STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO LINES

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STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO LINES

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CERTIFICATE

This is to certify that the thesis entitled ***“STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO LINES”*** *submitted to the Department of Horticulture**,** *Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (M. S.)*** *in* ***HORTICULTURE,*** *embodies the results of a piece of bonafide research work carried out by* ***SHARMIN SULTANA,*** *Registration No.* ***08-2696*** *under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.*

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

Dated: December, 2014

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dedicated to my

BELOVED PARENTS

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The Author

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ABSTRACT

The general combining ability (GCA), specific combining ability (SCA), and heterosis were studied in a half diallel cross among 45 genotypes (9 parents and 36 hybrids) tomato breeding lines using a randomized complete block design and the experiments was conducted in Horticulture Research Centre, Bangladesh Agricultural Research Institute during the winter season 2013-2014. The yield contributory characters viz. days to 50% flowering, plant height at last harvest, number of flower cluster per plant, number of fruits per plant, individual fruit weight , number of seed per fruit, fruit length, fruit breadth, number of locules per fruit, pericurp thickness, TSS%, fruit yield per plant were evaluated. The parent P_9 was the best general combiner for plant height at last harvest, number of flower cluster per plant, fruit size (length and breadth), number of locules and pericurp thickness. P_5 exhibited highest GCA effect for individual fruit weight, number of seed per fruit, P_6 showed highest GCA effect for number of fruit per plant, P_2 and P_8 were the best general combiner for earliness and parent P_1 showed highest significant positive GCA effect for fruit yield per plant although fruit size of this parent is not good enough. The highest SCA effect and heterosis over mid parent for earliness was observed in the cross combinations $P_7 \times P_8$ which also showed best heterosis over mid parent for earliness, fruit breadth and number of seed per fruit. Cross combination $P_8 \times P_9$ showed the highest SCA effect and higher mid parent heterosis for the highest plant height at last harvest and for plant height at last harvest; flower cluster per plant and TSS% ; $P_7 \times P_9$ showed the highest SCA effect and heterosis for number of flower per cluster; $P_6 \times P_9$ number of fruits per plant; $P_5 \times P_7$ for improvement of individual fruit weight; $P_5 \times P_8$ for number of seed per fruit and mid parent heterosis for fruit breadth; the highest SCA and mid parent heterosis observed in $P_2 \times P_8$ for fruit length; $P_4 \times P_8$ for fruit breadth; $P_2 \times P_6$ for number of locules; $P_1 \times P_5$ showed the highest SCA and heterosis over mid parent for increasing pericurp thickness; $P_1 \times P_6$ showed the highest SCA and heterosis for fruit yield per plant. Therefore earliness, higher yield and higher quality the hybrids $P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_8$, $P_4 \times P_8$ $P_5 \times P_7$, $P_6 \times P_9$, $P_7 \times P_8$ may be selected for further trial.

CHAPTER I

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill.) is one of the important Solanaceous vegetable crops grown throughout the world having the chromosome number 2n = 24 (Jenkins, 1948). The genus *lycopersicum* include nine species out of which only two are cultivated, *Lycopersicum esculentum* Mill. (common tomato) and *Lycopersicum pimpinellifolium* Mill (currant tomato) (Rashid, 1999). It is self-pollinate crop but a certain extent of cross pollination may take place.

Tomato generally accepted to have originated in the new world (The America) that is the Andean region which is composed of part of Bolivia, Chili, Colombia, Ecuador and Peru. Evidence from the diversity of cultivated type and culinary uses and from the abundance of native names of the tomato fruits, all suggests that tomato was originally domesticated in Mexico (Jenkins, 1948). Soon after the discovery of new world, tomato was taken to Europe and then gradually it spread throughout the rest of the world (Heisar, 1969). Plant explorers have found wild relatives of the tomato in the tropical rain forests of South America as well as in arid regions of the native Mexico (Villareal, 1980). So tomato is also an introduced crop in Bangladesh.

It is an important fruit vegetable and second most important vegetable crop after potato that is widely grown and consumed worldwide. Due to its diverse use, nutritional value and good taste, it has become one of the most important and popular vegetable in Bangladesh. The area and production is increasing day by day while the national average yield of tomato is 10 tons per ha (Anon., 2014). Tomato thrives at much latitude and under a wide range of soil types and method of cultivation (Villareal, 1980). Optimum fruit setting requires a night temperature of 15 to 20°C (Charles and Harris, 1972; Schiable, 1962).

Now-a-days tomato is grown in most of the countries around the globe except the colder regions (Hannan *et al.* 2007). Tomato being a moderate nutritional crop is considered as an important source of vitamin A and C and minerals which are important ingredients for table purpose, chutney, pickles, ketchup, soup, juice etc (Sekhar *et al.* 2010). Because of its versatile use as fresh and in processed form demands are increasing. Tomato is a universally popular vegetable. It tops the list among the canned vegetable (Rashid, 1999). As a matter of fact, the number of ways it can be used to improve the flavor and character of other foods is endless. Therefore, its production needs to be increased providing good tomato varieties using genetical manipulation.

Combining ability is one of the powerful tools in identifying the best combiner that may be used in crosses either to exploit heterosis or to accumulate fixable genes. It helps to know the genetic architecture of various characters that enable the breeder to design effective breeding plan for future up gradation of the existing materials. This information is also useful to breeder for selection of diverse parents and hybrid combinations.

Heterosis or hybrid technology is highly effective breeding method applied in an ever-growing number of agricultural crops for developing valuable economic characters. Hedriek and Booth (1907) were probably the first observer of heterosis effect in tomatoes. Subsequently, heterosis for yield and its component has been demonstrated by many workers (Burdick, 1954; Dasfcaloff *et al.*, 1967; Larson and Currence, 1944; Powers; 1945; Wellington, 1912). Larson and Currence (1944) observed that average yield of all tested hybrids (F_1) was 39 % more over the parental lines. Powers (1945) found that the mean value of total yield of red fruits of the hybrid surpassed by 60 % the mean value of the parental lines. In recent year heterosis and combining ability in tomato has also been reported by Bhatt *et al.* (1999), Bhatt *et al.* (2001a), Bhatt *et al.* (2001b), Singh and Singh (1993), Singh *et al.* (1995), Susic (1998), Vidyasagar *et al.* (1997) and many other authors. In Bangladesh probably Bhuiyan (1982) first time studied the heterosis and combining ability in tomato for yield and yield contributing characters. He reported that better parent heterosis in fruit yield per plant up to 124.5 % in the cross Fujuki × World Champion.

In Bangladesh most of the tomato varieties are of open pollinated, very recently exotic hybrid varieties are being introduced due to their high yield potentiality. Seed costs of those hybrid varieties are very high. Moreover, due to unique nature of hybrid variety, the tomato growers need to buy seed every year. To boost up production potentiality of tomato in the country, exploitation of hybrid technology might be an alternative method. In the past very little efforts for development of local hybrid tomato variety have been made. Considering necessity, demand and scope the present investigation was undertaken with the following objectives:

1. To determine the general combining ability (GCA) and specific combing ability (SCA) of the lines used in the crosses;
2. To determine the heterosis per hybrid vigor of the crossed material; and
3. To identify cross combinations for further investigation and regional yield trial.

