245-256.

Bhowmik, D., Kumar, K.P. S., Paswan, S. and Srivastava, S. (2012). Tomato a natural medicine and its health benefits. *J. Pharm. Phytochem*. **1**(1): 33-43.

Bhuiyan, M.S.R. (1982). Heterosis and Combining Ability in tomato (*Lycopersicon esculentum* Mill.). MS Thesis, BAU, Mymensingh, Bangladesh. pp. 64.

Chadha, K.L. (2001). Tomato; Handbook of Horticulture. ICAR publication pp. 8

Chadha, S., Vidyasagar and Kumar, J. (1997). Combining ability and gene action studies in tomato involving important bacterial wilt resistant lines. *Himachal J. Agric. Res*. **23** (1 -2):26-32.

Chandrasekhar, P. and Rao, M.R. (1989). Studies on combining ability of certain characters in tomato. *South Indian Hort*. **37**(1): 10-12.

Charles, W.B. and Harris, R.E. (1972). Tomato fruit set at high and low temperatures. *Canadian J. Plant. Sci.* **52**: 497-506.

Chattopadhyay, A. and Paul, A. (2012). Studies on heterosis in tomato (*Solanum lycopersicum* L.). *Intl. J. Bio-Res*. **3**(3): 278.

Chaudhary, B. and Khanna, K.R. (1996). Exploitation of heterosis in tomato yield and components. *South Indian J. Hort*. **49**: 59-85.

Chaudhury, R.C. and K.R. Khanna. (1972). Exploitation of heterosis in tomato yield and components. *South Indian Hort*. **20:** 59-65.

Chawla, H.S. and Gupta, V.P. (1984). Index India-Agric. *Indian Calcutta Agric*. **28**(4): 261-265.

Chowdhury, B., Punia, R. S. and Sangha, H. S. (1965). Manifestation of hybrid vigor in F_1 and its correlation in F_2 generation of tomato (*Lycopersicon esculentum* Mill). *Indian J. Hort.* **22**: 52-59.

Chukwu, S.C., Okporie, E.O., Onyishi, G.C., Ekwu, L.G., Nwogbaga, A.C. and Ede, N.V. (2016). Application of diallel analyses in crop improvement. *Agric. Biol. J. North America.* **7** (2): 95-106.

Cruz, C.D. and Regazzi, A.J. (1997). Modelos Biométricos aplicados ao melhoramento genético. Viçosa: UFV. p. 390.

Dhaliwal, M. S., Singh, S., Cheema, D. S. and Singh, P. (2004). Genetic analysis for important fruit characters of tomato by involving lines possessing male sterility genes. *Acta Hort.* **637**: 123-131.

Dharmatti, P.R., Mandalgeri, B., Band Patil, G. (2001). Combining ability studies in summer tomato. *Karnataka J. Agril. Res*. **14** (2): 417-422.

Dharva, P.B., Patel, A.I., Vashi, J.M. and Chaudhari, B.N. (2018). Heterosis studies for yield and its attributing traits in tomato (*Solanum lycopersicum* L.). *Int. J. Chem. Study* **6** (3): 1911-1916.

Dhillon, N.S., Sharma, P., Kumar, P. and Sharma, V. (2019). Assessment of tomato hybrids for yield and quality attributes under a protected environment. *Int. J. Curr. Microbiol. App. Sci*. **8** (5): 256-262.

Dod, V.N., And Kale, P.B. (1992). Heterosis for certain quality traits in tomato (*Lycopersicon esculentum* Mill.*). Crop Res. Hisar.* **9** (3): 407-412.

Duhan, D. Partap, P.S., Rana, M.K. and Dudi, B.S. (2005). Combining ability study for growth and yield characters in tomato. *Haryana J. hortic. Sci.* **34** (1-2): 128-134.

Edris, K.M., Islam, A.T.M.T., Chowdhury, M.S. and Huq, A.M.M.M. (1979). Detailed Soil Survey, Bangladesh Agricultural University Farm, Mymensingh. Department of Soil Survey, Govt. of the Peoples Republic of Bangladesh, Bangladesh. p. 118.

EI-Mahdy, I., E-Metwally, G., EI-Fadly and Mazrouh, A.Y. (1990). Inheritance of yield and fruit set quality of some tomato crosses grown under heat stress conditions in Egypt. *J. Agril. Res. Tanta Univ.* **16** (3): 517-526.

E-Metwally; A. El-Zewily; N. Hassan and O. Zanata. (1996). Inheritance of fruit set and yield of tomato under high-temperature conditions in Egypt. I[s1] Egypt-*Hung. Hort. Conf.,* **1**:112-122 p.

Falconer, D.S. (1989). Introduction to Quantitative Genetics. *Longman Inc. Ltd.,* New York, USA. p.433

Farzane, A., Nemati, H., Arouiee, H., Kakhki, A.M. and Vahdati, N. (2012). The estimate of Combining ability and heterosis for yield and some yield components in tomato *(Solanum lycopersicum* L*). J. Biol. Environ. Sci.* **6** (17):129-134.

Fasahat, P., Rajabi, A., Rad, J.M. and Derera, J. (2016). Principles and utilization of combining ability in plant breeding. *Biomet. Biostat. Intl. J.* **4** (1), 00085.

Gautam, N., Kumar, M., Vikram, A., Kumar, S. and Sharma, S. (2018). Heterosis studies for yield and its components in tomato (*Solanum lycopersicum* L.) under North Western Himalayan Region. *India. Int. J. Curr. Microbiol. App. Sci.* **7** (2): 1949-1957.

Gayosso-Barragán, O., López-Benítez, A., Rodríguez-Herrera, S.A., Ek-Maas, J.N., Hidalgo-Ramos, D.S. and Alcala-Rico, J.S.G.J. (2019). Studies on combining ability in tomato (*Solanum lycopersicum* L.). *Agro. Res*. **17**(1): 77–85.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing system. *Australian J. Biol. Sci*. **9**: 463-493.

