HETEROSIS AND COMBINING ABILITY ANALYSIS IN INTRASPECIFIC HYBRIDS OF LOCAL AND EXOTIC TOMATO (*Solanum lycopersicum* L.) GENOTYPES

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BY

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CERTIFICATE

This is to certify that the thesis entitled, "Heterosis and combining ability analysis in intraspecific hybrids of local and exotic tomato (Solanum lycopersicum L.) genotypes" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of ***MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING****, embodies the result of a piece of bona fide research work carried out by Saiful Islam Siddiky, Registration number 17-08259 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated: December, 2018
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(Prof. Dr. Naheed Zeba)

Supervisor

DEDICATED TO
MY
BELOVED PARENTS

Some commonly used abbreviations

Full word	Abbreviations	Full word	Abbreviations
Abstract	*Abstr*	International	*Intl.*
Advances/Advanced	*Adv.*	International Journal	*Intl. J.*
Agriculture	*Agric.*	Journal	*J.*
Agricultural	*Agril.*	Kilogram	Kg
Agronomy	*Agron.*	Limited	Ltd.
And others	*et al.*	Ministry	*Min.*
Analysis of Variance	ANOVA	Muriate of Potash	MP
Applied	*App.*	Negative logarithm of hydrogen ion concentration (-log $[H^+]$)	pH
Archives	*Arch.*		
Bangladesh Bareau of Statistics	BBS		
Biology	*Biol.*	Non-significant	^{NS}
Botany	*Bot.*	New South Wales	*NSW.*
Better parent	BP	Mid parent	MP
Breeding	*Breed.*	Parts per million	Ppm
Centimeter	cm	Percentage	%
Component variance	CV	Plant	*PI.*
Cross between two dissimilar parents	X	Proceedings	*Proc.*
		Randomized Complete Block Design	RCBD
Degree celcious	°C		
Division	*Div.*	Research	*Res.*
Economic	*Econ.*	Review	*Rev.*
Environment	*Environ.*	Science	*Sci.*
Etcetera	etc.	Serial	Sl.
Experimental	*Expt.*	Society	*Soc.*
Food and Agricultural Organization	FAO	Specific combining ability	SCA
Gazette	*Gaz.*	Statistics	*Stat.*
General	*Gen.*	That is	i.e.
General combining ability (GCA)	GCA	The First Generation of a cross between two dissimilar parents	F_1
Genetics	*Genet.*		
Gram	g	Triple Super Phosphate	TSP
Heredity	*Hered.*	University	*Univ.*
Horticulture/ HorticulturaL	*Hort.*	Variety	*var.*
		Vegetable	*Veg.*
Incorporated	*Inc.*	Videlicet (namely)	*viz.*
Information	*Inf.*	Weight	wt.

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The Author

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ABSTRACT

The present study was conducted in order to estimate heterosis and combining ability in intraspecific hybrids of some tomato genotypes at Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, during the period of November, 2017 to March, 2018. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications which included six tomato genotypes *viz.* G1 (SAU tomato 1), G2 (SAU tomato 2), G3 (SL001), G4 (SL002), G5 (BARI Tomato 2) and G6 (SL 003). Data was collected and analyzed for 10 characters *viz.* days to first flowering, days to 50% flowering, plant height at 50% flowering, number of cluster per plant, number of fruit per cluster, number of fruits per plant, fruit length, individual fruit weight, fruit diameter and locule number per plant. Seedlings of 31 days old were transplanted to main field. G2 showed significant negative GCA for days to 1st and 50% flowering and significant positive heterosis for number of fruits per plant. In case of hybrids, the lowest days required for 1st flowering was observed in G2XG6 and 50% flowering in G6XG5. Highest number of fruits was observed in G2XG6 and G3XG5 showed the lowest number of fruits per plant. G2XG3, G2XG4, G2XG5 and G2XG6 showed significant higher number of fruits per plant over better parent. In case of days to first flowering G1XG4, G2XG4, G2XG4, G4XG2, G5XG4 and G6XG4 showed significant negative heterosis over better parent and G2XG3, G2XG4 and G4XG2 showed significant negative heterosis over mid parent. G4XG1 and G6XG1 showed significant positive SCA for plant height at 50% flowering. G2 showed significant positive SCA for most of the characters both cased as female or male parent.

INTRODUCTION

CHAPTER I

INTRODUCTION

Tomato is a very popular vegetable in the world and also in Bangladesh. The scientific name of tomato is *Solanum lycopersicum* L. belonging to the family solanaceae. The Genus *Lycopersicum* has come from a Greek word and its meaning is wolf's peach. Among the nine species of this genus only two are cultivated. They are *Solanum lycopersicum* L. (common tomato) and *Solanum pimpinellifolium*. Tomato composes with 2n = 24 chromosome (Jenkins, 1948). Although it was once considered poisonous and inedible, it has become one of the most popular and extensively consumed vegetable around the world at present. Tomato has unique position among the vegetables because of its high nutritive values and myriad uses. It is consumed either fresh or cooked. Tomato is also processed into various products like juice, sauce and many more. Tomatoes are important source of Vitamin A, Vitamin C and some minerals. Tomato is also rich in some medicinal value, such as tomato pulp and juice are digestible, blood purifier, mild aperients. It also acts as a promoter of gastric secretion. Tomato contains antiseptic properties against intestinal infestations. It also contains antioxidant property of ascorbic acid and lycopene content. It is an important source of β-carotene. At present days, tomato is one of the most important raw materials for different food industries. Tomatoes are also known as "Poor man's apple" for their low price and availability.

The native of tomato is Peru, Equador region (Rick, 1969). Some scientist considered that tomato has originated in the new world (The America) i.e., the Andean region which includes part of Bolivia, Colombia, Chili, Ecuador and Peru. According to Heisar (1969), tomato gradually spread from its native land to European countries and rest of the world. Wild cultivars of tomato were found in the tropical rain forests of South America. Tomato is an exogenous crop in Bangladesh. Although tomato is a tropical day neutral nightshade plant, it is well

grown in sub-tropical region in Bangladesh. Tomato is mainly self-pollinated crop but a considerable percentage of cross-pollination also occurs.

The area and production of tomato in Bangladesh is increasing day by day for its diversified use. In Bangladesh, it is grown on an area of 68,366 acres with a production of 388725 M. Ton (BBS, 2017). A spacious range of latitude, soil form and methods of cultivation is favorable for tomato production. A range of night temperature of 15ºC to 20°C ensures optimum fruit setting (Charles and Harris, 1972; Schiable, 1962; Verkerk, 1955). So, winter season is the most preferable for tomato cultivation in Bangladesh.

Heterosis breeding is a suitable tool for genetic improvement in most of the crop and also in tomato. It has been recommended by many researchers ever since the phenomenon of hybrid vigor was observed by Hedrick and Booth (1907). Further, relative consolation in emasculation, pollination, more percentage of fruit fixing and ample seeds per fruit also expedite the exploitation of heterosis in tomato. The effect of heterosis in tomato was first noticed by Hedrick and Booth (1907). Later on, heterosis for yield and its element in tomato has been research by many workers (Burdick, 1954; Power, 1945; Larson and Currence 1944). They found that the average value of total yield of red fruits of the hybrid elapsed by 60% the average value of the parental lines. Average yield of all tested F_1 crossbreed was 39% upon the average yield of the parental lines observed by Larson and Currence (1944). The best hybrid elapsed the best market cultivar by about 300%. In later year, heterosis and combining ability in tomato has also been research by Bhatt *et al*. (2001a), Bhatt *et al*. (2001b), Susie (1998), Vidyasagar *et al*. (1997), Singh *et al*. (1995), Singh and Singh (1993). In Bangladesh, first time studied the heterosis and combining ability in tomato for yield and yield contributing characters (Bhuiyan, 1982). He mentioned that better parent heterosis in fruit yield per plant up to 124.5% in the cross Fujuki x World champion.

The word combining ability is very important for effective heterosis breeding. Combining ability analysis is a significant art to understand the genetic capability of parents and their hybrids. It boasts to mark out the best combiner. It may be utilized in crosses with others to utilize heterosis or to collect assemble genes. Diallel crossing technique is broadly used to work out combining ability of the parents and crosses to be included in hybrid production. By finding genetic architecture of different characters from combining ability, breeder can easily scheme significant breeding plans for up coming gradation of the present materials. The performance of hybrid combinations helps to access the genetic advancement of the existing tomato genotypes.

At present, we have released some improved varieties of tomato with good yielding potential. But these all are open pollinated types. Moreover, we also need broadly adapted disease resistant as well as high yielding tomato variety. So, best utilization of hybrid vigor is the most important to fulfill our national demand. Selection of high yielding and static varieties and the development of F_1 hybrids vigour will help the farmers to take variety/hybrid for successful economical cultivation of tomato. Considering all spectrum of aforementioned requirement in tomato, the present study was taken up with the following objectives.

1. To estimate heterosis among the crossing of local and exotic tomato species.
2. Selection of superior genotypes in F_1 generation based on their agro-morphogenic traits.
3. To analyze combining ability in F_1 and their parental lines.
4. To identify high yielding hybrid tomato.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The excellence of the hybrids plant above their parents in terms of vegetative growth, adaptation and productivity of plants is called heterosis (Hayes, 1952; Gustafsson, 1946; East, 1936; Shull, 1908). The surprise of hybrid vigor in tomato was first noticed by Hedrick and Booth (1907). A remarkable improvement has been made in the development of potential hybrids in tomato, later the discovery of hybrid vigor (Shull, 1914). Brief review of information available on the present studies has been collected and brought out here under.

2.1 Heterosis

When two inbred lines were mated, the performance of F_1 may be superior to mid parental value. This superiority over mean is called heterosis. The magnitude of heterosis depends upon accumulation of favorable dominant alleles in the F_1 offspring. If the parental populations differ from each other for useful dominant alleles, the magnitude of heterosis will be proportionally higher. This relationship is proved in the basic the formula for heterosis (Falconer, 1981), Heterosis in $F_1 = \sum dy^2$, Where, d = Magnitude of dominance, y = Difference between the parental population for allelic frequencies at the locus. Though tomato is a self-fertilized crop where degree of heterosis was theoretically noticed that it has been attributed to the fact that tomato was basically a highly out crossing genus which was later evolved into a self-fertilized one (Rick, 1965).

2.1.1 Early history of heterosis in crop plants

Heterosis refers to the dominance of hybrids over their parents. It is noticed that hybrids often possess comparatively increased vigour from their parents (Sprague, 1983). In 1900 Mendel's laws were rediscovered and drew the care of the biological world on problems of heredity and led to reintroduced interest in

hybrid vigour as one aspect of quantitative inheritance. Establishing of widespread understanding heterosis was laid by Shull in 1908. Shull was more suspense with the genetic basis for his observations and he established that a variety was a complex mixture of genotypes. The variability among strains undergoing inbreeding, including loss of vigour, was a consequence of segregation and the eventual homozygosity of desired and deleterious alleles. He also revealed that when certain lines were combined, F_1 yields exceeded those of the parental varieties. The word heterosis was coined by Shull and first proposed in 1914. In 1876, Darwin reconsidered earlier literature and also his own experiments in several crop species. Most of these studies point out that the offspring arising from cross-fertilization were more vigorous than those obtained by selfing. He also decided that self-fertilization is 'harmful' (Allard, 1960).

Bhatt *et al*. (2001a) conducted a study on tomato to find out the degree of heterosis for yield with two important quality characters, ascorbic acid and total soluble solids. Significant differences among genotypes were noticed for all the three characters. Similarly, in 2001 Kurian and Peter conducted an experiment with tomato hybridization and attained the F_l hybrids which showed highest significant heterobeltiosis for TSS(Total soluble solvent) and lycopene. The F_l hybrids usually performed better in fruit quality, i.e. uniform ripening, high lycopene and total solids. Premalakshme *et al.* (2005) presented a study for development of F_1 hybrids with high yield and quality in tomato through diallel crossing comprising six parents. The studies exposed remarkable heterosis over the better parent for earliness, plant height, and laterals per plant. In order of merit, the three best performing F_1 hybrids showed heterosis percentage of 14.43 and 13.90 for marketable fruit weight and fruit yield over the standard check, respectively.

2.1.2 Commercial exploitation of heterosis in crop plants

The 20^{th} century agriculture valued by commercial utilization of heterosis. Heterosis acts a vital role in the breeding and development of crop hybrids, although the genetic basis of the phenomenon remained imprecise (Rood *et al.*

1988; Me Daniel 1986). Maybe Hayes and Jones in 1916 first suggested that hybrid vigour be exploited in vegetables (Hayes, 1952). However, the commercial exploitation of heterosis first arisen in 1930's. Nowadays, most of the world's sugar is produced by hybrid sugarcane or hybrid sugar beets. In Japan, F_1 hybrid eggplants were economically used before 1952 (Kakizaki, 1930). Hybrid rice is now being produced on an increasing area in China. In short, the economic importance of hybrid varieties can be grasped in Gardner's (1968) statement. Development and utilization of heterosis has been the most important practical accomplishment of genetics so far.

2.1.3 Occurrence of heterosis in tomato

Hedrick and Booth (1907) was first noticed heterosis effect in tomatoes. Then, heterosis for yield and its component has been demonstrated by many researchers (Singh and Singh, 1993; Daskalof *et al*., 1967; Burdick, 1954). Here, in this text, an attempt has been done to review those early studies on heterosis of tomato are directly related to the present study.

2.1.3.1 Days to flowering

Heterosis over better parent and negative heterosis for days to flowering over the better parent in many of the hybrids vigour in their diallel progenies reported by Singh (1993) and Ahmed *et al*., (1988). Ahmad (2002) conducted a crossed 8 X 8 diallel set of tomato without reciprocal in May and July sowing and found highest heterobeltiotic effects in both the sowing in the hybrid TM051 X TM017 (-21.76% and -13.43% respectively). Again, heterosis was estimated for yield and yield related characters, plant height, days to 50% flowering, number of fruits per plant, average fruit weight, average fruit diameter, number of fruits per cluster and total yield per plant (Kumar *et al*., 1988). Vedyasagar *et al*. (1997) also studied a line (8) X tester (3) of tomatoes involving bacterial wilt (*Ralstonia Solanacearum*) resistant parents and observed that 12 F_1s each demonstrated superiority to their respective better parents for days to 50% (early) flowering. Again, significant differences among genotypes were noticed for all the traits such as, for fruit yield per plant, i.e. 29.95% over better parent and 32.36% over

standard check. The hybrid also revealed significantly high percentage of positive heterosis over better and standard parent for number of fruits per cluster, average fruit weight but revealed negative heterosis for plant height and day to 50% flowering which are desirable traits.