CHAPTER II

REVIEW OF LITERATURE

Tomato (*Lycopersicum esculentum* Mill.) being one of the most important and popular vegetable crops in both tropical and temperate regions, received much attention of the breeders throughout the world to develop new hybrid tomatoes varieties. Such effort in Bangladesh is meager and scanty information available. In the literature pertaining to the combining ability, mode of gene action and heterosis have been reviewed and have been presented chronologically and character wise in this chapter.

2.1 Combining ability

Two types of combining ability, general and specific, have been recognized in quantitative genetics. Specific combining ability is denied as the deviation in the performance of hybrids from the expected productivity based upon the average performance of lines involved in the hybrid combination, whereas general combining ability is denied as average performance of a line in a series of crosses. General combining ability is due to genes, which are largely additive in their effects and specific combining ability is due to the genes with dominance or epistatic effect. The genetic values of parents are expressed in terms of combining ability. The term combining ability was introduced by Sprague and Tatum (1942) when they used general combining ability (GCA) to designate 'the average performance of a line in hybrid combination' and ’specific combining ability (SCA)’ as those crosses in which certain combinations that do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Here, in this text, an attempt has been made to review those early studies on combining ability of tomato are directly related to the present investigation.

Kumar *et al.* (2015) carried out combining ability analysis in a field experiment through line × tester method using ten lines of tomato (*Solanum lycopersicum* L.) and four testers and their F_1 hybrids results showed that the best hybrid combination that exhibited the highest positive values of SCA can combine to produce a hybrid with good general performance.

Pravati *et al.* (2015) carried out the diallel analysis in eight lines of cherry tomato to study the combining ability effects for growth, yield and quality traits. The lines found to be good general combiners were ‘L 00427’ for plant height DAT, ‘L 00398’ for number of fruits per cluster, number fruits per plant, fruit yield per plant and lycopene content, ‘L 04780’ for ascorbic acid; ‘L 01696’ for total soluble solids and reducing sugar. The best specific combiners for plant height L 04780 × L 03686, the L 00427 × Arka Vikas is for number of fruits per cluster, number of fruits per plant and total soluble solids and the hybrids L 00427 × L 03686, L 01696 × L 03686 for ascorbic acid and lycopene content, respectively.

Hussien (2014) conducted a half diallel fashion analysis with five parental genotypes in tomato which indicated that the performance of available cross combinations was further compared on the basis of main yield and desirable heterotic response as well as SCA effects along with GCA effects of the parents in order to identify the most important crosses. Three crosses were classified on the basis of these parameters as the best crosses. The cross T-3 × T-9 were considered the best combination among the ten crosses evaluated in that work. Both T-8 × T-10 and T-3 × T-5 were derived from high × low general combiner parents and showed high mean yield per plant and highly significant SCA effects for yield.

Saeed *et al.* (2014) used Line × Tester analysis to identify the potential parents and their hybrids from a set of 12 crosses derived from three lines used as females ‘LA-2661’, ‘LA-2662’ and ‘017899’ and four testers, including ‘BL-1078’, ‘BL-1079’, ‘CLN-2413’ and ‘CLN-2418-A’. Results showed that parents and F_1 hybrids differed significantly for general combining ability and specific combining ability effects. The values of general combining ability (GCA) and specific combining ability (SCA) variances depicted non-additive and additive gene action with predominance of non-additive gene action in the genetic determination of all characters except fruit yield per plant. Parent lines ‘LA-2662’ and ‘CLN-2418A’ provided the best general combining ability effects in more than one yield contributing traits. Specific combining ability effects were recorded in two crosses viz. LA-2662 × CLN-2418A and‘LA-2662 × BL-1078. F_1 hybrid LA-2662 × CLN-2418A proved to be the best cross in overall performance.

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

Sunil *et al.* (2013), showed the combining ability effects and its variances estimated by line × tester analysis including 30 F_1 cross combinations using 13 parents after selfing (ten lines and three testers) at Vegetable Research Farm, BHU, Varanasi (India). These 43 genotypes (10 lines and 3 testers and 30 resulting F_1 hybrids) were evaluated for growth, yield and quality (T.S.S and shelf life) contributing traits. Ratio of ‘general combining ability (GCA)’ and ‘specific combining ability (SCA)’ variance revealed preponderance of non- additive genetic variances for all studied traits. On the basis of GCA effects across ten traits, Potato leaf, ‘Pant T-7’, ‘IC-177371’ and ‘NDTVR-60’ were identified as most promising parental lines for inclusion in hybridization programmers. Outstanding crosses based on SCA effect across ten traits were RCMT-2 × VR-20, LCT-6 × VR-20 and Azad T-5 × VR-20. These crosses were considered as most promising specific combiner for most of the traits in which ‘VR-20’ was have found to be best general combiner.

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

Farzane *et al.* (2012) conducted a study on 10 × 10 diallel cross set of tomato including reciprocals to find out the combining ability for yield per plant (kg) and yield components (number of fruits per plant, individual fruit weight (g)) and locule number. Significant differences among genotypes were obtained for all of traits. The variances for general combining ability (GCA) and specific combining ability (SCA) were highly significant indicating the presence of additive as well as non-additive gene effects except the number of fruits per plant and relative magnitude of these variances indicated that additive gene effects were more prominent for all of the traits. The tomato genotype 'Mb3' proved to be the best general combiner for yield and number of fruits per plant.

Souza *et al. (*2012), studied the general combining ability (GCA), specific combining ability (SCA) in a complete diallel cross of fifteen genotypes (five parents and ten hybrids) tomato breeding lines for plant fruit yield, 'IAC-2' was the best parental line with the highest GCA followed by IAC-4 and IAC-1 lines. The hybrids IAC-1 × IAC-2, IAC-1 × IAC-4 and IAC-2 × IAC-4 showed the highest effects of SCA.

Peter *et al.* (2012) from twenty-five varieties of tomato reported that the component characters locules per fruit and plant height were found to be important for the expression of genetic divergence.

Sekhar *et al.* (2012) conducted 10 × 10 diallel set which was generated by crossing these single cross hybrids in all possible combinations (excluding reciprocals) and 45 double cross hybrids result showed that The overall GCA and SCA status for SCH and DCH respectively revealed that among single cross hybrids ‘JK-Desi’ was the best general combiner for yield and most of the traits followed by ‘Pragathi’ and ‘Maharani’.

Singh *et al.* (2011) were performed a thirteen diverse lines of tomato cross with three testers in line × tester mating fashion to study the combining ability effects for plant height, number of primary branches per plant, fruit weight, bacterial wilt incidence and yield per plant. The analysis of variance revealed the predominance of non-additive gene action for all the traits. In respect of both GCA and SCA effects, the parents and hybrids differed significantly. Among the parents, ‘Sel-2’ and ‘BT-117-5-3-1’ were the best general combiners for yield per plant and other characters under study, and these may be used as valuable donors in the hybridization program for producing promising combinations in bacterial wilt prone areas. Among the crosses, BT-207 × KT-15, Type-I × KT-15, and FEB-2 × BT-117-5-3-l were the most valuable combiners for yield per plant and other characters under study could be utilized for bacterial wilt resistant breeding program.