Gul, R., Hidayat, U.R., Khalil, I.H., Shah, M.A. and Ghafoor, A. (2010). Heterosis for flower and fruit traits in tomato (*Lycopersicon esculentum* Mill). *African J. Biotechnol.* **9** (27):4144-4151.

Hannan, M.M., Ahmed, M.B., Razvy, R., Karim, R., Khatun, M., Hayar, A., Hossan, M. and Roy, U.K. (2007). Heterosis and correlation of yield and yield components in tomato (*Lycopersicon esculentum* Mill). *American-Eurasian J. Sci. Res*. **2** (2): 146-150.

Hayman, B. I. (1954). The analysis of variance of diallel tables. *Biometrics*. **10**: 235-244.

Hayman, B.I. (1960). The separation of epistatic from additive and dominance variation in generation means. *Genetics.* **31**: 133–146.

Hedrick, U.P. and Booth, N.O. (1907). Mendelian characters in tomatoes. *Proc. American.. Soc. Hort. Sci*. **5**:19–24.

Himadri, G. and Ashish, D. (2003). Optimal diallel cross designs for estimation of heritability. *J. static. planning.* **116** (1): 185-196.

Islam, M.R., Ahmad, S. and Rahman, M.M. (2012). Heterosis and qualitative attributes in winter tomato (*Solanum Lycopersicum* L.) hybrids. *Bangladesh J. Agril. Res.* **37** (1): 39-48.

Izge, A.U. and Garba, Y.M. (2012). Combining ability for fruit worm resistance in some commercially grown tomatoes in parts of northeastern Nigeria. *Int. J. Agric. Sci.,* **2** (8): 240-244.

Jinks, J.L. (1956). The F_2 and back cross generations from a set of diallel crosses. *Heredity.* **10**: 1-30.

Jinks, J.L. and Hayman, B.I. (1953). The analysis of diallel crosses. *Maize Genetics Coop Newsl.* **27**: 48–54.

Kabir, K.M., Momtaz, A. and Cross, H.Z. (1993). General combining ability effects and heterotic patterns in Maize (*Zea mays L.)* synthesis. *Bangladesh J. Plant Breed.Genet*. **6** (1): 35-43.

Kumar, K., Sharma, D., Singh, J., Sharma, T.K., Kurrey, V.K and Minz, R.R. (2018). Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicum* L.). *J. Pharma. Phytochem.* **7**(6): 1002-1005.

Kumar, P., Singh, N. and Singh, PK. (2017). A study on heterosis in tomato (*Solanum lycopersicum* L.) for yield and its component traits. *Int. J. Curr. Microbiol. App. Sci*. **6** (7):1318-1325.

Kumar, R., Srivastava, K., Singh, N.P., Vasistha, N.K., Singh, R.K. and Singh, M.K. (2013). Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicon* L.) *J. Agril. Sci.* **5** (2): 213-218.

Kumar, R., Srivastava, K., Somappa, J., Kumar, S. and Singh, R.K. (2012). Heterosis for yield and yield components in Tomato (*Lycopersicon esculentum* Mill). *Electron. J. Plant Breed*. **3** (2): 800-805.

Kumar, S., Banarjee, M.K. And Protap, P.S. (1995a). Studies on heterosis for various characters in tomato. *Haryana J. Hort. Sci.* **24** (1): 54-60.

Kumari, S. and Sharma, M.K. (2011). Exploitation of heterosis for yield and its contributing traits in tomato (*Solanum lycopersicum* L.). *Intl. J. Farm Sci.* **1** (2): 45-55.

Kumari, S. and Sharma, M.K. (2012). Line × tester analysis to study combining ability effect in tomato (*Solanum lycopersicum* L.). *Veg. Sci.* **39** (1):65-69.

Maluf, W.R. (2001). Heterosis and the use of F_1 hybrids in vegetables. **In**: Genetic resources and breeding-plants. Nass, L.L., Valoic, A.C.C., Melo, I.S. and Valadares, M.C. (eds.). Editora Fundacao MT, Rondonolis, p. 327-356.

Meena, R.K., Sanjay, K., Meena, M.L. & Shashank, V. (2017). Genetic variability, heritability and genetic advance for yield and quality attributes in tomato (*Solanum lycopersicum* L.). *J. Pharma. Phytochem.* **7**: 1937–1939.

Menkir, A., Badu-Apraku B. Thè, C. and Adepoju, A. (2003). Evaluation of heterotic patterns of IITA’s lowland white maize inbred lines. *Maydica.* **48:** 161–170.

Natarajan, S. (1992). Inheritance of yield and its components in tomato under moisture stress. *Madras Agric. J.* **79** (12): 705-710.

Panchal, B.B., Patel, N.B., Patel, A.I., Tank., R.V. and Patel, H.B. (2016). Combining ability analysis for yield and its related traits in tomato (*Solanum lycopersicum* L.). *Adv. Life Sci*. **5** (1): 188-193.

Pandey, S.K., Dixit, J., Pathak, V.N. and Singh, P.K. (2006). Line x tester analysis for yield and quality characters in tomato (*Solanum lycopersicum* Mill.). *Vegetable Sci.* **33** (1): 13-17.

Paterniani, E. and Viegas, G.P. (1987). Melhoramento e Produção de Milho.Campinas: Fundação Cargill. P.795.

Patwary, M.M.A., Rahman, M.M., Ahmad, S., Miah, M.A.K and Barua, H. (2013). Study of heterosis in heat-tolerant tomato (*Solanum lycopersicum*) during summer. *Bangladesh J. Agril. Res.* **38** (3): 531-544.