Kumar *et al.* (1995a) researches on seven tomato lines, their 21 F_1s and three commercial hybrid standards and observed more heterosis over superior parents for early yield (41.6%). Jamwal *et al*. (1984) also crossed 10 foreign lines and 3 local testers and studied heterosis. In 2014 Shankar *et al*. studied heterosis for quality and yield characters in tomato. The study revealed that majority of the hybrids exhibited significant qualified heterosis, heterobeltiosis, standard heterosis in desired direction. The hybrids showed higher performance and also showed high standard heterosis. The crosses recorded high negative standard heterosis for earliness and days to 50% flowering.

2.1.3.2 Days to marketable maturity

Negative heterosis was observed over mid and superior parent for marketable maturity (Kumari *et al*., 2010). Negative heterobeltiosis for this trait also reported by Singh and Sastry (2011), whereas, positive heterosis for this character had been reported by Hannan *et al*. (2007) and Mirshamssi *et al*. (2006). Negative heterobeltiosis and standard heterosis were seen for this trait by Kumar *et al*., (2009).

2.1.3.3 Plant height

Ahmad (2002) and Ahmed *et al.* (1988) reported highest heterosis over better parent in the cross TM026 X TM025 which were 32.24% and 26.90% respectively for May and July sowing. Mid-parent heterosis and better parent heterosis were observed for various quantitative characters in tomato (Chattopadhya *et al.*, 2012). Obvious heterosis over better-parent was observed for fruit yield per plant (148.82%), fruiting clusters per plant (111.64%), number of fruits per plant (103.33%), fruit weight (62.79%) and plant height (50.57%). Kumar *et al.* (1995b) examined on seven tomato lines, their 21 F_1s and three

saleable hybrids showed greatest heterosis (%) over superior parents for plant height. Heterosis of tomato in a 7X7 diallel set (without reciprocal) and found maximum -45.40% heterosis for plant height in the cross Japanese X Anobik over parental value studied by Bhuiyan (1982). Heterosis for plant height was also studied by Dod *et al*. (1992) from diallel cross.

2.1.3.4 Fruits per cluster

Souza *et al*. (2012) evaluated the yield and its components traits, *viz*., fruit yield per plant, fruit number per plant, average fruit weight, no. of cluster per plant, fruit number per cluster, fruit wall thickness and number of locules per fruit including some quality components, namely, total soluble solids, total titratable acidity, fruit length, fruit width, length to width ratio by studying heterosis in tomato. Again, Sharma and Sharma (2013) estimated the heterosis on the basis of mean performance and reported 43.67 percent heterosis over better parent for yield. The heterobeltiotic effect for number of fruits per cluster ranged from -34.39 to 33.0 percent. The fruit yield among the crosses varied from 764.33 to 1808.23 (g). Significant heterobeltiosis was observed in desirable direction for all the traits except days to first picking and total soluble solids.

2.1.4 Heterosis for yield and other characters in tomato

Maximum and significant heterosis in favorable direction was observed for yield, plant height, fruit number and fruits per cluster reported by Kumari and Sharma (2011). Heterosis was considerable in all hybrids. Resende *et al*. (2000) examined heterosis of tomato for number of fruits in 1^{st}, 2^{nd} and 3^{rd} trusses, found higher heterosis values in the hybrids than the standard cultivar Santa Clara for number of fruits per truss. Ninety-one F_1 crosses of tomato in a diallel set involving 13% (excluding reciprocals) to study heterosis for number of fruit/truss and found appreciable heterosis over best parental lines evaluated by Bhatt *et al*. (1999).

2.1.4.1 Fruits per plant

Hannan *et al*. (2007a) determined the heterosis in tomato for yield and yield component characters, *viz*., plant height at 60 days after transplantation, days to first flowering, number of flower per cluster, number of fruits per plant, fruit weight per plant, days to first fruit ripening. Gul *et al*. (2010) studied in tomato for degree of heterosis in yield and its five yield attributing components, *viz*., number of flowers per cluster, number of fruits set per cluster, fruit length, fruit width, fruit weight and fruit yield per plant. The degree of heterosis for plant height, fruit weight, bacterial wilt incidence and yield per plant were determined by Singh and Asati (2011). Ahmad (2002) found that highest heterosis over better parent in the cross TM041 X TM044 which were 159.70 and 181.36 percent respectively for May and July sowing.

Vidyasagar *et al*. (1997) studied in a line (8) X tester (3) analysis perceived better parents heterosis in 5 F_1s for marketable fruits/plant. Similarly, Sekar (2001) observed that more than 10% heterosis over the best parent for the number of fruits per plant and yield per plant. In a study of line X tester analysis Dev *et al*. (1994) observed heterosis over the better parent 115.7% for the number of fruits per plant. Jamwal *et al*. (1984) crossed among 10 foreign lines and 3 local testers and observed that heterois for fruit number per plant. Bhuiyan (1982) also observed that maximum better parent heterosis (113.92 percent) for number of fruits per plant in the cross Fujuki X CL. 8d-0-7-l-0-0. In the same way, Chaudhury and Khanna (1972) reported that heterosis in 17 hybrids out of 28 hybrids for fruit number and with maximum increases over the better parent of 49.93% under high temperature growing environment.

2.1.4.2 Average individual fruit weight (g)

Heterosis for the trait fruit weight was reported by many authors as Scott *et al*. (1986). Islam *et al*. (2012) studied the heterotic performance in F_1 generation of tomato. The hybrids showed that significant variation in heterosis. Chattopadhyay *et al*. (2012a) reported that mid-parent heterosis and better parent

heterosis for various quantitative traits in tomato. Prominent heterosis over better-parent was observed for fruit yield per plant (148.82%), fruiting clusters per plant (111.64%), number of fruits per plant (103.33%), fruit weight (62.79%) and plant height (50.57%). Better parent heterosis for average fruit weight in the cross TM051 X TM017 reported by Ahmad (2002). Greatest heterosis over superior parents for average fruit weight (30.8% and 32.27%) respectively, reported by Kumar *et al.* (1995a) and Kumar *et al.* (1995b). A line (8) X tester (3) analysis observed superiority of 3 F_1S to their respective better parents for fruit weight (Vidyasager *et al*., 1997).

2.1.4.3 Heterosis in some crosses for weight of fruits

Ahmed *et al*. (1988) also reported that heterosis over the better parent for fruit weight (Singh *et al.*, 1995). Heterosis for the trait fruit weight under high temperature environments was reported by Scott *et al.* (1986). Again, Alvarez (1985) studied that hybrid INCA 21X INCA 3 was superior to the better parent for average weight in summer. Maximum better parent heterosis (8.45 percent) for individual fruit weight in the cross Fujuki X World champion was observed by Bhuiyan (1982).

2.1.4.4 Fruits length

Heterosis over better parent for fruit size in few cases in tomato was reported by Scott *et al.* (1986). Highest better parent heterosis in the cross TM051 X TM025 (22.25 percent in May sowing and 2.87 percent in July sowing) for fruit length (Ahmad, 2002). A full diallel without backcrosses concerning seven parents recorded maximum heterosis for fruit length (4.62%) in the hybrid VI00 X 93/10 (Susie, 1998). Again, five new processing tomato lines as female parents to cultivars Meidong and Jiazhouzhiyong were crossed and perceived higher heterosis for fruit length (Wang *et al.*, 1998b). Singh *et al*. (1995) reported that heterosis in some crosses for length of fruit. Also Scott *et al*. (1986) and Chaudhury and Khanna (1972) reported that heterosis over better parent for fruit size in few cases in tomato.

2.1.4.5 Fruits diameter

Evaluation trial of tomato hybrids in summer where also found that heterosis in equatorial diameter in the majority of cases (Alverez, 1985). Highest better parent heterosis in the cross TM051 X TM017 (22.65% in May sowing and 15.97% in July sowing) for fruit breadth (Ahmad, 2002). Susie (1998) studied on full diallel without backcrosses concerning seven parents and recorded maximum heterosis for fruit width (4.56%) in the hybrid D150 X NO-IO. Wang *et al*. (1998b) studied on using five lines and two cultivars observed that higher heterosis for fruit length. Chaudhruy and Khanna (1972) also reported that heterosis for fruit size, with maximum increases over the better parent of 6.82% (Chaudhury and Khanna, 1972). Heterosis for equatorial diameter in tomato was reported by Alvarez (1985).

2.1.4.6 Locules per fruit

Lower number of locules in oval and pear shaped variation like Roma and Italian Red Pear (Roy and Choudhary, 1972). The locule number ranged between 4 or 5 among F_1 hybrids like Mangla, Rupali and Vaishali (Sethi and Anand, 1986). Heterosis for locule number is also studied by Ahmed *et al*. (2011), Anita *et al*. (2005), Premalakmhme *et al*. (2002), Srivastava *et al*. (1998a), Ghosh *et al*. (1997) and Dod and Kale (1992). Kumar *et al*. (2009) and Singh *et al*. (2005) reported that significant negative heterosis for number of locules per fruit. Heterosis using line x tester analysis between bacterial wilt (*Ralstonia solanaccarxm*) resistant/tolerant compliances (Sakthi, LE 214 and LE 206) and processing cultivars (HW 208F, St 64, Ohio 8129, Fresh Market 9 and TH 318) and identified heterotic hybrids for locule number (LE 206 X Ohio 8129 and LE214XSt 64) (Kurian and Peter, 2001).

2.2 Combining ability

According to Sprague and Tatum (1942), the general combining ability as the average performance of a line in hybrid combination and specific combining ability was used to designate those cases in which certain combinations do

relatively better or poorer than expected on the basis of average performance of lines convoluted. In general, combining ability, the genes with additive effects are most significant while specific combining ability is more needed on genes with dominance and epistatic effects. In this section, the literature relating to combining ability on various characters studied in the present study has been reviewed and summarized.

2.2.1 Days to flowering

Significant general combining ability and specific combining ability effects were studied by Singh *et al*. (2010); Mirshamssi (2006) and Singh *et al.* (2005). According to Ray and Syamal (1998), additive gene-action involved for days to fruiting in tomato. El-Mahdy *et al*. (1990) reported that the additive gene effects performed more significant than non-additive gene effects for the character and they study on whole diallel of 6 lines under heat stress observed highly significant general and specific combining ability for quick yield. Srivastava *et al*. (1998a) also reported that the predominance of non-additive variance for days to flowering due to less than unity of the ratio of general to specific combining ability. He reported that analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the trait days to flowering and non-additive gene effects were more prominent for days to flowering.

In a study of 91 F_1s and the parents Bhatt *et al*. (2001) found that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for days to first harvest and they found that the predominance of non-additive gene action. Shrivastava *et al*. (1993) also reported on combining ability from 9 cultivars and their F_1 and F_2 hybrids and found that Pusa Ruby X Money Maker was best combination for earliness. Combining ability of tomatoes in a set of eight determinate lines X three indeterminate testers and found that line Sonali was good general combiners for days to 50% flowering (Chadha *et al*., 1997). Out of the 24 F_1s studied, one cross combination was found to be good specific combiner for days to 50% flowering. Diallel cross of 8x8 without

reciprocals observed highly significant GCA and SCA effects for two different sowing (May sowing and July sowing) for days to 50% flowering (Ahmad, 2002). Brahma *et al*. (1991) studied on three parents and their F_1, F_2, BC_1 and BC_2 generations in 2 crosses (Jap X K7 and Jap X CT1) and reported that pronounced dominance effects for days to flowering in the cross Jap X CT1. Again, Perera and Liyanaarachchi (1993) studied on 13 x 13 half diallel cross and observed significant additive gene effects for days to flowering indicating significant differences between the parents. Ghosh *et al*. (1996) reported on the partial dominance for days to first flowering from a 9 x 9 diallel cross and graphical analysis of tomato.

2.2.2 Plant height

A number of reports are available on significant general combining ability and specific combining ability effect for plant long height in tomato (Asati, 2011; Sharma and Sharma, 2010; Singh *et al*., 2010; Ahmed *et al*., 2009; Pandey *et al*., 2006; Premalakshmi *et al*., 2006; Sharma *et al*., 2006; Duhan *et al*., 2005; Singh *et al*., 2005a; Gaikwad *et al*., 2002; Bhatt *et al*., 2001c; Dharmatti *et al*., 2001; Dharmatti *et al.*,1999; Kurian and Peter, 1995; Srivastava *et al.,* 1993; Chandrasekhar and Rao,1989; Raijadhav and Kale, 1987; Sidhu *et al*., 1981; Kalloo *et al*., 1974). Combining ability of tomato in a diallel set (without reciprocal) perceived significant GCA and SCA value for plant height signifying that both additive and non-additive gene action were involved in the inheritance of this trait (Bhuiyan, 1982).

In 2002, Ahmad carried out a study on 8 x 8 diallel set of tomato without reciprocal in May and July sowing and found predominance additive gene effects for this character and highest significant positive GCA effects (24.56 and 19.37) in the parent. Shrivastava *et al*. (1998b) studied on combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male) and they reported that the predominance of non-additive variance for length of plant, due to less than unity of the ratio of general to specific combining ability. Bhatt *et al*. (2001b) also crossed among the fourteen

line of tomato in a half diallel fashion and reported that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for plant height and results revealed the predominance of non-additive gene action.

2.2.3 Fruits per cluster

Bhatt *et al*. (2001b) studied on fourteen line of tomato in a half diallel fashion and assessed the resulting 91 F_1s and the parents and perceived that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for fruits per truss and results showed the predominance of non-additive gene action. Diallel cross of tomato for number of fruits in the 1^{st}, 2^{nd} and 3^{rd} trusses found significant general combining ability (GCA) effects in a group of parents for fruit number in the 1st and 2nd trusses (Resende *et al*., 2000). Similarly, Natarajan (1992) evaluated the parents and F_1 hybrids from a diallel cross involving 6 homozygous lines under moisture stress and reported that additive gene action was important for number of fruits set/cluster.

2.2.4 Fruits per plant

Fourteen varieties of tomato crossed in a half diallel fashion and assessed the resulting 91 F_1s and the parents and observed that variances of GCA and SCA were significant for fruits per plant and results showed the predominance of non-additive gene action (Bhatt *et al.*, 2001b). Five processing tomato cultivars crossed in a complete diallel fashion and observed that GCA and SCA were highly significant for fruits per plant. A predominance of variance due to general combining ability over specific combining ability was observed for fruits per plant indicating that additive gene action plays an important role in inheritance of this characters (Wang *et al.*, 1998b). Srivastava *et al*. (1998) also carried out a study on GCA in a field experiment through line x tester method using fifteen lines (female) and three testers (male) and they reported that the predominance of non-additive variance for number of fruits, due to less than unity of the ratio of general to specific combining ability. In 1992; Natarajan studied on combining ability in the parents and F_1 hybrids from a diallel cross including 6

homozygous lines under moisture stress and reported that both additive and non-additive gene action were important for the number of fruits/plant. Bhutani and Kalloo (1988) also studied on an eight parent's diallel set of 28 F_1 and 28 F_2 assessed for genetical studies for number of fruits in tomato. In 2000 Dhaliwal *et al.* carried out an investigation on tomato to study the combining ability of genetic male sterile (pollen abortive type) parents in combination with superior performing male parents.