Ahmed *et al.* (2011) conducted a study to estimate heterosis of 21 tomato cross combinations involving seven parents, analysis of variance indicated highly significant differences for all the characters suggesting the presence of genetic variability among the studied materials. Three combinations $P_2 \times P_3$, $P_3 \times P_4$ and $P_3 \times P_5$ showed significant early flowering, while two $P_1 \times P_7$ (16.67%) and $P_1 \times P_2$ (12.44%) for individual fruit weight.

Sekhar *et al.* (2010) generated a 10 × 10 diallel set by crossing single hybrids in all possible combinations (excluding reciprocals) and 45 double cross hybrids with a view to estimate combining ability to facilitate identification of heterosis combinations for all the ten characters studied. The overall GCA and SCA status for SCH and DCH respectively revealed that among single cross hybrids ‘JK-Desi’ was the best general combiner for yield and most of the traits followed by ‘Pragathi’ and ‘Maharani’.

Mondal *et al.* (2009) performed Line × Tester cross among nine parental lines to estimate heterosis and combining ability in tomato for fruit yield, yield components and fruit quality traits found that involvement of both additive and non-additive gene action was operative for the control of fruits per plant, fruit weight, locules per fruit and equatorial diameter of fruit. All the fruit quality characters like, TSS and lycopene contents of the fruit were governed by non-additive gene action. Taking into consideration the per se performance and SCA effect in the hybrid, H-24 × NF-31.

Hannan *et al.* (2007) conducted a study on 10 × 10 diallel set of tomato excluding reciprocals to find out the combining ability and nature of gene action for yield with two important quality traits: TSS% and days to first fruit ripening (DFFR). Significant differences among genotypes were obtained for all three traits. The magnitudes of variance due to general as well as specific combining ability were highly significant indicating the importance of both additive and non-additive gene action. However degree of dominance ($o^{-2}g/o^{-2}s$) 22 revealed the prevalence of a non-additive gene effect. Cross combinations $P_2 \times P_3$ (0.66), $P_5 \times P_7$ (7.85) and $P_2 \times P_5$ (1.22) were best specific combiners for TSS%, DFFR and yield per plant. Predominance of non-additive gene 96 action plays a greater role in the inheritance of TSS% and DFFR in tomato.

Rao *et al.* (2007) in a half diallel fashion of five parents including two early blight resistant and three early blight susceptible genotypes reported that Based on the heterotic performance and magnitudes of SCA effects in desirable direction for yield and its related attributes, Feb-2 × Pusa Sheetal and Feb-2 × Pusa Gaurav were found to be the best in terms of yield potential and also exhibited moderate resistance to early blight.

Thakur *et al.* (2005) conducted a line × tester analysis for shelf life reported that the ratio of GCA per SCA variances observed less than unity for all the characters, depicting the predominance of non-additive genetic variance.

Premalakshme *et al.* (2005) carried out a study to develop F_1 hybrids with high yield and quality in tomato (*Solanum lycopersicum* L.) through diallel crossing involving six parents. Resulted marketable fruit weight and fruit yield over the standard check $P_5 \times P_3$, $P_3 \times P_6$ and $P_6 \times P_5$ yielding 116.61% over the standard parent; these promising crosses also recorded the positive SCA. The high performing crosses for important characters showed that in general these crosses involved high × high, high × medium, medium × low and high × low, general combiners. The low × low crosses giving high SCA values may be due to the genetic diversity of the parents and non-allelic interaction.

Joshi *et al.* (2004), in a line ×tester analysis for shelf life and related traits, revealed that line 'FT-'5, '102', 'Magna' and 'Cal-ace' were good general combiners for fruit firmness, number of locules per fruit, per carp thickness and shelf-life. Among testers, 'V-16' was good general combiner for all the characters except number of locules per fruit. The ratio of GCA per SCA variances observed less than unity for all the characters, depicting the predominance of non-additive genetic variance.

Ahmad (2002) using a diallel cross of 8 × 8 excluding reciprocals reported the existence of nearly complete dominance for fruit number per plant, fruit length and yield per plant. From the graphical analysis he suggested incomplete or partial dominance for fruit length. He found the highest significant positive GCA effects in the parent TM002 for May and July sowings (0.64 and 0.61 respectively) observed the highest significant negative GCA effects in the parent 'TM026' for May sowing (-1, 36) and July sowing (-0.57) and largest negative SCA values in the crosses TM051 × TM017, TM053 × TM026, TM025 × TM041 and TM025 × TM044. The highest significant GCA effects found in the parent 'TM051' (12.44 and 11, 03) for May and July sowing respectively. He also found that eleven combinations in both the sowings showed highly significant positive SCA values. GCA effects for May and July sowing in the parent 'TM025' (7.03 and 7.40, respectively) and larger positive SCA values in nine.

Dharmatti *et al.* (2001) the general combining ability of the 15 parents (five female + ten male) and specific combining ability of 50 crosses were estimated for 7 characters in summer tomato using a Line × Tester analysis. The results revealed that the GCA: SCA ratios were less than unity for all the characters indicating the predominant role of non-additive gene action.

Chadha *et al.* (2001) conducted an experiment in a set of 10 lines and 4 testers and analysis showed that no-additive gene action was preponderant for marketable yield per plant and per cent marketable fruits, while additive for days to 50% flowering, marketable fruits per plant and locules per fruit and both GCA and SCA were influenced by the environment implying that the parents and crosses must be evaluated over a wide range of environments to have unbiased estimate.

Peter *et al.* (2001) in a line × tester analysis between bacterial wilt *(Ralstonia solanacearum)* resistant per tolerant accessions (‘Sakthi’, ‘LE 214’ and ‘LE 206’) and processing cultivars’ (‘HW 208F’, ‘St 64’, ‘Ohio 8129’, ‘Fresh Market 9’ and ‘TH 318’), identified heterotic hybrids for locule number (LE 206 × Ohio 8129 and LE 214 × St 64). Also found observed the highest significant heterobeltiosis in the F_1 hybrid of LE 206 × St 64 for TSS% in tomato.

Bhatt (2001a) in a 15 × 15 diallel set of tomato excluding reciprocals found reported the importance of both additive and non-additive gene actions and prevalence of non-additive gene effects for total soluble solids (TSS%). Cross combinations EC 818703 × EC 13042 (0.88) was the best specific combiner for yield per plant.

Bhatt *et al.* (2001b) observed the predominance of non-additive gene action for plant height, length of fruit and crop yield, fruits per tress yield per plant. Punjab Chhuhara showed highly significant desirable GCA effects. The highest significant SCA effect for yield per plant was observed in the cross Punjab Chhuhara × Azad Kranti.