Pemba, S., Seth, T., Shende, V.D., Pandiarana, N., Mukherjee, S. and Chattopadhyay, A. (2014). Heterosis, dominance estimate, and genetic control of yield and post-harvest quality traits of tomato. *J. App. Natural Sci.* **6** (2): 625-632.

Peter, K.V. and Rai, B. (2012). Genetic divergence in tomato. *Indian. J. Genet. Plant Breed*. **36** (3): 379-383.

Poehlman, J.M. (1979). Breeding Field Crops. Westport, Conn.: *Avi Publ*. Co.**16**:483.

Premalakshmi, V., Thangaraj, T., Veeraragavathatham, D. and Arumugam, T. (2002). Hybrid vigor for yield and shelf life in tomato (*Lycopersicon esculentum* Mill.). *South Indian Hortic.* **50** (4-6): 360-369.

Premalakshmi, V., Thangaraj, T., Veeraragavathatham, D. and Arumugam, T.(2006). Heterosis and combining ability analysis in tomato. (*Solanum lycopersicum* Mill.) for yield and yield contributing traits. *Veg. Sci*. **33**(1): 5-9.

Rai, G.K., Kumar, R., Singh, A.K., Rai, P.K., Rai, M., Chaturvedi, A.K. and Rai, A.B. (2012). Changes in antioxidant and phytochemical properties of tomato (*Lycopersicon esculentum* Mill.) under ambient condition. *Pak. J. Bot.* **44**(2): 667-670.

Raj, T., Bhardwaj, M.L., Pal, S. and Dogra, R.K., (2017). Combining ability and gene action studies in some genetic stocks of tomato (*Solanum lycopersicum* L.). *Int. J. Curr. Microbiol. App. Sci*. **6**(10): 138-144. *J. Crop. Weed*, **14**(1): 64-68 (2018)

Ramana, V., Srihari, D., Reddy, R.V.S.K., Sujatha, M. and Bhave, M.H.V. (2018). Estimation of heterosis in tomato (*Solanum lycopersicum* L.) for yield attributes and yield. *J. Pharm. Phytochem.* SP **1**: 104-108.

Reddy, G. E., Nandan, R., Reddy, M.P., Reddy, B. R. and Bhandari, H.R.(2017). Studies on combining ability analysis in tomato. *Green Farming* **8** (1): 56-59.

Rojas, B.A. and Sprague, G.F. (1952**).** A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with locations and years. *Agron. J.* **44**: 462–466.

Saleem, M.Y., Asghar, M., Ahsanul, M.H., Rafique, T., Kamran, A. And Khan, A.A. (2009). Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Lycopersicon esculentum* Mill.) *Pakistan J. Bot***. 41** (3): 1107-1116.

Sekar, K. (2001). Heterosis for yield and yield components in tomato *(Lycopersicon esculentum* Mill.). *Advances Hort. Forestry.* **8**: 95-102.

Sharma, A. (2014). Heterosis and combining ability studies in tomato (*Solanum lycopersicum* L.). Ph.D. Thesis. G.B. Pant University of Agriculture and Technology, Pantnagar - 263145 (Uttarakhand), India.p-146.

Sharma, D. and Sharma H.R. (2010). Combining ability analysis for yield and other horticultural traits in tomato. *Indian J. Hortic*, **67** (3): 402-405.

Sharma, P., Vidyasagar, Bhardwaj, N. (2006). Combining ability for certain quality traits in bacterial wilt resistant genotypes in tomato. *Environ. Ecol.* **24** (1): 102-105**.**

Sharma, T.K., Singh, J., Sharma, D., Mehta, N. and Saxena, R.R. (2018). Development of F_1 hybrids of tomato (*Solanum lycopersicum* L.) for protected cultivation. *J. Pharm. Phytochem.***7** (6): 838-843.

Shattuck, V.I., Christie, B. and Corso, C. (1993). Principles for Griffing's combining ability analysis. *Genetica* **90**:73–77.

Shende, V.D., Seth, T., Mukherjee, S. And Chattopadhyay, A. (2012). Breeding tomato (*Solanum lycopersicum* L.) for higher productivity and better processing qualities. *SABRAO J. Breed. Genet*. **44** (2): 302-321.

Shrivastava, A.K., Singh, S.P. and Joshi, A.K. (1993). Combining ability analysis for earliness, yield, fruit cracking, and shelf life in tomato (*Lycopersicon esculentum* Mill.). *Hort. J.* **6** (1): 51-55.

Singh, A., Singh. P.K., Dixit, J., Gautam, J.P.S., Singh, D.N. and Singh, A. (1996). Heterosis and inbreeding depression in tomato. *J. Res. Birsa Agric. Univ*. **8** (l):89-90.

Singh, J. and Sastry, E.V.D. (2011). Heterosis and stress sustainability index for fruit yield and contributing traits in tomato (*Lycopersicon esculentum). Indian J. Agril.Sci.* **81**(10): 957-966.

Singh, P. and Narayanan, S.S. (2004). Biometrical techniques in plant breeding. *Kalyani Publ., New Delhi, India.*

Singh, R..K. and Singh, V.K. (1993). Heterosis breeding in tomato (*Lycopersicon esculentum* Mill.). *Annals of Agril. Res.* **14**: 4, 416-420.

Singh, S. P., Thakur, M.C. and Pathania, N.K., (2010). Reciprocal cross differences and combining ability studies for some quantitative traits in tomato (*Lycopersicon esculentum* Mill.) under mid-hill conditions of Western Himalayas. *Asian J. Hort*. **5** (1): 172-176.

Solieman, T.H.I. (2009). Diallel analysis of five tomato cultivars and estimation of some genetic parameters for growth. *Alexandria sci. exchange J.* **30** (2).

Souza, L.M., Paterniani, M.E.A., Melo, P.C.T. and Melo, A.M. (2012). Diallel cross among fresh market tomato inbreeding lines. *Hortic. Bras.* **30**: 246-251.