Combining ability of tomatoes in a set of eight determinate lines crossing with three indeterminate testers observed which resulted that lines BWR-5 (HR), LE79-5 (W) and EC 129156 were good general combiners for marketable fruits/plant (Chadha *et al*., 1997). Bhuiyan (1982) carried out a study on combining ability of tomato in a diallel set (without reciprocal) and found that mean squares of number of fruits per plant due to both general combining ability and specific combining ability was highly significant showing that both additive and non-additive gene actions were responsible for the character number of fruits per plant. Highest significant GCA effects in the parents TM051 (12.44 and 11.03) for May and July sowing and also found that eleven combinations in both the sowings highly significant positive SCA values (Ahmad, 2002). De-Araujo and De- Campos (1991) carried out a cross among 5 cultivars in a diallel fashion and observed high GCA for total number of fruits in the parents Roma VFN and IPA3.

A diallel set of 12 tomato lines genetically analysed by Ratan and Saini (1976) for number of fruits per plant and in full diallel the graphical analysis shown partial dominance for number of fruits per plant and utilization of non-additive genetic variation was suggested for developing F_1 hybrids. The importance of dominance effects in the inheritance of number of fruits per plant (Sahrigy *et al*., 1970). Brahma *et al*. (1991) studied on three parents and their F_1, F_2, BC_1 and BC_2 generations in 2 crosses (Jap X K7 and Jap x CT1) and they found that dominance effects for fruits/plant in the cross Jap X CT1. In a study on 13 X 13 half diallel cross Perera and Liyanaarachchi (1993) observed that significant

additive gene effects for fruit number showing significant differences between the parents. Ghosh *et al*. (1996) observed that from a 9 X 9 diallel cross and graphical analysis of tomato reported the partial dominance for number of fruits/plant.

2.2.5 Average individual fruit weight

Wang *et al*. (1998a) studied on cross of five processing tomato cultivars in a complete diallel fashion and they found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruit weight. In 1997 Kumar *et al*. studied on nine parents and their 18 F_1 hybrids of tomato and reported that for average fruit weight selection is more gratifying due to the pervasiveness of additive gene action. Again, twelve tomato parents and their 66 F1s hybrids produced in a diallel fashion evaluated by Singh *et al*., (1999) and from the combining ability, components of variation they reported the importance of both additive and non-additive gene effects for fruit weight with the magnitude of the former being greater. Bhuiyan (1982) studied on combining ability of tomato in a diallel set (without reciprocal) and they found that highly significant variances due to general combining and specific combing ability for single fruit weight indicating that both additive and non-additive gene actions were involved in the expression of the character. Dhaliwal *et al.* (2000) carried out an investigation on tomato to study the combining ability of genetic male sterile (pollen abortive type) parents in combination with superior performing male parents.

In 1989 Chandrasekhar and Rao evaluated the F_1 progenies and parental genotypes for fruit weight and they reported the variations due to general combing ability (GCA) and specific combing ability (SCA) were significant. Similarly, Perera and Liyanaarachchi (1993) carried out an observation on a set of 13 X 13 half diallel cross and they observed that significant additive gene effects for fruit weight indicating significant differences between the parents. Ghosh *et al*. (1996) carried out an examination on 9 x 9 diallel cross and graphical analysis of tomato reported also the partial dominance for fruit weight.

Natarajan (1992) studied and evaluated the information on combining ability in the parents and F_1 hybrids from a diallel cross concerning 6 homozygous lines under moisture stress and reported that both additive and non-additive gene action were important for fruit weight and LE76 was the best general combiner for fruit weight. Again, Ahmad (2002) studied on a cross of a 8 x 8 diallel set of tomato without reciprocal in May and July sowing and observed highest significant positive general combining ability (GCA) effects in both the sowing in the parent TM025 (7.03 and 7.40). Out of 28 F_1's nine F_1's gave significantly larger positive specific combining ability (SCA) values in both the sowing. Chadha *et al*. (1997) carried out a study on combining ability of tomatoes in a set of eight determined lines X three indeterminate testers and they observed that lines BT-10, BWR-5 (HR) and EC 191540 were good general combiners for average fruit weight.

2.2.6 Fruits diameter

Ahmad (2002) crossed a 8 X 8 diallel set of tomato without reciprocal in May and July sowing and found that significant positive GCA effects in the parent TM025 (0.45 and 0.27) in both the sowings and he also reported that nine combinations revealed significant positive SCA effects in both sowing. In a study on diallel cross of tomato Resende *et al*. (2000) found significant general combining ability (GCA) effects in a group of parents for fruit diameter. Srivastava *et al*. (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male), they reported that the predominance of non-additive variance for width of fruit due to less than unity of the ratio of general to specific combining ability. Again, Wang *et al*. (1998a) crossed among five processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruit width. Susie (1998) crossed among seven phenotypically deviating genotypes (MLS49, VI00, D150, NO-10, 93/10 and R38) in a full diallel without backcross after investigating the parents and F_1 hybrids and he reported that partial

dominance was the mode of inheritance for fruit breadth in the F_1 generation. Ghosh *et al*. (1996) studied on a 9 X 9 diallel cross and graphical analysis of tomato reported that the partial dominance for equatorial fruit breadth and polar fruit breadth.

2.2.7 Locules per fruit

Analysis of combining ability of genetic male sterile (pollen abortive type) parents in combination with superior performing male parents in tomato was studied by Dhaliawal *et al.* (2000). Variance analysis for combining ability showed that both the additive and the non-additive gene effects governed the inheritance of the trait number of locules. The additive gene effects were more prominent for number of locules. A 9 X 9 diallel cross and graphical analysis of tomato reported that the partial dominance for number of locules/fruit (Ghosh *et al*., 1996). Again, Singh *et al*. (1998) carried out a study on sixty-six F_1 hybrids produced in a diallel fashion and their 12 parents and suggested that both fixable and non-fixable gene effects were convoluted in the inheritance of locule number.

Bhutani and Kalloo (1991) analyzed the 8-parent diallel cross including 28 F_1s and 28 F_2s for locule number. They reported that the importance of additive gene action at both variance and estimated component variance levels (CV). Punjab Chhuhara, with pear-shaped fruits, rated best for performance and combining ability. They also concluded that a desirable higher locule number can be brought about by simple selection. In 1995 Dod *et al*. studied on combining ability of tomato in a 12 parent's diallel (excluding reciprocals) for numbers of locules/plant and found that significant GCA and SCA variances indicating the importance of both additive and non-additive genetic components. The magnitude of general combining ability pared with specific combining ability was higher showing a predominant role for additive gene action. Again, Srivastava *et al*. (1998) carried out a study on combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male) and they reported that that predominance of non-additive

variance for number of locules, due to less than unity of the ratio of general to specific combining ability.

2.3 Heterosis for hybrid having post-harvest or processing quality

Hybrids had 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 (53.56%) was found in lycopene content of fruit followed by 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).

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The present study entitled “Heterosis and combining ability analysis of intraspecific hybrid of local and exotic tomato (*Solanum lycopersicum* L.) genotypes” was carried out at the experimental farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla nagar, Dhaka-1207, during Robi 2017 and 2018. The details of materials used and methodologies employed to conduct the experiment have been described in this chapter.

3.1. Experimental site

The study was carried out in the research farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla nagar, Dhaka during the Robi season of 2017-2018 and 2018-2019. The location of the site is 23°74’ N latitude and 90°35’ E longitudes at an elevation of 8.2 meters from sea level (Appendix I).

3.2 Soil

The soil belongs to "The Modhupur Tract", AEZ-28. Top soil was silty clay in texture, olive-gray with common line to medium distinct dark yellowish brown mottles. Soil pH range was from 6.0-6.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above hood level. The selected plot was medium high land. The details are presented in Appendix II.

3.3 Climate

The experimental site is located under the sub-tropical climatic zone which was characterized by three distinct seasons, winter season from November to February and the pre-monsoon period or hot season from March to April and monsoon period from May to October. The monthly average minimum and maximum temperature during the crop period was 12.00°C and 26.00°C respectively. The monthly mean minimum and maximum relative humidity was 57% and 79%, respectively. The monthly average rainfall during the crop period

was 17.59 mm. Details of the metrological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e- Bangla Nagar, Dhaka-1207 and presented in Appendix III.

3.4 Planting materials

A total number of six genotypes of tomato were used in the study as parents (Table 1). The seeds of six parents were obtained from the Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. Thirty diallel crosses were made with these six parents (Table 2). These thirty crosses and six parents were grown in next season to analysis heterosis and combing ability.

3.5 Raising of seedling

Seeds of six parental genotypes were sown densely on 20th October, 2017 in the primary seedbed. Eight days after sowing, the young seedlings at the cotyledonary stage were transplanted in the secondary seedbed at a spacing of 5 X 5 cm. Similarly, the seedlings of full diallel crosses along with parents were raised in the next season (20^{th} October, 2018) (Plate 1A and Plate 1B).

3.6 Design and layout of the experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 2 m X 2 m accommodating six plants in a plot having row to row and plant to plant spacing of 60 cm X 40 cm. The unit plot and blocks were separated by 50 cm and l m respectively.

3.7 Land preparation

The land was first ploughed in November, 2017 for growing of parents and for making of crosses. Similarly, the land was ploughed in November, 2018 for growing of plants of full diallel crosses along with parents. Six ploughing and cross- ploughing followed by laddering was done to have a good tillage and the weeds and other unwanted plants were removed thoroughly. Pits were prepared for transplanting seedling.

Table 1. Name and source of tomato genotypes used in the present study

Sl. No.	Genotypes	Name/Accession No.	Source of Collection
1	G1	SAU tomato 1	GEPB, SAU
2	G2	SAU tomato 2	
3	G3	SL001	
4	G4	SL002	
5	G5	BARI Tomato 2	
6	G6	SL003	

GEPB=Department of Genetics and Plant Breeding, SAU = Sher-e-Bangla Agricultural University

Table 2. Pattern of diallel crosses among the parents (6×6 full diallel)

	G1	G2	G3	G4	G5	G6
G1		G1×G2	G1×G3	G1×G4	G1×G5	G1×G6
G2	G2×G1		G2×G3	G2×G4	G2×G5	G2×G6
G3	G3×G1	G3×G2		G3×G4	G3×G5	G3×G6
G4	G4×G1	G4×G2	G4×G3		G4×G5	G4× G6
G5	G5×G1	G5×G2	G5×G3	G5×G4		G5×G6
G6	G6×G1	G6×G2	G6×G3	G6×G4	G6×G5	

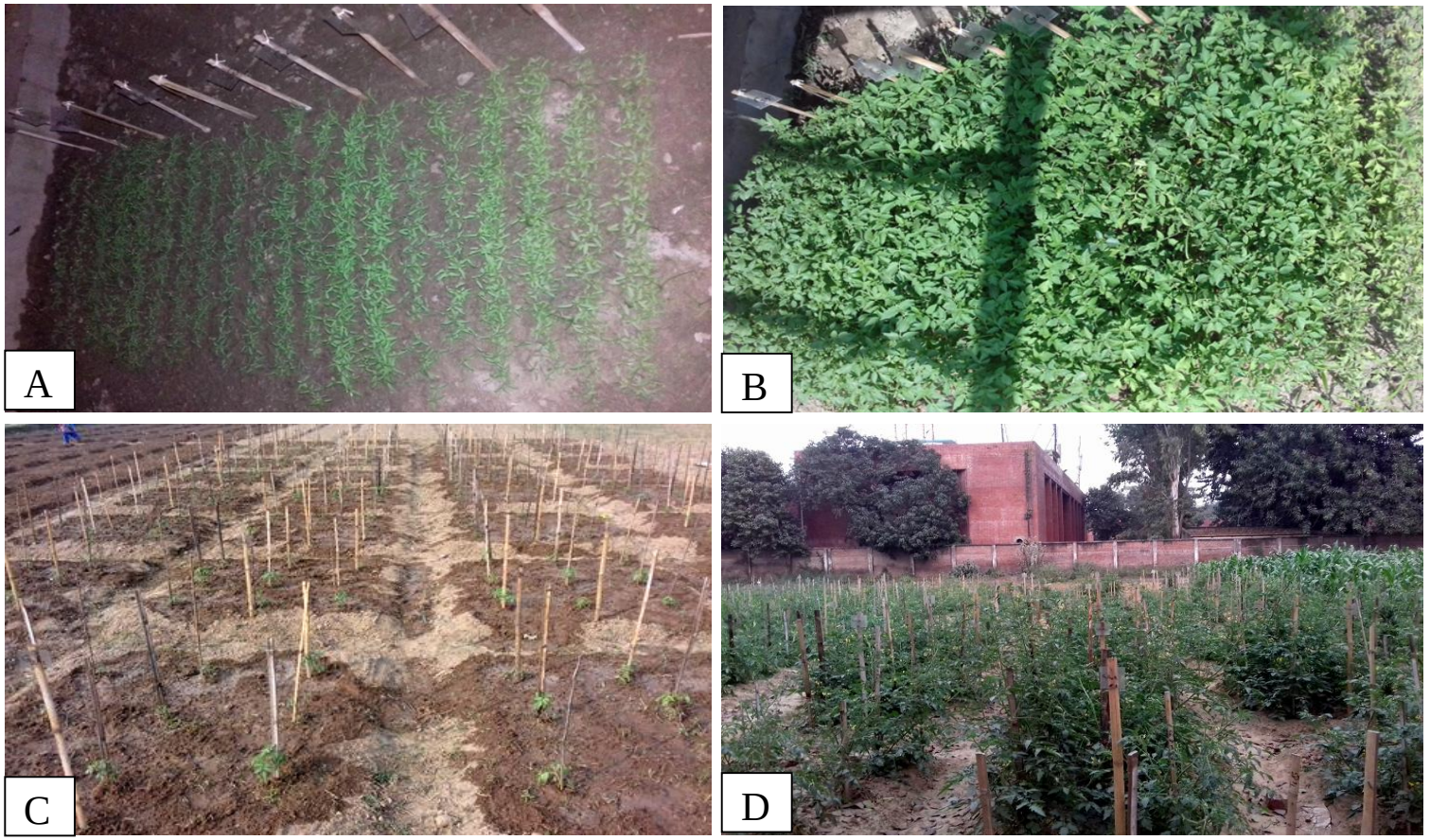

Plate 1. Raising of seedling and transplanting in the main field. A. Emergence of seedling in the seed bed, B. Growing of seedlings in the seed bed, C. Transplanting of seedlings in the main field, D. Growing of tomato plants in the main field.

3.8 Manure and fertilizers application

Half of the quantity of Cow dung and the entire amount of TSP were applied during final land preparation. The remaining cow dung and half of MP were applied before three days of planting. The whole Urea and half MP were applied in three equal splits as top dressing after 15, 30 and 50 days of transplanting respectively. The following doses of fertilizers (Islam *et al*., 2012) were applied in the plots.