Bhatt *et al.* (2000) conducted on a 15 × 15 diallel set of tomato excluding reciprocals to find out the extent of combining ability and nature of gene action for yield with two important quality traits: ascorbic acid (vitamin C) and total soluble solids (TSS%). The magnitude of variance due to general as well as specific combining ability were highly significant indicating the importance of both additive and non-additive gene action and Predominance of non-additive gene action plays a greater role in the inheritance of ascorbic acid and total soluble solids in tomato under hill conditions.

Dhliwal *et al.* (2000) investigated in tomato to study the combining ability of genetic male sterile (pollen abortive type) parents in combination with superior performing male parents and found that non-additive gene effect was more pronounced for days to flowering and total yield in tomato. The additive gene effect was more pronounced for number of locules per fruit. Parents ‘C 122’, ‘S 286’, ‘S 281’, ‘1 979’ and ‘X 331’ were good combiners for yield. A large number of hybrids exhibited significant specie combining ability (SCA) effects for yield. He also reported ‘that both, the additive and the non-additive gene effects governed the inheritance of the character total soluble solids (TSS %). The non-additive gene effects were more pronounced for total soluble solids (TSS %). Only one male parent ‘1181’ was good combiner for TSS%.

Resende *et al. (*2000) in a study of diallel cross of tomato found significant general combining ability (GCA) effects in a group of parents for fruit diameter, fruit number in the 1st and 2nd trees. Phaliwal *et al.* (2000) reported that both the additive and the non-additive gene effects governed the inheritance of the character fruit weight. The additive gene effect was more pronounced for fruit weight.

Sharma *et al. (*1999) in a line × tester analysis of tomato found that the lines ‘BTL-33’ and ‘BTL-1’ and tester ‘Roma’ proved the best general combiners for yield. The best specific cross-combinations were ‘BTN-46 × Roma’, ‘BTL-11 × AC-402’ and ‘BTR-49 × Roma’.

Chaudhary *et al.* (1999) estimate the general and specific combining ability in tomato through line × tester analysis involving 12 lines (females) and 2 testers (males); they reported that the best cross-combinations did not necessarily involve good general combiners as their parents. Based upon the contribution of lines, testers and their interactions, it was evident that the variability among the crosses was mainly due to the contribution of lines only.

Shrivastava *et al. (*1999) reported that additive arid the non-additive gene effects governed the inheritance of the character fruit weight. The additive gene effect was more pronounced for fruit weight.

Singh *et al. (*1999) reported the importance of both additive and non-additive gene effects for fruit weight and total yield with the magnitude of the former being greater.

Dharmatti *et al.* (1999) found that GCA-SCA ratio was less than unity for fruit yield per plant, indicating the role of non-additive gene action.

Shrivastava *et al. (*1998) carried out combining ability analysis in a field experiment through line × tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for days to flowering, due to less than unity of the ratio of general to specific combining ability.

Shrivastava *et al.* (1998a) crossed nine superior varieties of tomato in a diallel fashion and found higher GCA: SCA ratio indicating additive gene effects in the generations for fruit total soluble solids (TSS). Among parents 'Pusa Ruby' was the best combiner for TSS (0.84, 0.70). The best specific combiner was Pusa Ruby × Money Maker. The predominance of non-additive variance for number of locules per fruit.

Susic (1998) crossed seven phenotypic divergent genotypes in a fall diallel without back cross and found that the line 93 per 10 characterized by greatest fruit length showed the best general combining ability (GCA). The partial dominance was the mode of inheritance for fruit length, fruit width in tomato in the FI generation. The highest specific combining ability (SCA) values for fruit length were recorded in the hybrid obtained by crossing 'DI 50' and 'NO-10'.

Wang *et al. (*1998a) in a complete diallel cross of 5 processing tomato cultivars reported the predominance of additive gene action on fruit weight, fruit length, fruit width and crop yield with highly significant GCA and SCA. The additive and the non-additive gene effects governed the inheritance of the character fruit weight and TSS%.

Kumar *et al.* (1997) grew nine parents and their 18 F_1 hybrids of tomato and they reported the prevalence of additive gene action for average fruit weight and inheritance of processing character for TSS% non-additive gene action was predominant.

Chadha *et al.* (1997) reported the lines 'BWR-5 (HR)', 'LB79-5 (W)' and 'EC 129156' as good general combiners for marketable fruits per plant. They also found that four Fruits showed significant positive SCA effects and lines 'BT-1Q', 'BWR-5 (HR)' and 'EC 191540' as food general combiners for average fruit weight. Five F_1 showed significant positive SCA effects for average fruit weight.

Vidyasagar *et al.* (1997) in a line (8) × tester (3) analysis observed superiority of 3 F_1S to their respective better parents for fruit weight.

Ghosh *et al. (*1996) from a 9 × 9 diallel cross and graphical analysis of tomato reported the partial dominance for days to first flowering, plant height, equatorial fruit diameter and polar fruit diameter, number of locules per fruit and yield per plant. From graphical analysis they reported the over dominance for total soluble solids (TSS).

Dod *et al.* (1995) studied combining ability of tomato in a 12 parent's diallel (excluding reciprocals) for number of locules per fruit, TSS% and reported the importance of both additive and non-additive genetic components. They also found a predominant role for additive gene action. 'AC238', 'Punjab Chhuhara' and 'Pusa Ruby' were the best general combiners.

Perera and Liyanaarachchi (1993) from a 13 × 13 half diallel cross and the Vr/Wr graph analysis found complete dominance for flowering time and fruit weight.

Shrivastava *et al*, (1993) from 9 cultivars and their FI and 2 hybrids found that 'Pusa Ruby × Money Maker' was best combination for earliness. Chadha *et al. (*1997) studied combining ability of tomatoes in a set of eight determinate lines × three indeterminate testers and found that line 'Somali' was good general combiner and one cross combination was found to be good specific combiner for days to 50 % flowering.

Natarajan (1992) evaluated information on combining ability of tomato in 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 days to flowering, number of fruits set per cluster fruit weight and yield per plant. LE76 was the best general combiner for yield. The hybrids LE75 × LE76 and LE22 × LE76 produced the highest yields per plant.

De-Araujo and De-Campos (1991) crossed 5 cultivars in a diallel fashion and observed high GCA for total number of fruits in the parents 'Roma VFN' and 'IPA3'. They also found that hybrids with 'Roma VFN' as one of the parents showed high SCA for total number of commercial fruits.

Bhutan and Kalloo (1991) analyzed 8-parent diallel cross including 28 F_1S and 28 F_2S for locule number. They reported 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.

E-Mahdy *et al.* (1990) in a study of complete diallel set of 6 lines under heat stress reported that additive gene effect appeared more important than non-additive gene effects for early yield, fruit weight, TSS %.

Zhou and Xu (1990) studied Soluble Solids Content (SSC) in fruits from 20 hybrid combinations from a 5 × 4 diallel without reciprocals and observed 74.15 % GCA and 25.85 % SCA variance for SSC.