Sprague, G.F. (1966). Quantitative genetics in plant improvement. **In**: Plant Breeding, K. J. Frey (ed.). *Iowa State Univ. Press. Ames, IA, USA*, pp.315-354.

Susie, Z. (1998). Effects of parental germplasm on inheriting the characteristics of FI generation of tomato hybrids. *Rev. Res. Work the Faculty Agric. Belgrade.* **43** (2): 63-73.

Tee, E.S., Young, S.I., Ho, S.K. and Mirza, S.S. (1998). Determination of vitamin C in fresh fruits and vegetables using the dye-titration and microfluometric methods. *Pertanika.* **11** (1): 39-44.

Tesi, R., Grainfenberg, A. and Creatim, M.E. (1970). Heterosis and quality in F_1 hybrids of *Lycopersicon esculentum* Mill, growth under glass. *Riv. Ortoflorofruttic Ital.* **54**: 269-92.

Tiwari, A. and Lal, G. (2004). Studies on Heterosis for quantitative and qualitative characters in tomato (*Lycopersicon esculentum* Mill.). *Prog. Hort.* **36** (1): 122-127.

Vavilov, N.I. (1951). The Origin variation immunity and breeding of cultivated plant. Chronica Bot. **13**: 364.

Vedyasagar; Chadha, S. and Kumar, J. (1997). Heterosis in bacterial wilt resistant tomato lines. Himachal J. Agric. Res. **23** (1-2): 40-44.

Vencovsky, R. (1987). Quantitative inheritance. **In:** Paterniani Viegas, G.P. (ed). Improvement and production of corn. Campians : Cargill Foundation. pp. 137-209.

Villareal, R.L. (1980). Tomatoes in the tropics. West View Press, Boulder, Colorado. USA. Pp. 174.

Wang, Y.F., Wang, M., Wang, D.Y. and Wang, L. (1998b). Studies on heterosis in some processing tomato (*Lycopersicon esculentum* Mill.) lines. *Acta, agriculturae Shanghai.* **14** (3): 29-34.

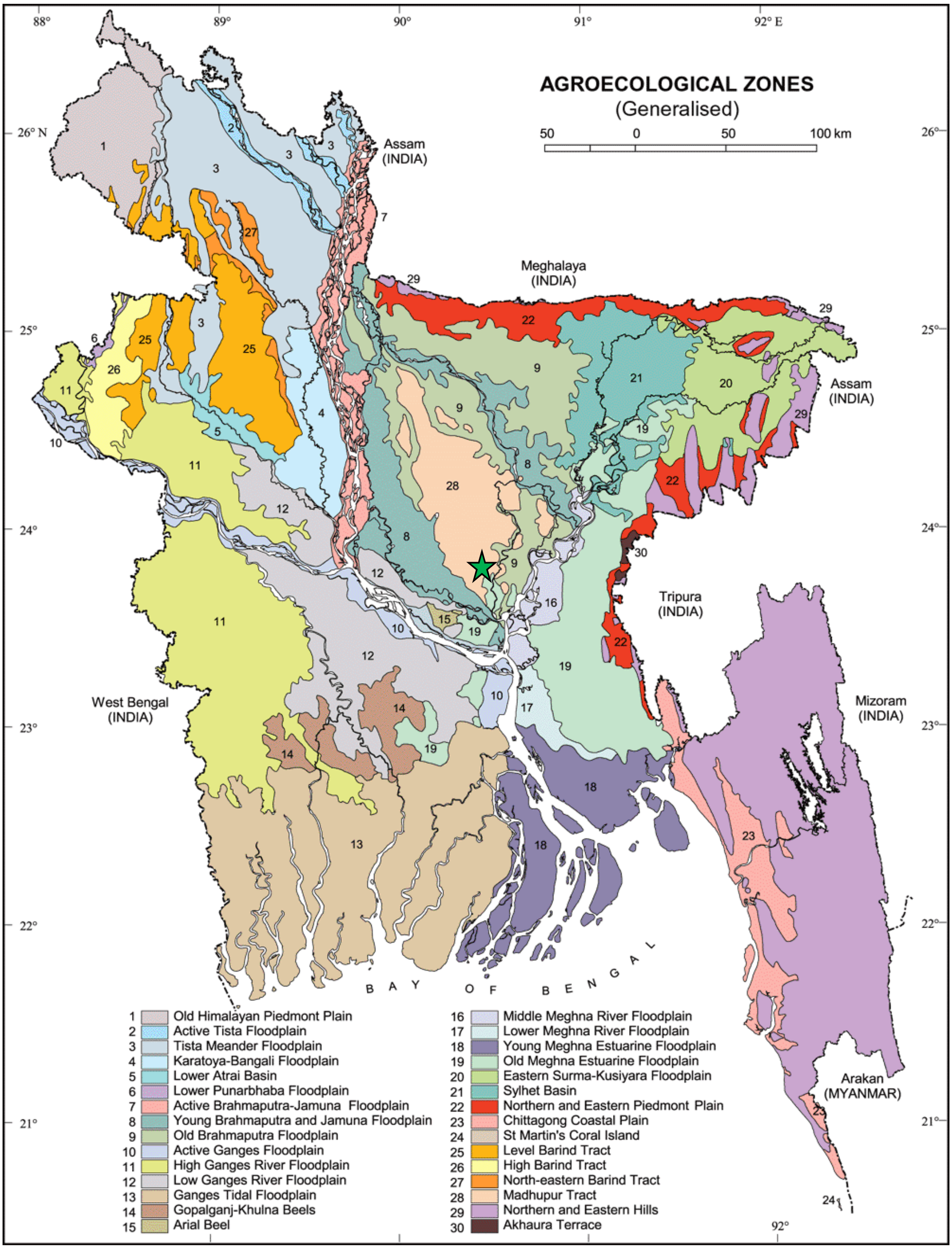
Yadav, S., Yadav, G.C., Kumar, V. and Yadav, S.K. (2016). Combining ability analysis for growth, yield and quality traits of tomato (*Solanum lycopersicon* (Mill.) Wettsd.) genotypes. *E. J. Plant Breed*. **7(3):** 761-766.