Table 3. 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

3.9 Transplanting of seedling

Thirty-one days old seedlings were transplanted in the main experimental field on 18th November, 2017 for performing crossing among the parents and on 18th November, 2018 both parents and F1s for heterosis and combining ability study. Transplanted seedlings and their vegetative growth are illustrated in Plate 1C and in Plate 1D.

3.10 Intercultural operations

The field was weeded and mulched (Plate 2A) as and when required. Then top dressing and irrigation were done at fifteen days of interval. Pruning was done by removing some of the lateral branches below the 1st inflorescence during the early stage of growth to allow the plants more sunlight and to reduce the incidence of insect infestation. Stacking was done with bamboo stick in such a way that necessary records could be taken from individual plant without much difficulty (Plate 2B). The insecticide Diazinon was sprayed to prevent the damage of the plants by the fruit borer and white fly, the vector of TYLCV.

Plate 2. Intercultural operation. A. Weeding, D. Staking the plants.

3.11 Hybridization in experimental tomato genotypes

The different steps of hybridization were carried out as described in Opena *et al.* (2011). These included parent selection, emasculation, pollination, bagging, tagging, labelling and harvesting of F_1 seeds. Genetically unlike, healthy and vigorous plants were selected for hybridization. Crosses were made in all possible combinations. Emasculation was done at 3-5 PM the previous day of pollination and accordingly pollinated on the next day by 10 AM. Necessary agronomic practices were done for proper growth of plant and fruit setting accordingly. The F_1 fruits were harvested after one and half month of pollination along with parental lines fruits. Different steps of emasculation and pollination are illustrated in Plate 3.

3.12 Harvesting

The fruits were collected from the field at afternoon and preserved in room temperature for at least 4 days. Harvesting continued for one month and 14 days because fruits of different lines matured progressively at different dates and over long time. The fruits were allowed to be rotten for two days in water, then after removing the flesh seeds were collected and dried in room temperature. The dried seeds were kept into the air tight zip bag and preserved at 4 °C until use. Hybrids seed along with their parental seeds were ready to be used for growing in the next winter season 2018-2019 for estimation of heterosis, combining ability and other characteristics.

3.13 Observation and collection of data

The vegetative growth, flowering and fruiting stages of the tomato plant were observed. Some of those stages are displayed in Plate 4. Five plants from each unit plot were randomly selected. Data on the following parameters were recorded. Different morphological data collection is shown in Plate 5. Some pictorial views of the experimental field are presented in Appendix IV.

3.13.1 Days to first flowering: Number of days for first flowering was counted from seedlings transplanting in the main field.

Plate 3. Emasculation and pollination. A-B. Emasculation, C. Emasculated flower. D-F. Pollination.

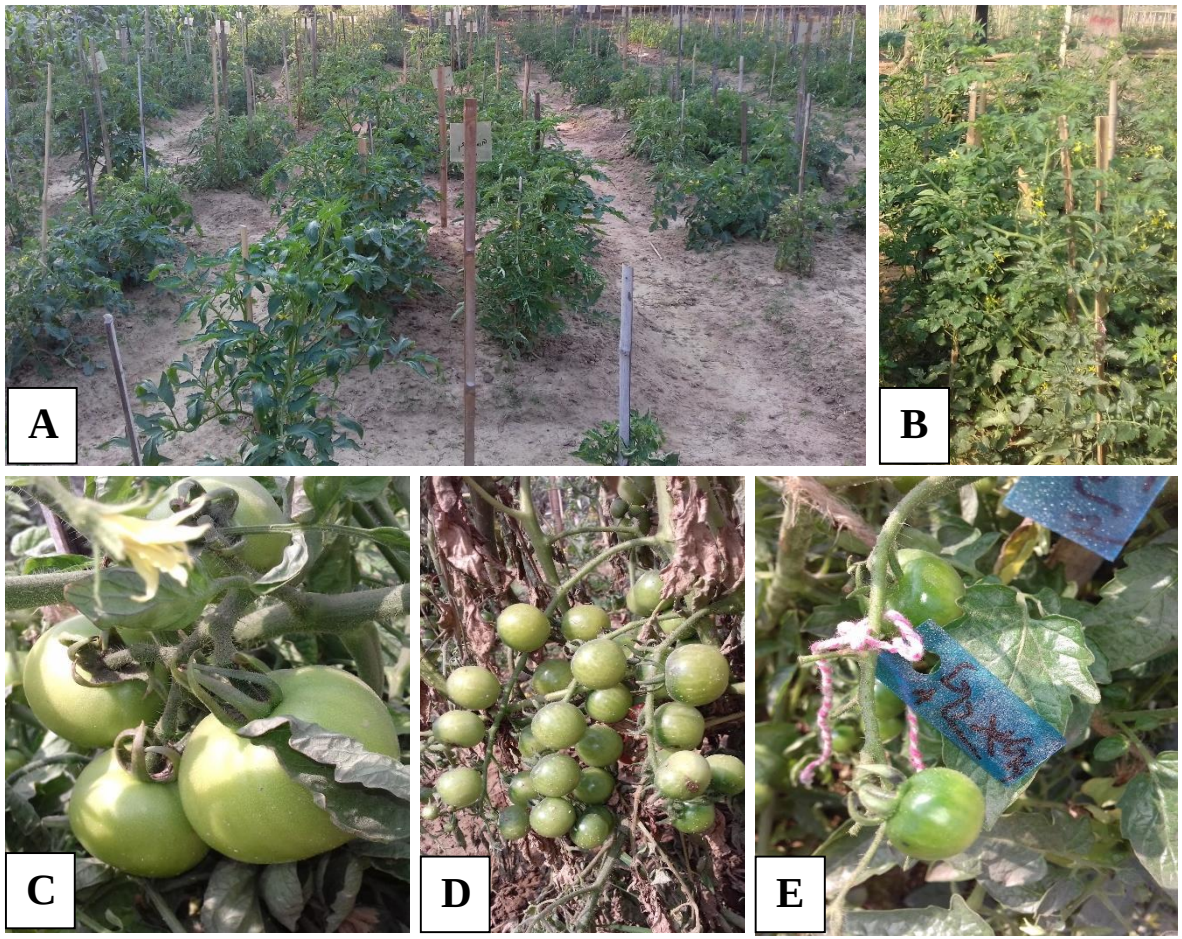

Plate 4. Vegetative, flowering and fruiting stage of tomato. A. Vegetative stage, B. Flowering stage, C-E. Fruiting stage.

Plate 5. Data recording. A. Data documentation. B. Fruit counting, C-D. Measurement of plant height.

3.13.2 Days to 50 % flowering: The number of days was required from the date of sowing to the date of 50% flowering of the plants of each replication.

3.12.3 Plant heights at 50% flowering (cm): The average of length of the main stem from the ground level to the tip, measured in centimeters at 50% flowering of the 5 selected plants.

3.13.4 Number of cluster per plant: The average value of total number of cluster of 10 plants.

3.13.5 Number of fruits per cluster: The average number of fruits per cluster of 10plants.

3.13.6 Fruits per plant: Average value of number of mature fruits harvested from the 5 selected plants.

3.13.7 Individual fruit weight (g): Individual fruit weight in gram was calculated based on the twenty representative fruits.

3.13.8 Fruit length (mm): Fruit length was measured with a digital slide calipers from the neck of the fruit to the bottom of the same from ten representative fruits and their average was taken as the length of the fruit.

3.13.9 Fruit diameter (mm): Fruit breadth was measured along the equatorial part of the same ten representative fruits taken for fruit length by digital slide callipers and their average was taken as the breadth of the fruit.

3.13.10 Locule number per fruit: Total number of locules presents in fruit was counted by cutting ten mature fruits and their average was taken.

3.14 Statistical analysis

Mean data of the characters were subjected to multivariate analysis. Univariate analysis of the individual character was done for all characters under study using the mean values (Singh and Chaudhury, 1985) and was estimated using MSTAT-

C computer programme. Duncan's Multiple Range Test (DMRT) was performed for all the characters to test the differences between the means of the genotypes. Mean, range and coefficient of variation (CV%) were also estimated using MSTAT-C. Multivariate analysis was done by computer using GENSTAT 5.13 and Microsoft Excel 2016 software.

3.14.1 Analysis of variance (ANOVA)

The collected data for various characters were statistically analyzed using MSTAT-C program to find out the variation among the different genotypes by F-test as it was a single factor experiment (Table 4). The variances of each character were partitioned into block, 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 (28) the genotypes.

Table 4. The general form of ANOVA for combining ability

Source of variation	df	Sum of squares	Mean sum squares	F-test	Expected mean squares
			(n+2)		
GCA	6	SSg	MSg	MSg/MSe	σ^2 e + —Σ G2 i (n-1) 2
SCA	21	SSs	MSs	MSs/MSe	σ^2e + ΣΣ S2ij n(n-l) i<j
Error	54	SSe	MSe	σ^2e	

3.14.2 Estimation of combining ability analysis: Combining ability analysis of the traits with significant genotypic differences was done according to the 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_1s were the population considered. This analysis portioned the variation due to genotypic differences into general combining ability (GCA) and specific combining ability (SCA) effects.

Griffing'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 (perhaps modified by epistatis) where SCA represents non-additive effects.

The mathematical model used in this analysis was as follows:

$Yij = m + Gi + Gj + Sij + l/bc \Sigma\Sigma eijkl$

Where,

Yij = is the mean of i x jth genotype over k and 1 I, j * 1, 2, ... n

k = 1, 2, ... b

l=1, 2, ... c

m = population mean

Gi = GCA effects of the i^{th} parent

Gj = GCA effects of the j^{th} parent

eijkl = environmental effects

$l/bc \Sigma\Sigma eijkl$= mean error effect

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_1s in the appropriate cells. The row sums, columns sum, 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 were estimated by using Griffing's (1956a, b).

GCA and SCA effects

The GCA and SCA effects were estimated according to Sharma (1998) by the following formula:

$$\text{GCA effects } (Gi) = \frac{1}{n+2}\left[\left(Yi. + Yii\right) - \frac{1}{n}(Y..)\right] \quad \text{Restricted to } \sum_{i} Gi = 0$$

$$\text{SCA effects } (Sij) = Yij - \frac{1}{n+2}\sum\left[(Yi. - Yii + Yj. + Yjj)\right] + \left[\frac{1}{(n+1)(n+2)}Yii\right] \quad (i<j)$$

To analysis GCA and SCA effects following Griffing's Approach under diallel method a computer software "The diallel cross: its analysis and interpretation" (Copyright 1988 B.R.Christie, V. I. Shattuck, J.A. Dick, University of Guelph, Canada) was used.

3.14.3 Calculation of heterosis

For estimation of heterosis in each character the mean values of the 30 F_1's have been compared with better parent (BP) for heterobeltosis and with mid parent (MP) for heterosis over mid parental value.

BP heterosis = $\overline{F_1}$-$\overline{BP}$

MP heterosis = $\overline{F_1}$-$\overline{MP}$

Percent heterosis was calculated as

Percent BP heterosis = $\{(\overline{F_1}-\overline{BP})/\overline{BP}\}X\ 100$

Percent MP heterosis = $\{(\overline{F_1}-\overline{MP})/\overline{MP}\}X\ 100$

Where,

$\overline{MP}$= Mean value of mid parent

BP= Mean value of better parent

$\overline{F_1}$= Mean value of F_1 generation

The significance test for heterosis was done by using standard error of the value of better parent and mid parent as –

$$\text{Significant test, } t = \frac{\text{Mean difference}}{\text{Standard error Difference (SED)}}$$

$$\text{Therefore, SED} = \sqrt{(\delta^2/n_1 \times \delta^2/n_2)}$$

Where,

SE= Standard error

t= Tabulated value of 't' at error df at 5% or 1% level of significance

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to perform the 6×6 full diallel analysis of different genotypes of tomato (*Solanum lycopersicum* L.) using yield contributing traits. This chapter comprises the presentation and discussion of the findings obtained from the experiment. The fruits were harvested when they began the color change from green to red. The data pertaining to ten characters have been presented and statistically analysed with the possible interpretations.

4.1. Mean performance and analysis of variance

Mean performance of ten yield related agro-morphological traits of parents and F1s combinations are presented in Table 5. Significant genotypic variations were observed for all the characters under studied indicated that wide range of variability present (Appendix V).

4.1.1 Days to first flowering

Among the six parents G1 took the lowest period for first flowering where G4 took the longest period. Among the 30 cross combinations G4×G1 (32.667) took the longest time for days to 1st flowering, and the lowest was observed in G2×G6 (24.00).

4.1.2 Days to 50% flowering

Out of six parents G1 and G2 took the longest period for 50% flowering where G6 took the lowest period. Among the 30 cross combinations G1×G5 (39.000) took the longest time for days to 1st flowering, and the lowest was observed in G2×G3 (28.333).

4.1.3 Plant height at 50% flowering

Among the six parents lowest plant height at 50% flowering was in G6 where G2

Table 5. Mean performance of 10 different characters in six parents and their 30 F_1s of *Solanum lycopersicum* L.