Chandrasekhar and Rao (1989) evaluated Kj progenies and parental genotypes mid reported significant variations of GCA and SCA. SCA effects were significant and positive in 6 crosses for plant height fruit weight and yield. ‘Pusa Early Dwarf’ was the best general combiner.

Bhutan *et al*. (1988) reported the non-additive type of gene action for the control of number of fruits in tomato and yield per plant in tomato.

Shashi and Satyanarayana (1986) reported that fruit yield during summer is hardly 100-150 g per plant, but in the crosses he made, the average yield ranged from 450 g to 800 g.

Alverez (1985) reported that hybrid INCA 21 × INCA 3 was superior to the better parent for average weight in summer.

Bhuiyan (1982) reported that additive nature of genetic system was largely operative in the inheritance of fruit weight. Parent Japanese was the best general combiner. The highest SCA effect was recorded in World champion × Big cherry.

Bhuiyan (1982) studied on combining ability of tomato in a diallel set (without reciprocal) and found that both additive and non-additive gene actions were involved in the inheritance of plant height and fruit yield per plant. The GCA: SCA ratio was more than one, indicating that the plant height was predominantly under the additive genetic control. He also reported that predominance of additive and additive × additive gene action ibr the character number of fruits per plant. Parent ‘Big cherry’ was the best general combiner, where the cross Fujuki × CL. 8d-0-7-l-0-0 was the best positive specific combiner. Parent ‘Fujuki’ and ‘Japanese’ showed significant positive GCA effects.

2.2 Heterosis

Heterosis a complex biological phenomenon observed as the superiority of hybrids over their parents has been a subject of interest for many years. Koelreuter as early as 1893 observed that hybrids often possess increased vigor by comparison with their parents (Sprague, 1983). Most of these studies indicated that the offspring arising from cross-fertilization were more vigorous than those obtained by selfing. He also concluded that self-fertilization is 'injurious' (Allard, 1960). He found the yields of the hybrids to be higher than those of the parents by as much as 50 % and suggested the use of varietal hybrids in maize (Sprague, 1983). Seal's earlier reports and extended the generality of superiority of varietal hybrids over the average of the parental forms (Sprague, 1983). The foundation for a more comprehensive understanding of heterosis was laid by Shull in 1908 and 1909 (Sprague, 1983). Limited earlier work on inbreeding of maize by others, had concentrated on the marked reduction in vigor. Shull was more concerned with the genetic basis for his observations. He concluded that a variety was a complex mixture of genotypes. The variability among strains undergoing inbreeding, including loss of vigor, was a consequence of segregation and the eventual homozygosity of desirable and deleterious alleles. He also demonstrated that when certain lines were combined, yields of F_1 exceeded those of the parental varieties (Sprague, 1983). The term heterosis was coined and first proposed by Shull (1914).

The commercial exploitation of heterosis in the breeding and development of crop hybrids has made an enormous contribution to 20th century agriculture, although the genetic basis of the phenomenon remained unclear (Me Daniel, 1986; Sinha and Rood *et al.*, 1988).

Hussien (2014) did five parental genotypes in tomato and crossed in a half diallel fashion analysis indicated that both additive and non-additive gene action were involved in the inheritance of most studied traits. However, total soluble solids%, number fruits per plant and ascorbic acid% are mainly controlled by non-additive gene effects. Therefore, these traits could be exploited by heterosis breeding. Both T-8 × T-10 and T-3 × T-5 were highly significant average heterosis for yield per plant.

Saeed *et al.* (2014), used Line × Tester analysis to identify the potential parents and their hybrids from a set of 12 crosses derived from three lines used as females 'LA-2661', 'LA-2662' and '017899' and four testers, including 'BL-1078', 'BL-1079', 'CLN-2413' and 'CLN-2418-A'. Results showed that heterosis and heterobeltiosis in desired direction were recorded in two crosses viz. LA-2662 × CLN-2418A and LA-2662 × BL-1078. F_1 hybrid LA-2662 × CLN-2418A proved to be the best cross in overall performance.

Singh *et al.* (2014) studied the heterosis for yield components and yield per plant using 7 × 7 half diallel cross between bacterial wilt-resistant per tolerant genotypes and high-yielding varieties. The heterosis over better parent(BP) was up to the extent of -38.14%, 42.04%,36.14, -5.70%, -5.65%, 26.32%, 63.44%, 4.83%, 16.50%, 38.88%, 62.70% and 45.89% was recorded for plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, days to maturity, fruit set, fruit length, fruit width, number of locules per fruit, number of fruits per plant, fruit weight and fruit yield per plant, respectively. The extent of heterosis was not as high as we are also looking for resistant to the bacterial wilt disease. The crosses showing heterosis for fruit yield per plant were not heterotic for all the characters under study. The heterosis for yield was generally accompanied by heterosis for yield components. Five promising crosses viz., Arka Ahuti × LO-5973, Arka Vikas × TWC 4, Arka Ahuti × TWC-4, BRH-2 × LO-5973 and CAU-TS-9 × LO-5973 were identified for developing high-yielding F_1 hybrids/varieties of tomato with many desirable traits.

Patwary *et al.* (2013) conducted a research to study heterosis using eight parents viz., 'P_1', 'P_2', 'P_3', 'P_4', 'P_5', 'P_6', 'P_7', and 'P_8'. Most of the combinations showed better parent heterosis for earliness. Eight crosses showed positive heterosis for flower production. The highest heterotic effect for fruit set (%) was found in the cross $P_6 \times P_7$ (62.59%) followed by that in $P_7 \times P_8$ (60.49%) and $P_1 \times P_7$ (40.00%). For fruits per plant, 8 crosses provided more than 15 % heterosis over better parent. Considering fruit yield per plant, higher degree of heterosis was manifested by 24 hybrids over better parent ranging from 13.58 to 282.63 %. Cross combination P_4 × P_7 showed the maximum significant positive heterosis followed by P_6 × P_7 (187.84 %), P_4 × P_8 (166.97 %), P_3 × P_7 (146.08 %), P_3 × P_6 (103.92 %), and P_1 × P_7 (100.45%) and the minimum in P_4 × P_6 (13.58 %). For viable pollens, P_3 × P_5 (20.56 %) exhibited the highest positive heterosis. In case of shelf life, the highest heterosis was observed by the cross P_3 × P_6 (22.78 %) followed by that in P_4 × P_6 (22.29 %) and P_2 × P_6 (14.40 %). For fruit flesh thickness, 12 hybrids exhibited more than 10 % heterosis. Pollen tubes as we'll as viable pollens showed positive correlation with fruit set.

Souza *et al.* (2012), studied heterosis in a complete diallel cross of tomato breeding lines. Fifteen genotypes (five parents and ten hybrids) were tested using a randomized complete block design, with three replications. High heterotic responses were found for fruit yield and plant fruit number with values up to 49.72% and 47.19%, respectively. The best hybrids for fruit yield and plant fruit number were IAC-1 × IAC-2, IAC-1 × IAC-4 and IAC-2 × IAC-5, for fruit yield and plant fruit number, the main yield components.