Yallou, C.G., Menkir, A., Adetimirin, V.O. and Kling, J.G. (2009). Combining ability of maize inbred lines containing genes from Zea diploperennis for resistance to Striga hermonthica (Del.) Benth. *Plant Breed. J.* **128**: 143–148.

Zengin, S., Kabaş. A., Oğuz1, A., Eren, A. and Polat, E. (2015). Determining of general combining ability for yield, quality and some other traits of tomato (*Solanum lycopersicum* L.) inbred lines. *Akdeniz Univ. Ziraat Fak. Derg*. **28** (1):1-4.

APPENDICES

Appendix I. Map showing the geographical locations under the study



★ The experimental site under the study

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

A. Morphological characteristics of the experimental field

A. Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly 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 III. Monthly average temperature, average relative humidity, and total rainfall and average sunshine of the experimental site during the period from October 2017 to March 2018

Month	Average temperature (°c)		Average RH (%)	Rainfall (mm) (total)	Average sunshine (hr)
	Minimum	Maximum			
October, 2017	25	32	79	175	6
Novenber, 2017	21	30	65	35	8
December, 2017	15	29	74	15	9
January, 2018	13	24	68	7	9
February, 2018	18	30	57	25	8
March, 2018	20	33	57	65	7

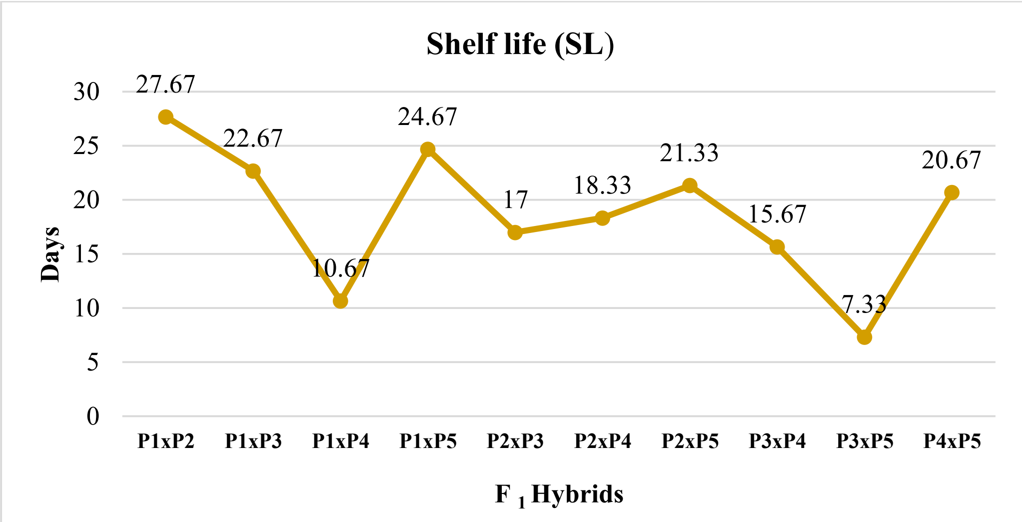
Source: Bangladesh Meteorological Department (Climate & Weather Division), Agargoan, Dhaka – 1207

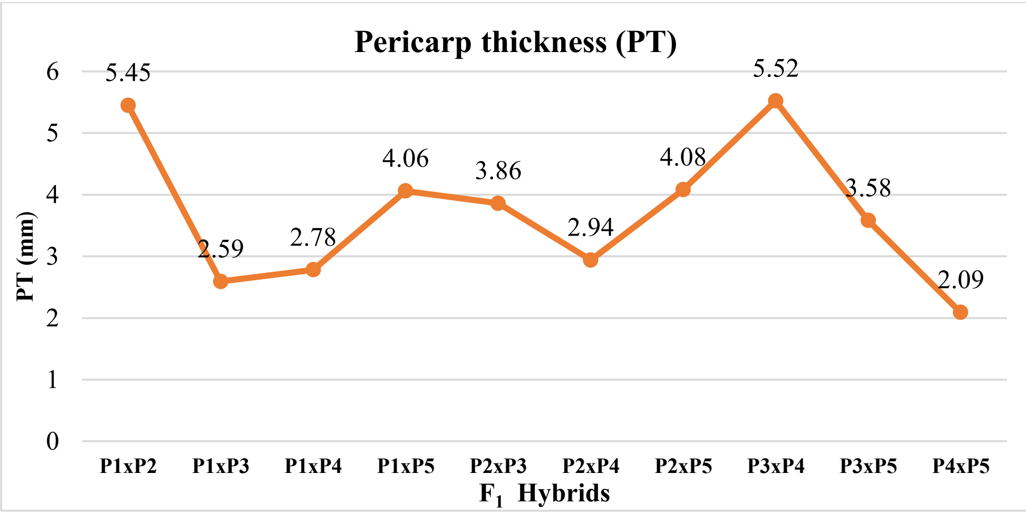
Appendix IV. Monthly average temperature, average relative humidity, and total rainfall and average sunshine of the experimental site during the period from October 2018 to March 2019