Genotype	Df	D1F	D50%F	PH50%F	NCPP	NFPC	NFPP	FL (mm)	IFW (g)	FD (mm)	LNPF
G1	8	24.333	34.000	54.567	12.333	17.333	106.000	21.333	9.367	23.667	2.000
G2	8	28.000	34.000	63.267	16.000	13.000	111.000	22.667	9.433	25.000	2.000
G3	7	27.333	33.667	49.933	12.667	7.333	13.333	23.333	8.233	23.000	8.333
G4	7	32.667	33.333	48.100	9.000	7.333	16.667	50.667	127.467	70.000	9.000
G5	7	27.333	32.333	43.500	10.667	4.667	13.667	42.667	143.867	73.333	13.000
G6	7	27.333	31.667	40.367	16.667	5.667	21.667	49.667	75.933	53.000	5.000
G1×G2	8	29.333	35.333	51.600	6.333	8.333	15.000	28.000	5.933	22.000	3.000
G1×G3	8	30.333	34.333	42.000	7.333	6.667	28.333	42.667	41.700	40.667	5.000
G1×G4	8	28.667	32.000	54.867	9.667	9.667	29.333	22.667	6.400	24.333	2.000
G1×G5	8	29.667	39.000	48.100	5.333	21.333	31.000	28.167	27.700	26.333	4.000
G1×G6	8	29.000	35.000	65.833	8.667	7.667	43.333	40.000	32.300	36.000	3.000
G2×G1	8	25.667	31.000	72.000	13.667	14.333	127.000	24.333	8.267	27.333	2.000
G2×G3	8	24.333	28.333	67.100	12.667	14.333	151.667	29.333	22.767	36.000	2.000
G2×G4	8	24.667	29.667	65.233	15.000	15.667	157.000	23.667	8.867	25.333	2.000
G2×G5	7	25.000	30.667	60.233	14.667	18.667	164.000	23.000	8.833	26.000	2.000
G2×G6	8	24.000	29.000	57.967	19.333	17.000	196.333	24.333	10.833	25.333	3.000
G3×G1	7	31.667	35.667	47.733	18.333	3.333	15.333	52.667	195.000	79.667	7.000
G3×G2	8	28.667	32.667	45.233	16.667	5.000	29.333	59.000	151.667	69.333	7.000
G3×G4	8	31.667	33.667	51.533	8.667	6.333	10.000	53.333	158.567	71.333	6.000
G3×G5	8	28.000	31.000	49.000	8.667	4.667	8.667	37.000	34.267	40.667	2.000

D1F- Days to first flowering, D50%F- Days to 50% flowering, PH50%F- Plant height at 50% flowering, NCPP- Number of cluster per plant, NFPC- Number of fruits per cluster, FL- Fruit length, IFW- Individual fruit weight, FD-Fruit diameter, LNPF- Locule number per fruit

Table 5. (Cont'd)

Genotype	Df	D1F	D50%F	PH50%F	NCPP	NFPC	NFPP	FL (mm)	IFW (g)	FD (mm)	LNPF
G3×G6	8	29.333	32.000	41.400	8.667	6.000	13.333	40.000	104.067	62.667	6.000
G4×G1	7	32.667	35.667	26.567	5.000	4.000	11.000	47.333	93.300	62.000	11.000
G4×G2	7	25.333	28.667	45.400	14.667	4.667	44.667	61.667	147.367	61.667	6.000
G4×G3	7	29.333	31.000	37.700	9.667	3.333	17.000	59.667	145.467	61.667	11.000
G4×G5	7	27.333	29.667	50.900	11.333	4.000	29.667	54.333	85.800	50.667	5.000
G4×G6	7	29.667	33.667	46.133	9.000	5.000	15.333	46.000	140.733	70.000	7.000
G5×G1	7	26.667	31.667	51.900	17.333	4.000	24.000	44.667	72.367	52.000	4.000
G5×G2	6	26.333	30.333	48.200	12.333	5.333	20.667	51.333	118.433	62.000	6.000
G5×G3	6	28.667	32.667	48.000	14.000	18.333	31.000	46.767	51.333	48.333	6.000
G5×G4	6	28.000	31.000	43.533	15.000	3.667	28.000	48.000	92.367	61.000	4.000
G5×G6	6	29.000	34.467	44.867	10.000	10.000	21.333	46.333	90.033	58.667	8.000
G6×G1	7	28.000	30.667	40.367	16.667	5.667	21.667	53.333	78.600	51.000	2.000
G6×G2	7	25.667	30.333	55.667	7.667	5.000	17.667	62.000	63.200	43.000	3.000
G6×G3	7	27.667	31.000	47.400	9.667	5.667	15.000	69.000	67.667	46.333	3.000
G6×G4	7	26.667	30.667	48.367	16.333	4.333	13.000	70.333	90.200	47.667	3.000
G6×G5	7	27.000	28.667	40.567	12.000	4.000	9.667	82.000	131.333	59.667	3.000
average	7.306	27.917	32.180	49.865	11.991	8.370	45.046	43.924	73.880	47.685	4.926
maximum	8.000	32.667	39.000	72.000	19.333	21.333	196.333	82.000	195.000	79.667	13.000
minimum	6.000	24.000	28.333	26.567	5.000	3.333	8.667	21.333	5.933	22.000	2.000

D1F- Days to first flowering, D50%F- Days to 50% flowering, PH50%F- Plant height at 50% flowering, NCPP- Number of cluster per plant, NFPC- Number of fruits per cluster, FL- Fruit length, IFW- Individual fruit weight, FD-Fruit diameter, LNPF- Locule number per fruit

was longest. Among the 30 cross combinations G2×G1 (72.000) was of the longest plant height at 50% flowering, and the lowest was observed in G4×G1 (26.567).

4.1.4 Number of cluster per plant

G5 among the six parents had the lowest cluster per plant where G1 was the highest. Among the 30 cross combinations G1×G5 (21.333) was the highest for in mean number of cluster and lowest was observed in G4×G3 (3.333).

4.1.5 Number of fruit per cluster

G4 among the six parents had the lowest fruit per cluster where G6 was the highest. Out of the 30 cross combinations G2×G6 (19.333) was the highest for in number of fruit in each cluster and lowest was observed in G4×G1 (5.00).

4.1.6 Number of fruits per Plant

Among the six parents lowest number of fruits per plant was in G3 and G2 was the highest. Among 30 cross combinations, in G2×G6 (196.333); number of fruit per plant was highest and in G3×G5 (8.667) it was observed the lowest.

4.1.7 Fruit Length (cm)

Among the six parents G1 was the smallest fruit length where G4 was the longest. Among the 30 cross combinations G6×G5 (82.000) had the largest fruit length and the lowest was observed in G1×G4 (22.667).

4.1.8 Individual fruit weight (g)

Individual fruit weight was highest in G5 and lowest in G3 among the six parents and in the 30 cross combinations G3×G1 (195.000) was the highest and G1×G2 (5.933) showed the lowest.

4.1.9 Fruit diameter (mm)

Out of the six parents G3 was of the smallest fruit diameter where G4 was the longest. Among the 30 cross combinations G3×G1 (79.667) had the largest fruit diameter and the lowest was observed in G1×G2 (22.00).

4.1.10 Locules per fruit

Locules per fruit was highest in G5 and lowest in G1 and G2 among the six parents and in the 30 cross combinations G4×G1 and G4×G3 (11.000) was the highest and G6×G1 (2.00) showed the lowest number of locules in each fruit.

4.2. Heterosis

The analysis of variance for genotypes i.e., parents and crosses showed significant difference for all the characters studied(Table 6). The estimates of percent heterosis observed in F_1 generation over better parents and mid parents are presented through Table 6.

4.2.1 Days to first flowering

Among the 30 cross combinations; 21 crosses showed negative heterobeltosis for days to 1st flowering, and 17 crosses showed significant negative heterosis that is earliest than their respective better parent (Table 6). Heterosis for this character ranged from -24.49% to 15.86%. The highest negative heterosis was observed in G2×G4 (-24.49%). The highest positive heterosis effect was observed in the cross G3×G1 (15.86%).

Sixteen crosses showed positive heterosis over mid parent and 6 of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -18.68 to 22.58%. The highest significant positive heterosis was observed in the cross G3×G1 (22.58%). The highest significant negative heterosis was observed in the cross G2×G4 (-18.68%).

Table 6. Estimation of heterosis over better parent and mid parent of 10 morphological traits in *Solanum lycopersicum* L.

	D1F		D50%F		PH50%F		NCPP		NFPC		NFPP	
	Better	**Mid**	**Better**	**Mid**	**Better**	**Mid**	**Better**	**Mid**	**Better**	**Mid**	**Better**	**Mid**
G1×G2	4.76^{ns}	12.10**	3.92^{ns}	-60.42**	-60.42**	-60.42**	-60.42**	-60.42**	-51.92*	-45.06^{ns}	-86.49**	-86.18**
G1×G3	10.98*	17.42**	0.98^{ns}	-42.11^{ns}	-42.11^{ns}	-42.11^{ns}	-42.11^{ns}	-42.11^{ns}	-61.54**	-45.94^{ns}	-73.27**	-52.51**
G1×G4	-12.24**	0.59^{ns}	-5.88^{ns}	-21.62^{ns}	-21.62^{ns}	-21.62^{ns}	-21.62^{ns}	-21.62^{ns}	-44.23^{ns}	-21.62^{ns}	-72.33**	-52.17**
G1×G5	8.54^{ns}	14.84**	14.71*	-56.76*	-56.76*	-56.76*	-56.76*	-56.76*	23.08^{ns}	93.94**	-70.75**	-48.19**
G1×G6	6.10^{ns}	12.26**	2.94^{ns}	-48.00*	-48.00*	-48.00*	-48.00*	-48.00*	-55.77*	-33.33^{ns}	-59.12**	-32.12**
G2×G1	-8.33^{ns}	-1.91^{ns}	-8.82^{ns}	-14.58^{ns}	-14.58^{ns}	-14.58^{ns}	-14.58^{ns}	-14.58^{ns}	-17.31^{ns}	-5.50^{ns}	14.41^{ns}	17.05**
G2×G3	-13.10**	-12.05**	-16.67**	-20.83^{ns}	-20.83^{ns}	-20.83^{ns}	-20.83^{ns}	-20.83^{ns}	10.25^{ns}	40.98^{ns}	36.64**	143.97**
G2×G4	-24.49**	-18.68**	-12.74*	-6.25^{ns}	-6.25^{ns}	-6.25^{ns}	-6.25^{ns}	-6.25^{ns}	20.52^{ns}	54.10^{ns}	41.44**	145.95**
G2×G5	-10.71*	-9.64^{ns}	-9.80^{ns}	-8.33^{ns}	-8.33^{ns}	-8.33^{ns}	-8.33^{ns}	-8.33^{ns}	43.59^{ns}	111.32**	47.75**	163.10**
G2×G6	-14.29**	-13.25**	-14.71*	16.00^{ns}	16.00^{ns}	16.00^{ns}	16.00^{ns}	16.00^{ns}	30.77^{ns}	82.14^{ns}	76.88**	195.98**
G3×G1	15.86**	22.58**	4.90^{ns}	44.73^{ns}	44.73^{ns}	44.73^{ns}	44.73^{ns}	44.73^{ns}	-80.77**	-72.97**	-85.53**	-74.30**
G3×G2	2.38^{ns}	3.62^{ns}	-3.92^{ns}	4.17^{ns}	4.17^{ns}	4.17^{ns}	4.17^{ns}	4.17^{ns}	-61.54*	-50.82^{ns}	-73.57**	-52.82**
G3×G4	-3.06^{ns}	5.56^{ns}	0.00^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-13.64^{ns}	-13.64^{ns}	-40.00^{ns}	-33.33^{ns}
G3×G5	2.44^{ns}	2.44^{ns}	-7.92^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-31.58^{ns}	-36.36^{ns}	-22.22^{ns}	-36.58^{ns}	-35.80^{ns}
G3×G6	7.32^{ns}	7.32^{ns}	-4.95^{ns}	-48.00*	-48.00*	-48.00*	-48.00*	-48.00*	-18.18^{ns}	-7.69^{ns}	-38.46^{ns}	-23.81^{ns}
G4×G1	0.00^{ns}	14.62**	4.90^{ns}	-59.46*	-59.46*	-48.25**	-6.69**	-3.46^{ns}	-76.92**	-67.57**	-89.62**	-82.07**
G4×G2	-22.45**	-16.49**	-15.69**	-8.33^{ns}	-8.33^{ns}	-18.47^{ns}	-5.99**	-0.74^{ns}	-64.10*	-54.09^{ns}	-59.76**	-30.03**
G4×G3	-10.21*	-2.22^{ns}	-7.92^{ns}	-23.68^{ns}	-23.68^{ns}	-23.09^{ns}	-1.06^{ns}	4.27^{ns}	-54.55^{ns}	-54.55^{ns}	2.00^{ns}	13.33^{ns}
G4×G5	-16.33**	-8.89^{ns}	-11.00^{ns}	6.24^{ns}	6.24^{ns}	11.14^{ns}	-4.58*	-0.73^{ns}	-45.45^{ns}	-33.33^{ns}	78.00^{ns}	95.60^{ns}
G4×G6	-9.18*	-1.11^{ns}	1.00^{ns}	-46.00*	-46.00*	4.29^{ns}	-8.45**	-4.24^{ns}	-31.82^{ns}	-23.08^{ns}	-29.23^{ns}	-20.00^{ns}
G5×G1	-2.44^{ns}	3.23^{ns}	-6.86^{ns}	40.54^{ns}	40.54^{ns}	5.85^{ns}	-7.55**	-7.02**	-76.92**	-63.64^{ns}	-77.36**	-59.89**
G5×G2	-5.95^{ns}	-4.82^{ns}	-10.79^{ns}	-22.92^{ns}	-22.92^{ns}	-9.71^{ns}	1.15^{ns}	2.71^{ns}	-58.98^{ns}	-39.63^{ns}	-81.38**	-66.84**
G5×G3	4.88^{ns}	4.88^{ns}	-2.97^{ns}	10.52^{ns}	10.52^{ns}	2.75^{ns}	-6.87**	-5.61**	150.01**	205.55**	126.82^{ns}	129.63^{ns}
G5×G4	-14.29**	-6.67^{ns}	-7.00^{ns}	40.62^{ns}	40.62^{ns}	-4.95^{ns}	-3.87^{ns}	0.00^{ns}	-49.99^{ns}	-38.88^{ns}	68.00^{ns}	84.61^{ns}
G5×G6	6.10^{ns}	6.10^{ns}	6.60^{ns}	-40.00^{ns}	-40.00^{ns}	7.00^{ns}	5.34*	5.95**	76.46^{ns}	93.54^{ns}	-1.54^{ns}	20.75^{ns}
G6×G1	2.44^{ns}	8.39^{ns}	-9.80^{ns}	0.00^{ns}	0.00^{ns}	-14.96^{ns}	-2.26^{ns}	-1.15^{ns}	-67.31**	-50.72^{ns}	-79.56**	-66.06**
G6×G2	-8.33^{ns}	-7.23^{ns}	-10.79^{ns}	-54.00*	-54.00*	7.43^{ns}	2.32^{ns}	3.31^{ns}	-61.54*	-46.43^{ns}	-84.08**	-73.37**
G6×G3	1.22^{ns}	1.22^{ns}	-7.92^{ns}	-42.00*	-42.00*	4.98^{ns}	1.93^{ns}	2.72^{ns}	-22.72^{ns}	-12.82^{ns}	-30.77^{ns}	-14.29^{ns}
G6×G4	-18.37**	-11.11**	-8.00^{ns}	-2.00^{ns}	-2.00^{ns}	9.34^{ns}	-2.47^{ns}	2.03^{ns}	-40.91^{ns}	-33.34^{ns}	-40.00^{ns}	-32.18^{ns}
G6×G5	-1.22^{ns}	-1.22^{ns}	-11.34^{ns}	-28.00^{ns}	-28.00^{ns}	-3.26^{ns}	2.67^{ns}	3.26^{ns}	-76.92**	-67.57**	-89.62**	-82.07**

D1F- Days to first flowering, D50%F- Days to 50% flowering, PH50%F- Plant height at 50% flowering, NCPP- Number of cluster per plant, NFPC- Number of fruits per cluster, ^{ns}=Non-significant, *=Significant at 5% probability level, **= Significant at 1% probability level

Table 6 (Cont'd)