Peter *et al.* (2012) from Twenty-five varieties of tomato viewed that selection of parents differing in locule number and plant height may be worthwhile for heterosis breeding.

Chattopadhyay *et al. (*2012) a total of 25 entries consisting of 13 diversified genotypes of tomato along with their 12 F_1 hybrids were evaluated during two consecutive rabi seasons which showed that Pronounced heterosis over better- parent was observed for number of locules per fruit, fruit length etc. Heterosis over mid parent and better parent, however, for most of the characters were in negative direction. Some of the parents having good potentiality for generating high cross combination for most of the quality traits under study were identified.

Singh *et al.* (2012) in a complete 7 × 7 half diallel cross of tomato evaluate with parents for heterotic manifestation of yield and yield attributing characters. The crosses showing heterosis for yield per plant were not heterotic for all the characters under study. Five promising crosses viz., Ox-heart × Sutton Roma, Marglobe Supreme × Sutton Roma, Money Maker × Pusa Early Dwarf, Marglobe Supreme × Money Maker and Sutton Roma × Pusa Early Dwarf were identified for developing high yielding F_1 hybrids/varieties of tomato with many desirable traits.

Islam *et al.* (2012) carried out a research to evaluate the heterotic performance in F_1 generation of tomato. The hybrids showed significant variation in heterosis. The highest heterobeltiotic effects were observed in the cross $P_3 \times P_8$ (-18.46%) for earliness, $P_1 \times P_6$ (8.57 %) for flowers per cluster, $P_2 \times P_6$ (21.73%) for fruits per cluster, $P_6 \times P_7$ (75.54%) for plant height, $P_5 \times P_6$ (67.44%) for fruits per plant, $P_9 \times P_{10}$ (54.82 %) for yield per plant, $P_2 \times P_8$ (21.21 %) for individual fruit weight, $P_7 \times P_8$ (3.09 %) for fruit length, $P_3 \times P_8$ (14.11 %) for fruit diameter and $P_1 \times P_6$ (13.11 %) for TSS content. In respect of fruit external characters like shape, pedicel area, shape of pistil scar, blossom end shape genotypes were found diverse. Internal qualitative character like firmness, fleshiness and less seeded and locule numbers were highly variable among the genotypes. Considering all the characters the crosses $P_1 \times P_8$, $P_2 \times P_6$, $P_2 \times P_7$, $P_2 \times P_8$, $P_3 \times P_8$ and $P_5 \times P_6$ were found suitable for further studies to variety selection.

Kumar *et al. (*2011), derived heterosis for yield and other component characters of 45 F_1 hybrids of tomato from the crosses between 15 lines and 3 testers through line × tester technique. Maximum and significant heterosis in favorable direction was observed for yield, fruit number, plant height and fruits per cluster. Heterosis was appreciable in all hybrids, but was more in four hybrids viz Sioux × FT 5, S-1001 × Solan Vajr, EC-521041 × FT-5 and S-1001 × EC-15998.

Singh *et al. (*2011) were performed a thirteen diverse lines of tomato cross with three testers in line × tester mating fashion to study heterosis for plant height, number of primary branches per plant, fruit weight, bacterial wilt incidence and yield per plant shows that the highest heterotic effect over better parent was exhibited by the cross Type-1 × KT-15 for yield per plant and plant height under bacterial wilt condition.

Ahmed *et al.* (2011) conducted a study to estimate heterosis of 21 tomato cross combinations involving seven parents, analysis of variance indicated highly significant differences for all the characters suggesting the presence of genetic variability among the studied materials. In the study, the cross combinations $P_4 \times P_7$ (62.31%), $P_2 \times P_6$ (37.44%), $P_4 \times P_6$ (34.77%), $P_2 \times P_7$ (33.67%), $P_3 \times P_7$ (32.09%), and $P_3 \times P_4$ (29.82%) manifested higher heterosis over better parent for yield per plant.

Sekhar *et al.* (2010) generated a 10 × 10 diallel set by crossing single hybrids in all possible combinations (excluding reciprocals) and 45 double cross hybrids were planted during February, 2007 with three replications with a view to estimate heterosis. The range of heterosis (%) over mid parent and better parent was wide for number of clusters per plant and number of locules per fruits as compared to other characters. The number of significant heterosis hybrids in desirable direction for both mid parent (28 hybrids) and better parent (24 hybrids) was the highest for number of locules per fruit followed by number of cluster per plant (mid parent-17 hybrids, better parent-11 hybrids). Out of top five double cross hybrids, only two hybrids viz., JK-Desi × Sasya and JK-Desi × Shivaji expressed significant high positive heterosis over mid-parent and better parent along with better performance in term of yield per plant.

Mondal *et al.* (2009) performed Line × Tester cross among nine parental lines to estimate heterosis in tomato for fruit yield, yield components and fruit quality traits. Taking into consideration the performance, heterosis effect in the hybrid, H-24 × NF-31 and H-24 × Hissar Arun were the best hybrid.

Gaikwad *et al. (*2009) Studied on heterosis through a set of 12 × 12 set of diallel cross excluding reciprocals reported that The cross combination $P_6 \times P_9$ showed maximum heterosis of 16.51 per cent, for days from fruit setting to turning stage over hybrid check

‘TH-1’. The cross combination P_1 × P_2 had maximum marketable yield of 0.97 kg per plant.

Hannan *et al.* (2007) conducted a study on 10 × 10 diallel set of tomato excluding reciprocals to find out the extent of heterosis for yield with two important quality traits: TSS% and days to first fruit ripening DFFR. Significant differences among genotypes were obtained for all three traits. Positive high significant heterosis was found for yield (211.00, 232.00 and 298.00), for TSS% (61.04, 106.70 and 37.76) and for DFFR (8.92, 9.33 and 6.07) over the mid, the better and standard parent respectively.

Premalakshme *et al.* (2005) carried out a study to develop F_1 hybrids with high yield and quality in tomato (*Solanum lycopersicum* L.) through diallel crossing involving six parents. The study revealed that the remarkable heterosis for earliness, plant height and laterals per plant were observed over the better parent. In order of merit, the three best performing F_1 hybrids P_1 × P_5, P_3 × P_6 and P_2 × P_3 exhibited heterosis percentage of -8.57, 14.43 and 13.90 respectively, for marketable fruit weight and fruit yield over the standard check P_5 × P_3, P_3 × P_6 and P_6 × P_5 yielding 116.61% over the standard parent, these promising crosses also recorded the positive SCA.

Joshi *et al.* (2004), in a line × tester analysis for shelf life and related traits, revealed that Amongst crosses, H-711492 × 101, 260 × V-16 exhibited the maximum heterosis over better parent for whole fruit firmness, Pericurp thickness, respectively. Whereas, cross combination FT-5 × V-16 recorded the highest significant heterobeltiosis for shelf-life.