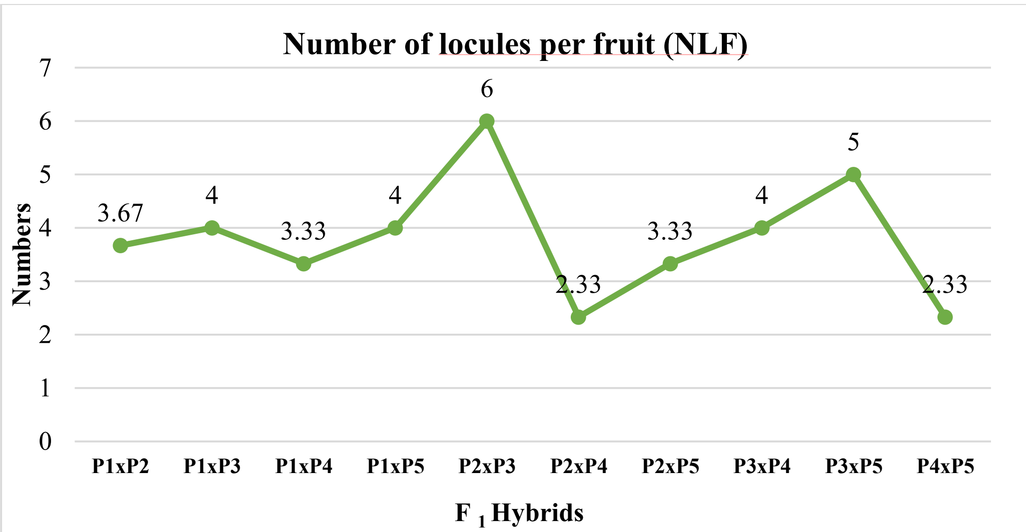
Month	Average temperature (°c)		Average RH (%)	Rainfall (mm) (total)	Average sunshine (hr)
	Minimum	Maximum			
October, 2018	23.8	31.6	77	172.3	11.6
Novenber, 2018	19.2	29.6	64	34.4	8
December, 2018	14.1	26.4	73	12.8	9
January, 2019	12.7	25.4	67	7.7	9
February, 2019	16	28.1	56	28.9	8.1
March, 2019	20.4	32.5	56	65.8	7

Source: Bangladesh Meteorological Department (Climate and Weather Division), Agargoan, Dhaka – 1207

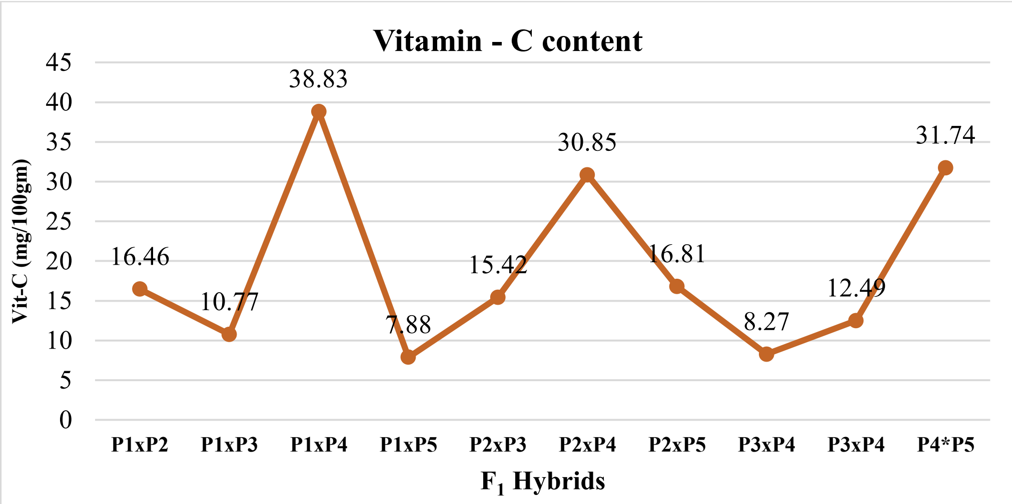
Appendix V(a). The line graphs showing the mean performance of different F_1 hybrid lines for shelf life, pericarp thickness, and the number of locules per fruit