	FL (mm)		IFW (g)		FD (mm)		LNPF	
	Better	**Mid**	**Better**	**Mid**	**Better**	**Mid**	**Better**	**Mid**
G1×G2	23.53**	27.27**	-37.10^{ns}	-36.88^{ns}	-12.00 ^{ns}	-9.59 ^{ns}	50.00 **	50.00 **
G1×G3	82.86**	91.05**	345.18 **	373.86 **	71.83 **	74.29 **	-40.00 **	-3.22 ^{ns}
G1×G4	-55.26**	-37.04**	-94.98 **	-90.65 **	-65.24 **	-48.04 **	-77.78 **	-63.64 **
G1×G5	-33.98**	-11.98^{ns}	-80.75 **	-63.85 **	-64.09 **	-45.71 **	-69.23 **	-46.67 **
G1×G6	-19.46**	12.68**	-57.46 **	-24.27 **	-32.08 **	-6.09 ^{ns}	-40.00 **	-14.29 ^{ns}
G2×G1	7.35^{ns}	10.60^{ns}	-12.36 ^{ns}	-12.05 ^{ns}	9.33 ^{ns}	12.33 ^{ns}	0.00 ^{ns}	0.00 ^{ns}
G2×G3	25.71**	27.53**	141.35 **	157.75 **	44.00 **	50.00 **	-76.00 **	-61.29 **
G2×G4	-53.29**	-35.45**	-93.04 **	-87.05 **	-63.81 **	-46.67 **	-77.78 **	-63.64 **
G2×G5	-46.09**	-29.59**	-93.86 **	-88.48 **	-64.55 **	-47.12 **	-84.62 **	-73.33 **
G2×G6	-51.01**	-32.72**	-85.73 **	-74.62 **	-52.20 **	-35.04 **	-40.00 **	-14.29 ^{ns}
G3×G1	125.72**	135.83**	1981.78 **	2115.91 **	236.62 **	241.43 **	-16.00 **	35.49 **
G3×G2	152.86**	156.52**	1507.83 **	1617.05 **	177.33 **	188.89 **	-16.00 **	35.49 **
G3×G4	5.26^{ns}	44.14**	24.40 **	133.70 **	1.90 ^{ns}	53.40 **	-33.33 **	-30.77 **
G3×G5	-13.28**	12.12**	-76.18 **	-54.94 **	-44.54 **	-15.57 **	-84.62 **	-81.25 **
G3×G6	-19.46**	9.59^{ns}	37.05 **	147.29 **	18.24 **	64.91 **	-28.00 **	-10.00 ^{ns}
G4×G1	-6.58^{ns}	31.48**	-26.80 **	36.37 **	-11.43 *	32.38 **	22.22 **	100.00 **
G4×G2	21.71**	68.18**	15.61 **	115.29 **	-11.90 *	29.83 **	-33.33 **	9.09 ^{ns}
G4×G3	17.76**	61.26**	14.12 **	114.39 **	-11.90 *	32.62 **	22.22 **	26.93 **
G4×G5	7.24^{ns}	16.43**	-40.36 **	-36.76 **	-30.91 **	-29.30 **	-61.54 **	-54.55 **
G4×G6	-9.21*	-8.31**	10.41 **	38.38 **	0.00 ^{ns}	13.82 **	-22.22 **	0.00 ^{ns}
G5×G1	4.69^{ns}	39.58**	-49.70 **	-5.55 ^{ns}	-29.09 **	7.22 ^{ns}	-69.23 **	-46.67 **
G5×G2	20.31**	57.14**	-17.68 **	54.51 **	-15.45 **	26.10 **	-53.85 **	-20.00 **
G5×G3	9.61*	41.72**	-64.32 **	-32.50 **	-34.09 **	0.35 ^{ns}	-53.85 **	-43.75 **
G5×G4	-5.26^{ns}	2.86^{ns}	-35.80 **	-31.92 **	-16.82 **	-14.88 **	-69.23 **	-63.64 **
G5×G6	-6.71^{ns}	0.36^{ns}	-37.42 **	-18.08 **	-20.00 **	-7.12 ^{ns}	-38.46 **	-11.11 **
G6×G1	7.38^{ns}	50.23**	3.51 ^{ns}	84.29 **	-3.77 ^{ns}	33.04 **	-60.00 **	-42.86 **
G6×G2	24.83**	71.43**	-16.77 **	48.07 **	-18.87 **	10.26 ^{ns}	-40.00 **	-14.29 ^{ns}
G6×G3	38.93**	89.04**	-10.89 **	60.79 **	-12.58 *	21.93 **	-64.00 **	-55.00 **
G6×G4	38.81**	40.20**	-29.24 **	-11.31 **	-31.90 **	-22.49 **	-66.67 **	-57.14 **
G6×G5	65.10**	77.62**	-8.71 **	19.50 **	-18.64 **	-5.54 ^{ns}	-76.92 **	-66.67 **

FL- Fruit length, IFW- Individual fruit weight, FD-Fruit diameter, LNPF- Locule number per fruit , ^{ns}=Non-significant,*=Significant at 5% probability level, **= Significant at 1% probability level

4.2.2 Days to 50% flowering

Among the 30 cross combinations 21 crosses showed negative heterobeltosis for days to 50% flowering and four cross showed significant negative heterosis that is earliness than their respective better parent (Table 6). Heterosis for this character ranged from -16.67% to 14.71%. The highest negative heterosis was observed in G2×G3 (- 16.67%). The highest positive heterosis effect was observed in the cross G1×G5 (14.71%). Singh and singh (1993), Kumar *et al*. (1995 a) and Vidyasagar *et al*. (1997) also reported negative heterosis for days to 50% flowering.

Twenty two crosses showed negative heterosis over mid parent and 3 cross showed significant negative heterosis (Table 6). The estimate of heterosis ranges from -16.26% to 17.59%. The highest significant positive heterosis was observed in the cross G1×G5 (14.84%). The highest significant negative heterosis was observed in the cross G2×G3 (-16.67%).

4.2.3 Plant height at 50% flowering(cm)

Out of 30 cross combinations twenty one crosses showed negative heterosis over better parent out of which three crosses showed significant negative heterosis (Table 6). The estimate of heterosis ranges from -51.31% to 20.65%. The highest significant positive heterosis was observed in the cross G1×G6 (12.26%). The highest significant negative heterosis was observed in the cross G4×G1 (-59.46%).

Sixteen crosses showed positive heterosis over mid parent and 1 of them showed significant positive heterosis (Table 6) The estimate of heterosis ranges from -48.25% to 38.69%. The highest significant positive heterosis was observed in the cross G1×G6 (38.69%). The highest significant negative heterosis was observed in the cross G4×G1 (-48.25%)

4.2.4 Number of cluster per plant

Out of 30 cross combinations twenty two crosses showed negative heterosis over better parent out of which 8 crosses showed significant negative heterosis (Table 6). The estimate of heterosis ranges from -60.42% to 44.73%. The highest significant positive heterosis was observed in the cross G3×G1 (44.73%). The highest significant negative heterosis was observed in the cross G1×G2 (-60.42%). 11 crosses showed positive heterosis over mid parent (Table 6). The estimate of heterosis ranges from -55.30% to 52.54%. The highest significant positive heterosis was observed in the cross G5×G4 (52.54%). The highest significant negative heterosis was observed in the cross G1×G2 (-55.30%).

4.2.5 Number of fruits per Cluster

Out of 30 cross combinations 7 crosses showed positive heterosis over better parent out of which 1 cross showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -80.77% to 150.01%. The highest significant positive heterosis was observed in the cross G5×G6 (76.88%). The highest significant negative heterosis was observed in the cross G4×G1 (-89.62%). The heterosis for fruit per plant was also reported by several workers like Vidyasagar *et al*. (1997), Bhatt *et al*. (1999) and Sekar (2001).

21 crosses showed negative heterosis over mid parent and 2 of them showed significant negative heterosis (Table 6). The estimate of heterosis ranges from -72.97 to 205.55%. The highest significant positive heterosis was observed in the cross G5×G3 (205.55%). The highest significant negative heterosis was observed in the cross G3×G1 (-72.97%).

4.2.6 Number of fruits per Plant

Out of 30 cross combinations 9 crosses showed positive heterosis over better parent out of which 4 crosses showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -89.62% to 78%. The highest significant positive heterosis

was observed in the cross G2×G6 (76.88%). The highest significant negative heterosis was observed in the cross G4×G1 (-89.62%). The heterosis for fruit per plant was also reported by several workers like Vidyasagar *et al*. (1997), Bhatt *et al*. (1999) and Sekar (2001).

Three crosses showed positive heterosis over mid parent and all of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -77.78 to 50.00%. The highest significant positive heterosis was observed in the cross G1×G2 (50.00%). The highest significant negative heterosis was observed in the cross G1×G4 (-77.78%).

4.2.7 Fruit Length (mm)

Among the 30 cross combinations 18 cross showed positive better parent heterosis and out of which 13 crosses showed significant positive heterosis. The heterosis over better parent ranges from -55.26% to 82.86% (Table 6). The highest significant positive heterosis was observed in the cross G1×G3 (82.86%). The highest significant negative heterosis was observed in the cross G1×G4 (-55.26%). Singh *et al*. (1995), Susie (1998) and Wang *et al*. (1998b) also reported heterosis for fruit length.

Twenty four crosses showed positive heterosis over mid parent and 20 of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -37.04 to 156.52%. The highest significant positive heterosis was observed in the cross G3×G2 (156.52%). The highest significant negative heterosis was observed in the cross G1×G4 (-37.04%).

4.1.8 Individual fruit weight (g)

Among the 36 cross combinations only 10 crosses showed positive better parent heterosis and out of them 10 crosses showed significant positive heterosis over better parent for individual fruit weight (g). The heterosis over better parent ranges from – 94.98% to 67.609% (Table 5). The highest significant positive heterosis

was observed in the cross G1×G3 (67.609%). The highest significant negative heterosis was observed in the cross G1×G4 (-94.98%). Singh *et al.* (1995), Kumar *et al*. (1995a), Kumar *et al*. (1995b) and Vidyasagar *et al.* (1997) also reported heterosis from this trait.

Fiftteen crosses showed positive heterosis over mid parent and all of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -90.65 to 2115.91%. The highest significant positive heterosis was observed in the cross G3×G1 (2115.91%). The highest significant negative heterosis was observed in the cross G1×G4 (-90.65%).

4.2.9 Fruit diameter (mm)

In case of fruit breathe out of 30 cross combinations 7 crosses showed positive heterosis over better parent and 4 of them showed significant positive heterosis. The heterobeltotic effect ranges from -65.24% to 71.83% (Table 6). The highest significant positive heterosis was observed in the cross G1×G3 (71.83%). The highest significant negative heterosis was observed in the cross G1×G4 (-65.24%). Haterosis for fruit breath was also reported by Chaudhury and Kanna (1972), Susie (1998) and Wang *et al.* (1998 b).

17 crosses showed positive heterosis over mid parent and 13 of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -48.04% to 241.43%. The highest significant positive heterosis was observed in the cross G3×G1 (241.43%). The highest significant negative heterosis was observed in the cross G1×G4 (-48.04%).

4.2.10 Locules per fruit

Out of 30 cross combinations, 3 crosses showed positive heterosis over better parent and all of them showed significant positive heterosis (Table 6). The estimate of heterosis ranges from -77.78 to 50.00%. The highest significant positive heterosis was observed in the cross G1×G2 (50.00%). The highest significant

negative heterosis was observed in the cross G1×G4 (-77.78%). Kurian *et al*. (2001) also identified heterotic hybrids for locule number.

24 crosses showed negative heterosis over mid parent and 18 of them showed significant negative heterosis (Table 6). The estimate of heterosis ranges from -81.25% to 100.00%. The highest significant positive heterosis was observed in the cross G4×G1 (100.00%). The highest significant negative heterosis was observed in the cross G3×G5 (-81.25%).

From the result noticeable better parent heterosis was found for almost all the 10 characters (Table 6). It also shows the possibility of increasing yield by exploiting heterosis. From the present analysis it can be said that for high yielding and quality cultivars of tomato, hybrid can be used to smooth the progress of development.

4.3 Combining Ability

The analysis of variances for general combining ability (GCA) and specific combining ability (SCA) were found significant for most of the traits studied (Table 7) indicating both additive and non-additive gene actions for the expression of these traits. The general combining ability (GCA) variances for all the traits studied higher in the magnitude than the specific combining ability variances indicating the predominance of the additive effect for these traits. The general combining ability (GCA) variances for the characters' fruits per cluster, fruits per plant, individual fruit weight and fruit diameter were higher in the magnitude than+\/the specific combining ability (SCA) variances indicating that additive gene effect is predominant for these traits. 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 diameter in tomato The GCA component is predominantly a function of the

Table 7. Analysis of variances (MS values) of GCA and SCA

Source	df	D1F	D50%F	PH50%F	NCPP	NFPC	NFPP	FL (mm)	IFW (g)	FD (mm)	LNPF
GCA	5	12.693**	12.103**	208.499**	12.910 ns	44.269**	7751.477**	575.543**	5665.967**	708.658**	18.440**
SCA	15	4.871**	2.991 ns	22.541 ns	7.811 ns	11.411 ns	606.429**	100.563**	2152.951**	191.824**	6.048**
Reciprocal	15	2.904**	6.118**	108.021**	22.130**	38.200**	3143.763**	286.614**	3061.297**	297.230**	7.867**
Error	70	1.208	2.593	37.372	8.117	9.839	52.936	2.553	5.866	6.619	0.087
GCA:SCA		2.606	4.047	9.250	1.653	3.880	12.782	5.723	2.632	3.694	3.049
σ2g		0.662	0.760	15.457	0.424	2.742	596.909	39.845	298.523	43.567	1.049
σ2s		2.127	0.231	-8.612	-0.178	0.913	321.383	56.909	1246.694	107.539	3.461

D1F- Days to first flowering, D50%F- Days to 50% flowering, PH50%F- Plant height at 50% flowering, NCPP- Number of cluster per plant, NFPC- Number of fruits per cluster, FL- Fruit length, IFW- Individual fruit weight, FD-Fruit diameter, LNPF- Locule number per fruit, GCA-General Combining Ability, SCA-Specific Combining Ability.

additive genetic variance and GCA variances with each parent plays significant role in the choice of parents. A parent with higher positive significant GCA effects is considered as a good general combiner and the magnitude and direction of the significant effects for the six parents provide meaningful comparisons and would give indications to the future breeding programme. The results of GCA effects for ten different characters were estimated and presented in Table 8. The SCA effects signify the role of non-additive gene action in the expression of the traits. It indicates the highly specific combining ability leading to highest performance of some specific cross combinations. That is why it is related to a particular cross. 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 programme. The SCA effects of 30 F_1 crosses for the same characters are presented in Table 9 to Table 18.

4.3.1 Days to 1st flowering

The mean square (MS) values for GCA and SCA were highly significant for this trait which suggests the presence of both additive and non-additive gene action for this character. Among the six parent studied the parent G3 and G4 showed the significant positive GCA effects. The GCA value of G4 (1.194**) was higher than G3 (0.778**). On the other hand, G2 (-1.667**) showed significant negative GCA effect. So the parent G4 was the best general combiner for Day of first flowering (Table 8).

Among the 30 cross combinations 2 crosses; G1×G3 (1.860**) and G2×G1 (1.883*) showed significant positive SCA effects (Table 9). Thus these 2 crosses were good specific combiner for day of first flowering. The cross G1×G3 was the best specific combiner and no crosses showed significant negative SCA effects.