Ahmad (2002) reported better parent heterosis for TSS % in the cross TM017 × TM044 (21.00 %) and TM017 × TM026 (13.54 %) for May and July sowing respectively. He found the highest better parent heterosis in the cross TM051 × TM017 (22.65 % in May sowing and 15.97 % in July sowing) for fruit breadth and fruit weight, plant height, the highest better parent heterosis in the cross TM051 × TM025 (22.25 % in May sowing and 2.87 % in July sowing) for fruit length. He found the highest heterobeltiotic effects in the hybrid TM051 × TM017 (-21.76 % and -13.43 % for May and July sowing respectively), the highest heterosis over better parent in title cross TM026 × TM025 which were 32.24 % and 26.90 % for May and July sowing respectively.

Sekar (2001) observed more than 10 % heterosis over the best parent for the number of fruits per plant and yield per plant.

Bhatt (2001a) in a 15 × 15 diallel set of tomato excluding reciprocals found that highly significant positive heterosis for yield (41.97, 157.84 and 28.94 %), over the top, the better parent and the commercial control, respectively.

Bhatt (200la) obtained highly significant positive heterosis for TSS% (25.97, 11.93 and 19.02 %) over the top, the better parent and the commercial control, respectively.

Bhatt *et al.* (2000) conducted on a 15 × 15 diallel set of tomato excluding reciprocals to find out the extent of heterosis for yield with two important quality traits: ascorbic acid (vitamin C) and total soluble solids (TSS%).

Resende *et al.* (2000) in .a study of heterosis of tomato for number of fruits in the 1st, 2nd and 3rd trusses, found higher heterosis values in the hybrids than the standard cultivar ‘Santa Clara’ for number of fruits per tress.

Bhatt *et al.* (1999) evaluated ninety-one F_1 crosses of tomato in a diallel set involving 14 parents (excluding reciprocals) and found maximum heterosis (63.79 %) in the cross Punjab Chhuhara × Punjab Kesari over the top parent ‘Punjab Chhuhara’ for plant height, number of fruits per tress and total yield per plant.

Susic (1998) crossed seven phenotypic divergent genotypes in a fall diallel without back cross found that the maximum heterosis in tomato for fruit length (4.62 %) in the hybrid V100 × 93/10 and for fruit width (4.56 %) in the hybrid D150 × NO-10.

Shrivastava (1998b) found maximum heterosis in the crosses NT-3 × HS-101. (23.59 %) for total soluble solids.

Wang *et al.* (1998b) crossed five new processing tomato lines as female parents to cultivars ‘Meidong’ and ‘Jiazhouzhiyong’ and observed higher heterosis for fruit length.

Shama *et al. (*1997) evaluated for heterosis through thirty hybrids and thirteen parental lines for plant height, weight and number of fruits per plant, size of fruit and TSS% in a bacterial wilt sick plot. They find out that Heterotic hybrids can be developed from the parental lines possessing bacterial wilt resistance.

Vidyasagar *et al. (*1997) examined a line × tester of tomatoes involving bacterial wilt *(Ralstonia solanacearum)* resistant parents and observed that 12 F_1 Search exhibited superiority to their respective better parents for days to 50 % (early) flowering.

Misra *et al. (*1997) studied Heterosis and combining ability for plant height, number of branches and plant dry weight in eight varieties of tomato resulted In the twenty eight hybrids thus obtained (reciprocals pooled) heterosis as expressed over the superior parent is observed in fourteen hybrids for height, in eighteen hybrids for number of branches and in twenty hybrids for dry weight.

E-Metwally *et al.* (1996) reported significant heterosis over better parents for early yield. Kumar *et al. (*1995a) studied on seven tomato lines, their 21 F_1S and three commercial hybrid standards and observed greatest heterosis over superior parents for plant height (24.54 %). fruit number (143.1 %), average fruit weight (30.8 %) early yield (41.6).

Singh *et al.* (1995) observed heterosis in some crosses for fruit length of tomato and fruit weight over better parent.

Dev *et al. (*1994) in a line × tester analysis observed heterosis over the better parent 115.7 %, for the number of fruits per plant.

Sherif and Hussein (1992) observed significant heterosis for fruit yield per plant, as reflected by differences in the highest yields of parents and F_1 hybrids: 845.6 and 2084.7 g per plant for ‘Yellow Pear’ and Sweet 100 × Yellow Pear, respectively.

Mahady *et al.* (1990) reported that significant heterosis over the mid-parent for TSS% in tomato under heat stress condition in Egypt.

Ahamed *et al.* (1988) also reported heterosis over the better parent for plant height and fruit weight, fruits per plant, yield per plant or total yield in tomato.

Jamwal *et al.* (1984) and Scott *et al. (*1986) reported heterosis over better parent for yield per plant or total yield in tomato. The heterosis for yield has also been reported by Nelson, 1954

Scott *et al.* (1986) also reported heterosis for the trait fruit weight under high temperature environments.

Chaudhury and Khanna (1972) reported heterosis for fruit size, with maximum increases over the better parent of 6.82 %. Alverez (1985) reported heterosis for equatorial diameter in the tomato. Jamwal *et al.* (1984) crossed 10 foreign lines and 3 local testers and observed heterosis.

Bhuiyan (1982) observed maximum better parent heterosis (113.92 percent) for individual fruit weight, number of fruits per plant in the cross Fujuki × World champion.

Hedrick *et al.* (1907) were probably the first to observed heterosis effect in tomatoes. Subsequently, heterosis for yield and its component has been demonstrated by many workers (Bhuiyan, 1982; Burdick, 1954; Daskaloff *et al.*, 1967; Larson and Currence, 1944; Powers, 1945; Singh and Singh, 1993; Wellington, 1912).

Here, in this text, an attempt has been made to review those early studies on heterosis of tomato are directly related to the present investigation.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the period from October 19, 2013 to May 2014 to study the heterosis and combining ability in tomato. The materials and methods that were used for conducting the experiment have been presented in this chapter. It includes a brief description of the location of experimental site, soil and climate condition of the experimental plot, materials used for the experiment, design of the experiment, intercultural operation, data collection procedure and procedure of data analysis.

3.1. Experimental site

The present study was conducted at the research farm of Olericulture Division, Horticultural Research Centre (HRC), of Bangladesh Agriculture Research Institute (BARI) Joydebpur, Gazipur during the winter season of 2013-2014. The experimental site of Joydebpur is located at the site of 24˚.09΄N longitude at an elevation of 8.4 meter from the sea level and 26˚.54΄E latitude covering 53.00 meter altitude, respectively. Brief descriptions of the ecological conditions of the experimental areas are given below:

3.2. Climate

The early and latter period of the year is suitable for tomato cultivation in Bangladesh including Joydebpur, Gazipur. The minimum temperature prevails during cool season (December to February) and higher during hot season. The average annual rainfall was recorded 2000 mm. In Bangladesh overall mean temperature in summer ranges between 25^0C and 33^0C, and in winter, between 15^0C to 27^0C (Anon. 2013). (Appendix 1.)

3.3. Soil

The soils of the experimental areas of Joydebpur were silty loam having pH in the range from 6.10 to 6.58. Chemical analysis of the soils of experimental fields (0-30 cm depth) was performed in the Soil Science Division of BARI, Joydebpur, Gazipur and the morphological characteristics of the soils of experimental sites shown in Appendix 2.