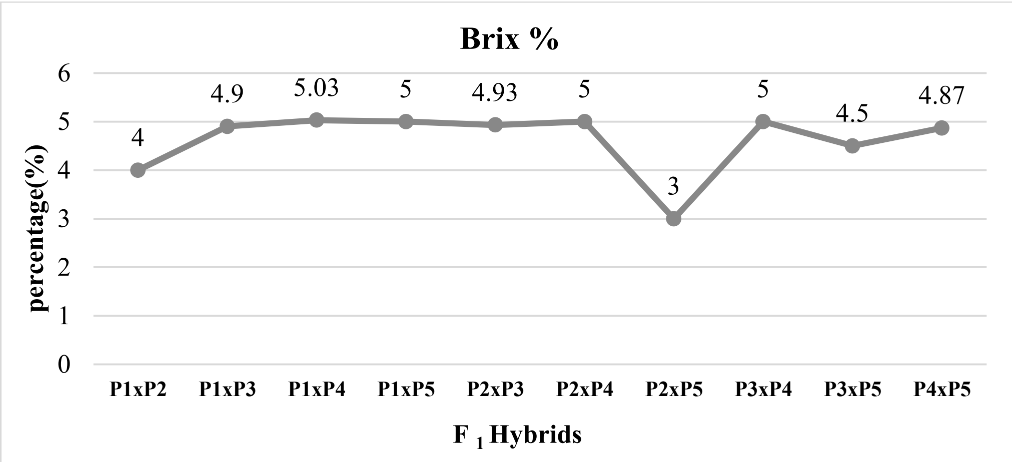


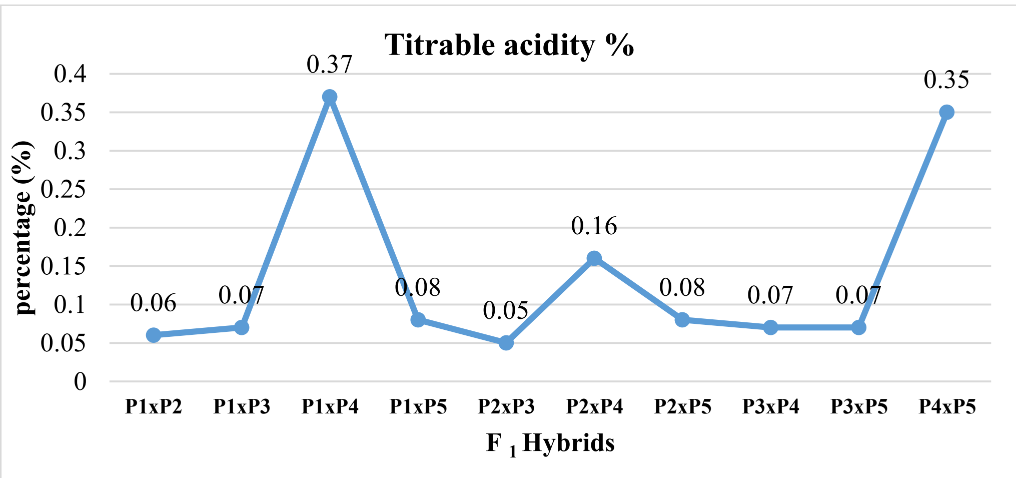




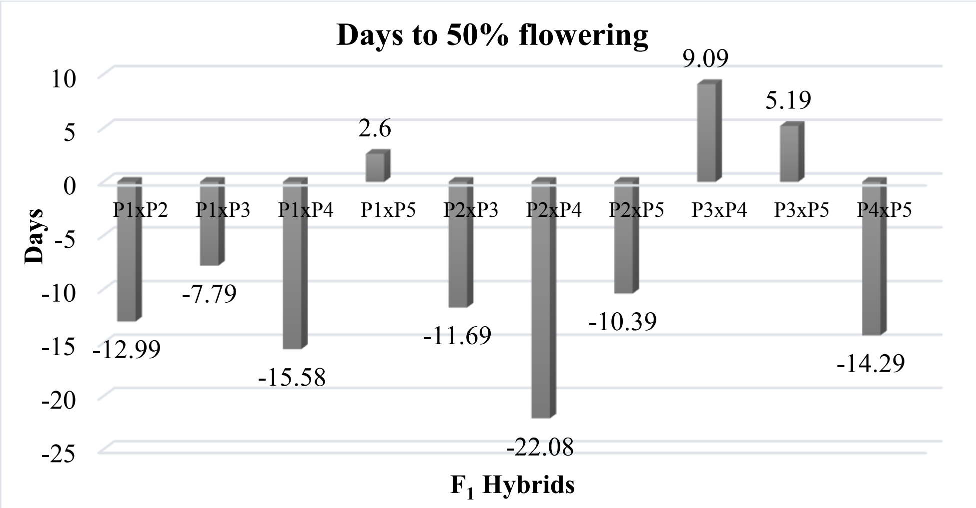
Appendix V(b). The line graphs showing the mean performance of different F_1 hybrid lines for Vitamin-C content, Brix %, and titrable acidity %