Table 8. General Combining Ability (GCA) effects of parents used in a full diallel cross of *Solanum lycopersicum* L.

Parents	Days to 1st flowering	Days to 50%flowering	Plant height at 50%flowering	Cluster number	Fruits per cluster	Fruits per plant	Fruit length (mm)	Individual fruit weight (g)	Fruits diameter (mm)	Locule per fruit
G1	0.444^{ns}	1.848**	0.977^{ns}	-0.907^{ns}	1.602^{ns}	1.454^{ns}	-8.382**	-25.521**	-8.63**	-1.009**
G2	-1.667**	-1.013*	8.066**	1.759*	2.824**	50.398**	-7.924**	-26.794**	-10.352**	-1.593**
G3	0.778**	0.293^{ns}	-1.784^{ns}	-0.352^{ns}	-1.009^{ns}	-16.185**	0.751^{ns}	8.534**	2.537**	1.046**
G4	1.194**	-0.319^{ns}	-2.662^{ns}	-0.963^{ns}	-2.093*	-12.685**	5.104**	28.12**	8.62**	1.324**
G5	-0.389^{ns}	-0.196^{ns}	-2.173^{ns}	-0.157^{ns}	0.241^{ns}	-12.102**	1.654**	9.47**	4.981**	0.907**
G6	-0.361^{ns}	-0.613^{ns}	-2.423^{ns}	0.62^{ns}	-1.565^{ns}	-10.88**	8.798**	6.19**	2.843**	-0.676**
SEgij	0.290	0.424	1.611	0.751	0.827	1.917	0.421	0.638	0.678	0.078
SE (gi-gj)	0.449	0.657	2.496	1.163	1.281	2.970	0.652	0.989	1.050	0.121

*=5% significant at 5% probability level, **1%= singnificant at 1% probability level.

Table 9. Estimates of GCA and SCA effects in tomato for days to first flowering

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		0.806	1.860**	1.111	0.194	0.500	0.444
G2	1.833		-0.528	-2.444	-0.194	-1.054	-1.667**
G3	-0.667	-2.176		0.611	0.028	0.176	0.778**
G4	-2.000	-0.333	1.176		-1.056	-0.583	1.194**
G5	1.500	-0.667	-0.333	-0.333		0.833	-0.389
G6	0.500	-0.833	0.833	1.500	1.000		-0.368
Max						1.861	
Min						-2.444	
SEgij							0.290
SE(gi-gj)							0.449
SE(sij)							
SE(sij-sik)						1.004	
SE(sij-skl)						0.898	

Table 10. Estimates of GCA and SCA effects in tomato for days to 50% flowering

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		0.152	0.680	0.124	1.502	-0.581	1.848**
G2	2.167		-0.959	-1.681	-0.470	-0887	-1.013*
G3	-0.667	0.500		1.333	-1.331	-0.667	0.293
G4	-1.833	0.500	1.333		-1.331	0.919	-0.319
G5	3.667**	0.167	-0.883	-0.667		0.196	-0.196
G6	2.167	-0.667	0.500	1.500	2.900**		-0.613
Max						3.667	
Min						-2.167	
SEgij							0.424
SE(gi-gj)							0.657
SE(sij)						0.968	
SE(sij-sik)						1.470	
SE(sij-skl)						1.314	

Table 11. Estimates of GCA and SCA effects in tomato for plant height at 50% flowering (cm)

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		2.893	-4.191	-7.463	1.331	4.681	0.977
G2	-10.200		0.020	0.048	-1.541	1.309	8.066**
G3	-2.687	10.933*		-0.802	2.593	-1.257	-1.784
G4	14.150**	9.917*	6.917		2.187	2.470	-2.662
G5	-1.900	6.017	0.500	3.683		-2.552	-2.173
G6	12.733**	1.150	-3.000	-1.117	2.150		-2.423
Max						14.150	
Min						-10.200	
SEgij							1.611
SE(gi-gj)							2.946
SE(sij)						3.674	
SE(sij-sik)						5.581	
SE(sij-skl)						4.991	

Table 12. Estimates of GCA and SCA effects in tomato for cluster per plant

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-2.843	2.102	-2.787	0.407	0.963	-0.907
G2	-3.667		1.269	2.046	-0.093	-0.870	1.759*
G3	-5.500	-2.000		-1.509	-0.148	-3.093	-0.352
G4	2.333	0.167	-0.500		2.296	1.019	-0.963
G5	-6.000	1.167	-2.667	-1.833		-1.454	-0.157
G6	-4.000	5.833**	-0.500	-3.667	-1.000		0.62
Max						5.833	
Min						-6.000	
SEgij							0.751
SE(gi-gj)							1.163
SE(sij)						1.712	
SE(sij-sik)						2.601	
SE(sij-skl)						2.326	

Table 13. Estimates of GCA and SCA effects in tomato for fruits per cluster

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-1.463	-3.963	-1.046	2.454	-1.741	1.602
G2	-3.000		-0.519	1.065	0.565	1.370	2.824**
G3	1.667	4.667*		-0.435	3.898*	0,037	-1.009
G4	2.833	5.500*	1.500		-2.685	-0.046	-2.093*
G5	8.667**	6.667**	-6.833	0.167		-0.046	0.241
G6	1.000	60.000**	0.167	0.333	3.000		-1.565
Max						8.667	
Min						-6.833	
SEgij							0.827
SE(gi-gj)							1.281
SE(sij)						1.885	
SE(sij-sik)						2.863	
SE(sij-skl)						2.561	

Table 14. Estimates of GCA and SCA effects in tomato for fruits per plant

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-25.898	-8.481	-13.648	-6.898	-3.120	1.454
G2	-56.000		11.241*	18.074**	8.991*	22.435**	50.398**
G3	6.500	61.167**		-2.676	3.074	-3.815	-16.185**
G4	9.167	56.167**	-3.500		8.574	-7.315	-12.685**
G5	3.500	71.667**	-11.167	0.883		-6.565	-12.102**
G6	10.833*	89.333**	-0.833	1.167	5.833		-10.88**
Max						89.333	
Min						-56.000	
SEgij							1.917
SE(gi-gj)							2.970
SE(sij)						4.372	
SE(sij-sik)						6.642	
SE(sij-skl)						5.941	

Table 15. Estimates of GCA and SCA effects in tomato for fruits length

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-1.451	11.374	-5.645	-0.779	2.327*	-8.382**
G2	1.833		7.416**	1.563	-0.487	-1.631	-7.924**
G3	-5.000	-14.833		6.721**	-4.445	1.027	0.751ns
G4	-12.333	-19.333	-3.167		0.485	0.341	5.104**
G5	-8.250	-14.167	-4.883	3.167**		9.791**	1.654**
G6	-6.667	-18.833	-14.500	-12.167	-17.833		8.798**
Max						11.374	
Min						-19.000	
SEgij							0.421
SE(gi-gj)							0.652
SE(sij)						0.960	
SE(sij-sik)						1.459	
SE(sij-skl)						1.305	

Table 16. Estimates of GCA and SCA effects in tomato for fruits diameter

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-4.037	18.574**	-4.509	-4.870	1.602	-8.63**
G2	-2.667		12.796**	-2.454	1.685	-6.009	-10.352**
G3	-19.500	-16.667		7.657**	-10.704	1.435	2.537**
G4	-18.833	-18.167	4.833*		-5.454	-0.315	8.62**
G5	-12.833	-18.000	-3.833	-5.167		3.657*	4.981**
G6	-7.500	-8.833	8.167**	11.167**	-0.500		2.843**
Max						18.574	
Min						-19.500	
SEgij							0.678
SE(gi-gj)							1.050
SE(sij)						1.546	
SE(sij-sik)						2.349	
SE(sij-skl)						2.101	

Table 17. Estimates of GCA and SCA effects in tomato for individual fruit weight

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		-14.465	61.457**	-26.629	-7.795	0.902	-25.521**
G2	-1.167		31.596**	2.910	7.077**	-16.259	-26.794**
G3	-76.670	-64.450		41.482**	-49.082	-2.737	8.534**
G4	-43.450	-69.250	6.550**		-22.387	7.277**	28.12**
G5	-22.333	-54.800	-8.533	-3.283		21.144**	9.47**
G6	-23.150	-26.183	18.200**	25.267**	-20.650		6.19**
Max						61.457	
Min						-76.650	
SEgij							0.638
SE(gi-gj)							0.989
SE(sij)						1.455	
SE(sij-sik)						2.211	
SE(sij-skl)						1.978	

Table 18. Estimates of GCA and SCA effects in tomato for locule per fruit

Parent	SCA						GCA
	G1	G2	G3	G4	G5	G6	
G1		0.167	1.037**	1.259**	-0.824	-0.741	-1.009**
G2	0.500		0.120	-0.657	-0.241	0.343	-1.593**
G3	-1.000	-2.500		1.204**	-2.880	-0.796	1.046**
G4	-4.500	-2.000	-2.500		-2.657	-0.574	1.324**
G5	0.000	-2.000	-2.000	0.500		0.343	0.907**
G6	0.500	0.000	1.500**	2.000**	2.500**		-0.676**
Max						2.500	
Min						-4.500	
SEgij							0.078
SE(gi-gj)							0.121
SE(sij)						0.178	
SE(sij-sik)						0.270	
SE(sij-skl)						0.247	

4.3.2 Days to 50% flowering

The mean square for GCA was significant but SCA was insignificant for days to 50% flowering which suggest the presence of additive and absence of non-additive genetic variance in the population for this trait (Table 10). Here higher magnitude of GCA variance than SCA variance indicated pre dominance of additive gene action. Bhatt *et al.* (2001b), Dhaliwal *et al*. (2000) and Srivastava *et al*. (1998a) also reported the predominance of non-additive variance for days to flowering. Where El-Mahdy *et al*. (1990) and Natarajan (1992) reported that additive gene effects appeared more important than non-additive gene effects.

The estimate of GCA effects for this trait is given in (Table 8). Among the six parent studied the parent G2 showed significant negative GCA effect (- 1.013*) and G1 showed significant positive GCA effect (1.848**) for days to 50% flowering. So the parent G2 was the best general combiner for earliness. E.l. Mahdy *et al*. (1990) reported highly significant GCA effect for early yield in certain lines under heat stress in tomato. El-Mahdy *et al*. (1990) also found such effect in heat tolerance tomato lines. Chadha *et al.* (1997) also found a lines performing as a good general combiner.

Among the 30 F_1s only G5×G1 (3.667**) and G6×G5 (2.900) showed significant positive SCA effect. Between them G5×G1 (3.667**) showed comparatively the highest positive SCA than G6×G5 (2.90**). On the other hand, no cross showed significant negative SCA. Shrivastava *et al.* (1993) also reported a hybrid as a best combination for earliness. Chadha *et al*. (1997) found a hybrid as a good specific combiner for days to 50% flowering.

4.3.3 Plant height at 50% flowering

The mean square for GCA was significant but SCA was insignificant for Plant height at 50% flowering which suggest the presence of additive and absence of non-additive genetic variance in the population for this trait (Table 11). Here

higher magnitude of GCA variance than SCA variance indicated pre dominance of additive gene action.

Among the six parent studied the parent only G2 (8.066**) showed the significant positive GCA effects. On the other hand, no parents showed significant negative GCA effect. So the parent G2 was the best general combiner for plant height at 50% flowering (Table 8).

Among the 30 cross combinations, 4 crosses *viz.* G3×G2(10.933*), G4×G1 (14.150**), G4×G2 (9.917*), G6×G1 (12.733**) showed significant positive SCA effects. Thus these 4 crosses were good specific combiner for plant height at 50% flowering. The cross G4×G1 was the best specific combiner. On the other hand, no cross showed significant negative SCA effects.

4.3.4 Number of cluster per plant

The mean square for GCA and SCA was insignificant for number of cluster per plant which suggest the absence of non-additive genetic variance in the population for this trait (Table 12). Higher magnitude of GCA variance than SCA variance indicated pre dominance of additive gene action.

Among the six parent studied the parent only G2 (1.759*) showed the significant positive GCA effects. On the other hand, no parents showed significant negative GCA effect. So the parent G2 was the best general combiner for number of cluster per plant.

Among the 36 cross combinations, only G6×G2(5.833**) showed significant positive SCA effects. Thus crosses were good specific combiner for number of cluster per plant. The cross G6×G2 was the best specific combiner. On the other hand, no cross showed significant negative SCA effects.

4.3.5 Number of fruits per cluster

The analysis of variance for fruits per cluster indicated the importance of both additive and non-additive gene action as the variance due to GCA and SCA were

significant (Table 13). But the higher magnitude of GCA variances to SCA variances suggested the pre dominance of additive gene action for this character. Natarajan (1992) reported the pre dominance of additive gene action for number of fruits set per cluster. Contrary Bhatt *et al.* (2001b) reported predominance of non-additive gene action.

Table 13 represents the GCA and SCA effects for fruits per cluster. Among the six parents only G2 showed positive GCA effects and its (2.824**) and G3 (-2.093*) showed negative GCA effects. The other parent did not show significant value. Thus G2 was good general combiner for fruits per cluster. Resende *et al*. (2000) also reported significant general combining ability (GCA) effects in a group of parents.

Nineteen cross combinations out of 30 showed positive SCA effect for this character, among them only six crosses exhibited significant positive SCA effect. The highest significant positive SCA effect was obtained by the cross G5×G1 (8.667**) followed by G5×G2 (6.667**) and G6×G2 (6.000**). The crosses with highest positive SCA are considered as the best specific combiners for this character. There was no parent showing negative significant SCA value.

4.3.6 Number of Fruits per Plant

The mean square for GCA and SCA were highly significant for this character which suggests the presence of both additive and non-additive gene action for this character (Table 14). Bhuiyan (1982) and Natarajan (1992) supported the result and considerably higher GCA component compared to SCA component suggested that the additive portion of genetic variance was substantial. Wang *et al.* (1998a) also reported important role of additive gene action. Bhuiyan (1982) reported predominance of additive and additive x additive gene actions for this character. On the other hand, Bhatt *et al*. (2001b), Srivastava *et al*. (1998b) and Bhutani and Kalloo (1988) observed non-additive control for this character.

The parent G2 showed highly significant positive GCA effects (50.398**). The highest significant negative value was obtained by the parent G3 (-16.185**) followed by G4 (-12.685**) and G5 (-12.102*). G2 were the best general combiners which could be used in crosses for the increasing number of fruits per plant and in this trait G2 is the best for increasing number of fruits per plant. Chadha *et al*. (1997), Natarajan (1992) and De-Araujo and De-Campos (1991) reported some good general combiners for number of fruits per plant.