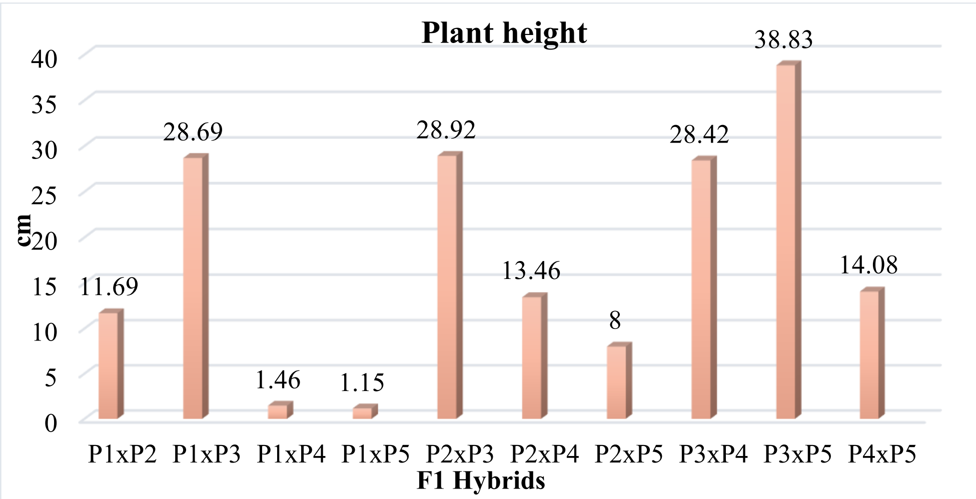


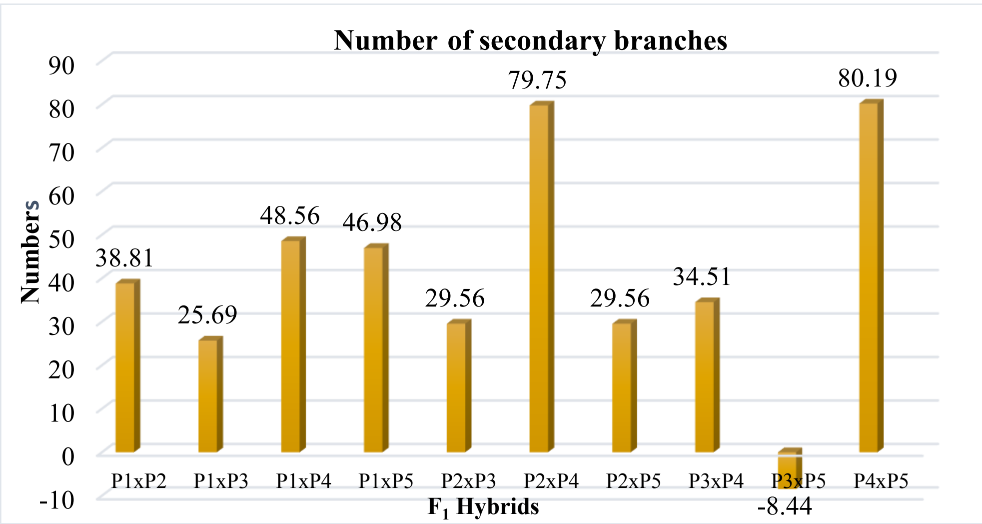




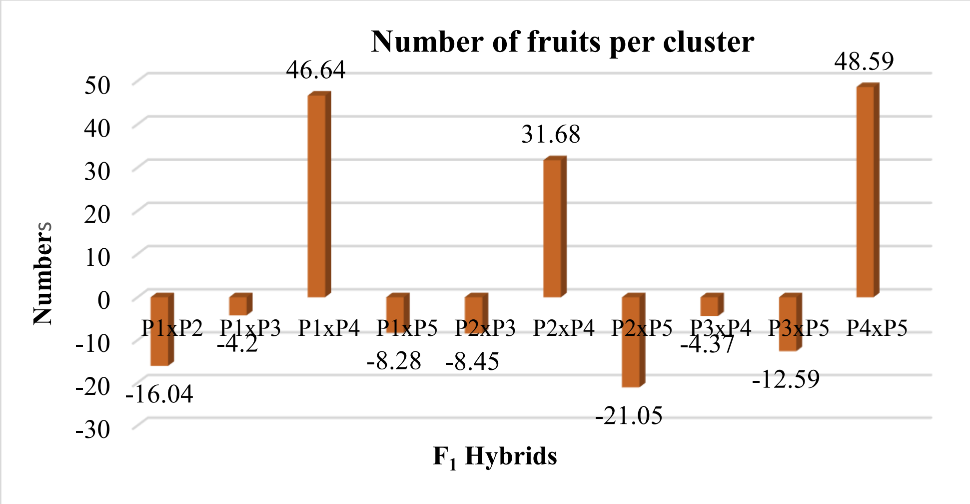
Appendix VI (a). The bar graph showing the standard heterosis over check variety for days to 50% flowering, plant height, and number of secondary branches

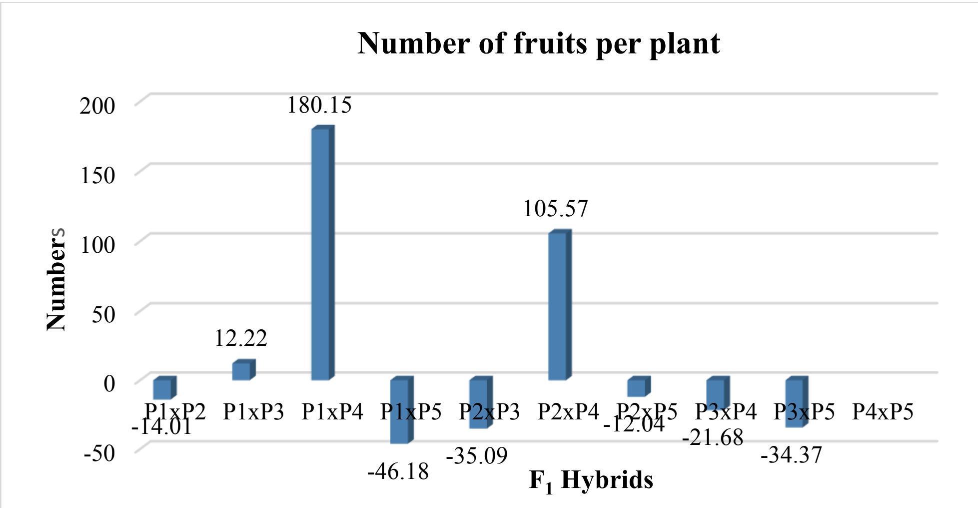


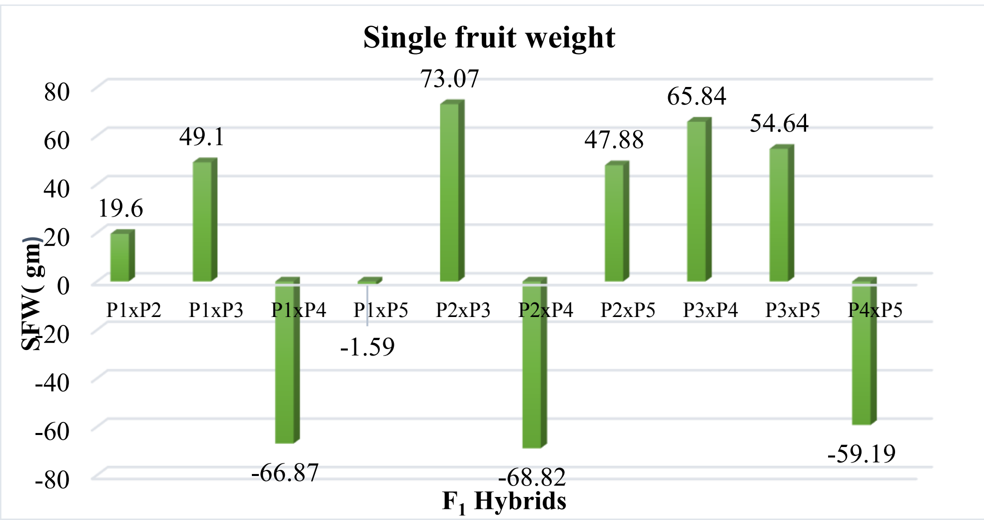




Appendix VI (b). The bar graphs showing the standard heterosis over check variety for number of fruits per cluster, number of fruits per plant, and single fruit weight







Appendix VI (c). The bar graphs showing the standard heterosis over check variety for fruit diameter, fruit length, days to first harvesting, and yield per plant