Out of 30 cross combinations 18 crosses showed positive SCA effects but 9 showed significant positive SCA effects. The highest significant positive effect was observed in the cross G6×G2 (89.333**) followed by G5×G2 (71.667**), G3×G2 (61.167**) and G4×G2 (56.167**). These crosses were the best specific combiner for increasing fruits per plant. The cross G5 and G2 was the best specific combiner for this character. Bhuiyan (1982) also found some hybrids showed significant positive SCA in tomato.

4.3.7 Fruit Length (mm)

The combining ability variances for fruit length are presented in the Table 15. The significant value for GCA suggests the presence of additive gene action for this trait. The lower GCA components than SCA component indicated the pre dominance of non-additive gene action. Similar result was also reported by Ahmed (2002) and Srivastavae *et al.* (1998a). However, Wang *et al.* (1998a) and also observed highly significant GCA and SCA, but pre dominance of additive gene effects for fruit length in tomato.

Among the six parents only 3 parents showed significant positive GCA effects. The highest significant positive GCA value was observed in G6 (8.798**) followed by G4 (5.104**). Therefore, the parent G6 and G4 were good general combiner for fruit length. Two parent G1 (-8.382**) and G2 (-7.932) showed

significant negative GCA effects. Susie (1998) and Ahmed (2002) also reported some good general combiners for fruit length.

Among the 30 cross combinations six cross showed significant positive SCA effects but 10 crosses showed positive effects and no cross showed significant negative SCA effects. But Susie (1998) reported a good specific combiner for fruit length in tomato. Superior hybrids for fruit length were also reported by Ahmad (2002).

4.3.8 Fruit diameter(mm)

The analysis of variance for fruit diameter indicated the importance of both additive and non-additive gene actions as the variances due to GCA and SCA were significant. The significant value for GCA suggests the presence of additive gene action for this trait (Table 16). However, considerably greater GCA variances compare to SCA variances suggested that the additive portion of genetic variance was substantial, Wang *et al*. (1998a). Contrary Srivastava *et al*. (1998b) reported non-additive effects of genetic variance for fruit diameter in tomato.

Table 16 represented the combining ability effects (GCA and SCA) for fruit diameter. Among the six parents the highest GCA effects for fruit diameter was exhibited by the parent G4 (8.62**) followed by G5 (4.981**) and G6 (2.843*).

The parent G4 and G5 were the good general combiners for fruit diameter. The highest significant negative GCA effects was obtained from G2 (-10.352**) followed G1 (-8.63**). Susie (1998) and Ahmad (2002) also reported some good general combiners for this trait in tomato.

Among the 30 cross combinations 11 crosses showed positive SCA effects for fruit diameter out of which 7 crosses showed significant positive SCA effects. The highest significant positive SCA was obtained in the cross combination G1×G3 (18.574*) followed by G2×G3 (12.796*) and G6×G4 (11.167*). So G1×G3 was

the best specific combiners for this trait. Rest of the cross combinations showed significant negative SCA effects, Susie (1998) and Ahmad (2002) also reported about some superior hybrids for fruit diameter.

4.3.9 Individual fruit weight

The analysis of variance for individual fruit weight indicated the importance of both additive and non-additive gene action as the variances due to GCA and SCA were significant (Table 17). But the higher GCA component compared to SCA component indicated the pre dominance of additive gene action. Similar result was also reported by Bhuiyan (1982). Additive gene action was also reported by Kumar *et al*. (1997) and Wang *et al*. (1998a) where Perera and Liyanaarachchi (1993) reported directional dominance and epistatic effects for fruit weight.

Among six parent studies 4 parents G3, G4, G5 and G6 showed significant positive GCA value (8.534**, 28.12**, 9.47** and 6.19* respectively) for individual fruit weight (Table 8). So parents G3, G4 and G5 were the best general combiners those could be used in crosses for the improvement of individual fruit weight as indicated by the significance and higher GCA effect. On the other hand, 2 parents showed negative GCA value and the significant negative GCA value was found in parents G1 (- 25.521**) and G2 (-26.794**). Ahmed (2002), Chadha *et al*. (1997) and Bhuiyan (1982) also reported some good general combiners for individual fruit weight.

Among 30 cross combinations 11 crosses showed positive SCA effects for individual fruit weight out of which only 9 crosses showed significant positive SCA value. The highest significant positive SCA value was found in G1×G3 (61.457**) followed by G3×G4 (41.482**), G2×G3 (31.596**) and G6×G4 (25.267**). This indicated that this hybrid produced substantial fruit weight compared to the mean of their parents. So the three crosses was the best specific

combiner for individual fruit weight. Chadha *et al*. (1997) selected some hybrids for individual fruit weight.

4.3.10 Locules per fruit

The analysis of variance for locules per fruit indicated the importance of both additive and non-additive gene actions as the variances due to GCA and SCA were significant (Table 18). But here lower magnitude of GCA variance than SCA variance indicated pre dominance of non-additive genetic variance. Non-additive genetic variance for locules per fruit in tomato was also reported by Srivastava *et al.* (1998a) whereas additive genetic variance was reported by Dod *et al*. (1995) and Dhaliwal *et al.* (2000).

Among the six parents 3 parents showed positive GCA effects out of which three parents showed significant positive GCA effects for this trait. The highest significant positive GCA value was obtained by the parent G4 (1.324**) followed by G3 (1.046**) and G5 (0.907**). The parent G4 and G3 were good general combiner for locules per fruit. Rest 3 parent G2 (-1.593**), G1 (-1.009**) and G6 (-0.676**) showed significant negative GCA value. Dod *et al*. (1995) reported that Punjab Chhuhara and Pusa Ruby as good general combiners for locules per fruit.

Among the 30 cross combinations 14 crosses showed positive SCA effects, out of which only 9 cross combinations showed significant positive SCA effects for locules per fruit. The highest significant positive SCA effects was obtained by the cross combination G6×G5 (2.500**), followed by G6×G4 (2.000**), G6×G3 (1.500**), G3×G4 (1.204**) and G1×G4 (1.259**). Thus G6×G5 and G6×G4 was good specific combiner for this trait. The highest negative SCA effect was obtained in the cross G4×G1 (-4.500) followed by G3×G5 (-2.880) and G3×G2 (-2.500).

From the above results and discussion, it is observed that the parent G4 showed significant positive GCA effects for day to 1st flowering, fruits length, fruit diameter, individual fruit weight, locule number. The parent G1 showed significant

positive GCA effects for plant height at 50% flowering. The parent G2 showed significant positive GCA effects for plant height at 50% flowering, number of cluster per plant, number of fruit per cluster, number fruit per plant.

The parent G3 showed significant positive GCA effects for day to 1st flowering, individual fruit weight, fruit diameter and fruits per plant. The parent G6 showed significant positive GCA effects for individual fruit weight, fruit length and fruit diameter where, G5 showed significant positive GCA effects for fruit length, fruit diameter, individual fruit weight and locules per fruit.

The maximum SCA effects was observed in the cross combinations G1×G3, G2×G1 for day to first flowering, G5×G1 for day to 50% flowering,G3×G2, G4×G1, G4×G2, G6×G1 for plant height at 50% flowering, G6×G2 for cluster per plant, G3×G2, G3×G5, G4×G2, G5×G1, G5×G2 for fruit per cluster, G2×G3, G2×G4, G2×G5, G2×G6, G3×G2,G4×G2, G5×G2, G6×G1, G6×G2 for fruit per plant, G1×G3, G1×G6, G2×G3, G3×G4, G5×G4, G5×G6 for fruit length, G1×G3, G2×G3, G3×G4, G4×G3, G6×G4 for individual fruit weight, G1×G3, G2×G3, G3×G4, G6×G3, G6×G4 for fruit diameter and G1×G3, G1×G2, G3×G4, G6×G3, G6×G4, G6×G5 for locule number.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The heterosis and combining ability in tomato were studied during winter season of 2018-2019 at the experimental farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla nagar, Dhaka-1207. The nature of combining ability and heterosis of six parents and 30 cross combinations were evaluated for ten parameters.

Among the six parents G2 and G4 were considered as the best general combiner for early flowering, G2 for plant height at 50% flowering, G2 for cluster per plant, G2 for fruits per cluster, G2 for fruit per plant, G4 and G6 for fruit length, G4 and G5 for fruit breath, G3, G4 and G5 for individual fruit weight.

The cross combinations G1XG3 and G6XG5 showed significant SCA effects for earliness. Significant combinations were observed in G3XG1, G4XG1 , G4XG2 and G6XG1 for plant height at 50% flowering, G6XG2 cluster per plant, G3XG2, G4XG2, G5XG1, G5XG2 , G6XG2, G3XG5 for fruits per cluster, G2XG3, G2XG4, G2XG5, G2XG6, G3XG2, G4XG2, G5XG2, G6XG1 for fruits per plant, G1XG3, G2XG3, G2XG5, G3XG4, G4XG3, G4XG6, G5XG6, G6XG3, G6XG4 for individual fruit weight, G1XG3, G1XG6, G2XG6, G3XG4, G5XG4, G5XG6 for fruit length, G1XG3, G2XG3, G3XG4, G4XG3, G5XG6, G6XG3, G6XG4 for fruit breadth, G1XG3, G1XG4, G3XG4, G6XG4, G6XG5 for locules per fruit.

Heterotic responses over the better parent were calculated and significant heterosis was found. Highest significant positive heterobeltosis for fruits length was observed in the cross G1XG3 followed by G6XG5, G3XG1 and G6XG3. The best heterotic cross for fruits per plant was G2XG6, followed by G2XG5, G2XG4, G2XG3 and for individual fruit weight cross G1XG3 followed by G3XG1, G3XG2.

Significant heterosis over the better parent was found in a number of characters in many hybrids. Highest significant positive heterobeltosis for fruits length was observed in the cross G1XG3, for fruits per plant cross G2XG6, for individual fruit weight cross G1XG3.

Combining ability analysis involving 6x6 full-diallel cross indicated that additive gene actions are important in governing the yield, its accrediting components and quality indicating the prospect of improving the crop by direct selection of individual plant.

The cross combinations G1XG3 was superior for earliness, G3XG1 for plant height at 50% flowering, G3XG2 for fruits per cluster, G2XG3 for fruits per plant, G1XG3 for individual fruit weight, G1XG3 for fruit breadth and G1XG3 for locules per fruit. Such SCA effects may be used for the development of the relevant characters.

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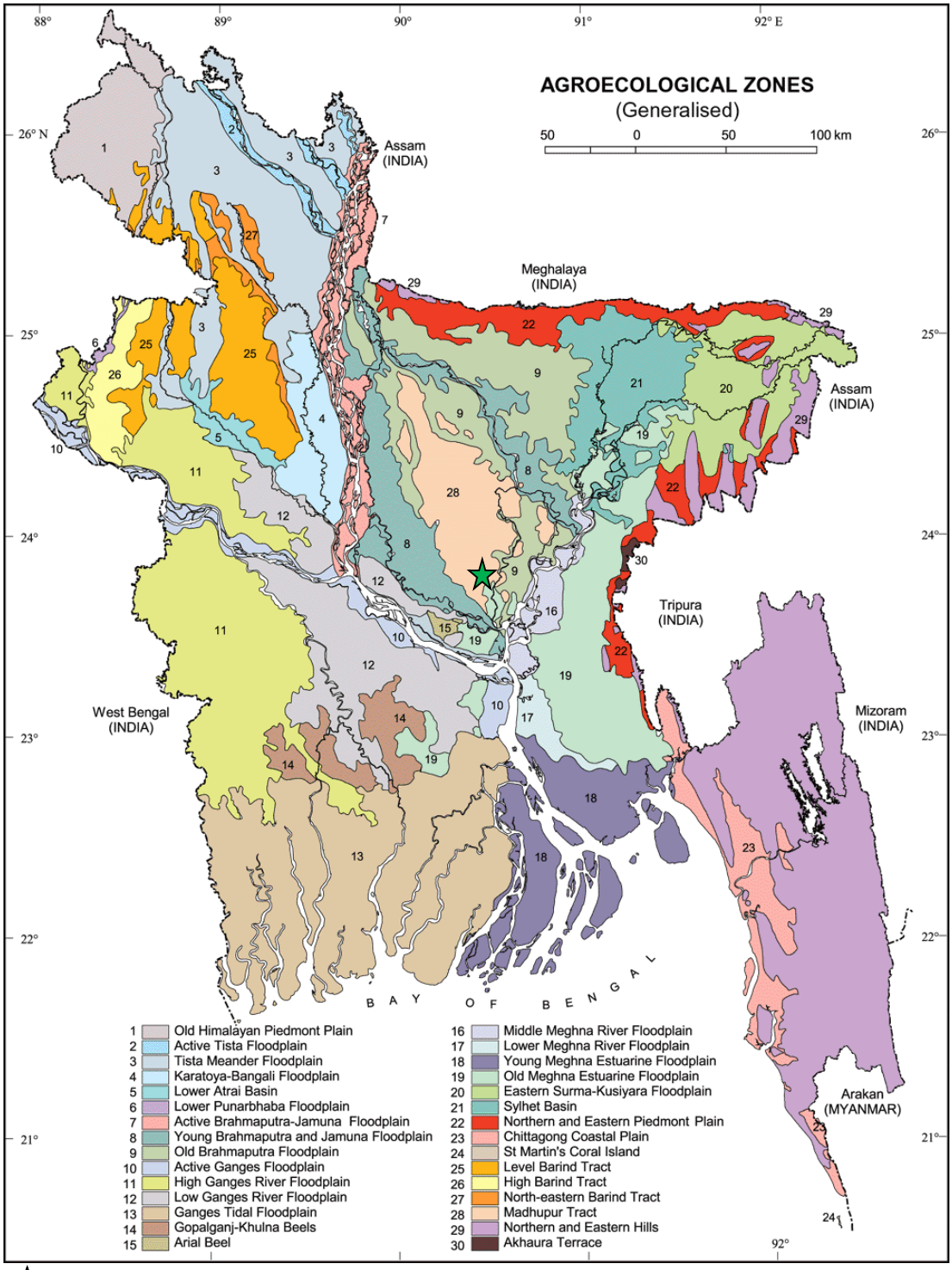
APPENDICES

Appendix I. Map showing the experimental site under the study



★ The experimental site under the study

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

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General soil type	Deep red brown terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly 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

Appendix II. (Cont'd)

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 – 1212

Appendix IV. Some pictorial views of the experimental field.

Visit of research supervisor in the field

Appendix V. Analysis of variance (MS Value) for 10 different characters of *Solanum lycopersicum* L.

Source	df	D1F	D50%F	PH50%F	NCPP	NFPC
Replication	2	20.111	20.218	18.117	28.676	25.231
Genotype	35	15.436**	16.898**	257.222**	44.028*	82.758**
Error	70	3.625	7.78	112.117	24.352	29.517

Appendix V. (Cont'd)

Source	df	NFPP	FL (mm)	IFW (gm)	FD (mm)	LNPF
Replication	2	82.676	5.216	25.151	67.009	0.148
Genotype	35	8143.736**	744.46**	9132.305**	932.494**	25.793**
Error	70	158.809	7.66	17.599	19.857	0.262