3.4. Plant materials used

Seeds of 36 cross combinations from a diallel cross without reciprocals and along with their 9 parental lines were obtained from Olericulture Division of HRC and the list of parents are presented in Table 1.

Table 1. List of parental lines used in the study

SL. NUMBER	PARENTS
1	P_1 (TLB-182)
2	P_2 (BARI Tomato 15)
3	P_3 (BARI Tomato 2)
4	P_4 (GWT-038)
5	P_5 (BARI Tomato 14)
6	P_6 (GWT 034)
7	P_7 (GWT 070)
8	P_8 (TLB-182PE)
9	P_9 (SL CNG 010)

The parents were selected based on their performance on percent fruit set and genetic diversity and other horticultural traits.

3.5. Seedling raising

Nine parents along with their 36 crosses were seeded in the seedbed on October 19, 2013. Seedlings of 30 days aged were transplanted in the main plot on November 19, 2013. After germination of seed, the bed was covered with 60 mesh nylon net to avoid whitefly infestation that act as vector of virus diseases.

3.6. Land preparation

The land was prepared by several ploughing and cross ploughing followed by laddering to have good tillage and weeds and other unwanted plants were removed thoroughly. Pits were prepared for transplanting seedling.

3.7. Application of manure and fertilizers

The following doses of fertilizer were applied in the plots-

Cow dung- 10 ton per ha
Urea- 500 kg per ha
TSP-450 kg per ha
MOP-250 kg per ha
Gypsum-120 kg per ha
Boron-2 kg per ha

Before planting of seedlings, land was prepared properly and basal dose of fertilizers were applied then seedlings were top dressed as following doses (ha) and procedures: Half of cow dung; the entire quantity of TSP, Boron, Gypsum, and 1 per 3^{rd} of MOP were applied during final land preparation. The remaining half of cow dung was applied during pit preparation. The remaining $2/3^{rd}$ of MOP was applied in two equal installments at 20 and 40 days after transplanting. The entire Urea was applied in 3 equal installments at 20, 40 and 60 days after transplanting.

3.8. Design and layout

The experiment was laid out in the randomized complete block design (RCBD) with 3 replications. 45 treatment combinations were randomly allotted in each block. The size of a unit plot was 4.8 m × 1 m, and the plant spacing was 60 cm × 40 cm. Each unit plot contained 2 rows of plants (24 plants per plot) and border rows were planted with same tomato entries in the four sides. While the space in between plots was 50cm too.

3.9. Transplanting of seedling

Healthy and uniform tomato seedlings of 30 days old seedlings with 4-5 leaves were transplanting in the experimental plots on November 19, 2013. The seedlings were uprooted carefully from the seed bed to avoid damage to the root system. To minimize the damage to the roots of seedlings, the seed beds were watered one hour before uprooting the seedlings. Transplanting was done in the afternoon. The seedlings were watered immediately after transplanting. Seedlings were sown in the plot with maintaining distance between row to row and plant to plant was 60 cm and 40 cm, respectively.

3.10. Intercultural operations

After raising seedlings, various intercultural operations such as gap filling, weeding, earthing up, irrigation pest and disease control etc. were accomplished for better growth and development of the tomato seedlings.

3.10.1. Irrigation

Four irrigations were given throughout the growing period. The first irrigation was given 40 days after planting followed by irrigation at 20 days after the first irrigation. Mulching was also done after each-irrigation at appropriate time by breaking the soil crust.

3.10.2. Control of pest and diseases

Admire 10EC @ 0.5 ml per liter of water was applied at 10 days interval starting from transplanted plants and continued up to 60 DAT for controlling vectors of virus diseases and tomato fruit borer (*Helicoverpa armigera*). Early blight caused by *Alternaria solani*, and *Cercospora* leaf spot are two major diseases of tomato. Therefore, Ridomil Gold 50WP @ 2g and Bavistin DF @2g per liter of water was applied for controlling early blight and *Cercospora* leaf spot diseases at the appearance of disease symptoms.

3.10.3. Staking and pruning practices

When the plants were well established, staking with bamboo stick was supported to each plant to keep them erect. Pruning was started just after first flower cluster initiation and only main stems were allowed. Usually, 2 to 3 pruning were done during the whole period of the cropping period. As routine pruning work, all side suckers, fruits and old leaves were pruned up to last stage of crop.

3.11. Harvesting

As different parents and hybrids matured progressively at different times harvesting stared 90 days after transplanted and continued for about 45 days.

3.12. Data collection

Five plants were randomly selected for data collection from each unit which was recorded plot wise. Data were collected in respect of the following parameters to assess plant growth; yield attributes and yields.

3.13. Measured characteristics

I. **Days to first flowering:** Number of day's required form sowing to first flower opening of the plants of each replication.

II. **Days to 50% flowering:** Number of days required from sowing to first flower opening of the 50% plants of each replication.

III. **Plant heights at last harvest:** The average length in centimeter of the main stem from the ground level to the tip, measured in centimeters at the time of last harvest of the 5 randomly selected plants.

IV. **Number of flower cluster per plant:** Number of flower per plant was counted from 5 randomly selected plants and average value was calculated.

V. **Number of fruits per plant:** Total number of fruits per plant counted forms 5 randomly selected plants of each plots and average was calculated.

VI. **Individual fruit weight:** Individual fruit weight in gram was calculated form 20 selected plants of each plots and average was calculated.

VII. **Number of seed per fruit:** Total number of seeds per fruit was counted from 5 random plants and their average was calculated as seeds per fruits of each plot.

VIII. **Fruit length:** Fruit length was measured with a digital slide calipers from the neck of the fruit to the bottom of the same from 5 respective fruits from each plot and their average was calculated as their length and expressed in centimeter.

IX. **Fruit breadth:** The diameter of individual fruit was measured in several directions with meter scale and the average of all directions was finally recorded and expressed in centimeter (cm).

X. **Number of locules:** Total number of locules present in fruit was counted by cutting 20 mature fruits from each plant from each plot and their average was taken as locule per fruit.

XI. **Pericarp thickness:** Thickness of pericurp was measured with slide calipers from 5 selected fruits from each plot and their average was calculated as their pericurp thickness and expressed in millimeter.

XII. **TSS%:** TSS% was recorded by hand refractometer.

XIII. **Fruit yield per plant:** Total yield of fruits in grams of 5 plants from each plot was weighted and their average was calculated as total yield of fruits per plants and expressed in kilogram.

3.14. Statistical analysis

The data obtained for different characters were statistically analyzed to find out the significance of the difference among the tomato lines. The mean values of all the characters were evaluated and analysis of variance was performing by the ‘F’ test. The significance of the difference among the treatments means was estimated by the least significant difference (LSD) test at 5% and 1% level of probability (Gomez and Gomez, 1984).

3.15. Statistical procedure used for combining ability analysis

Combining ability analysis of the traits with significant genotypic difference was done according to the model 1 (fixed genotypic effects) and method 2 (half diallel) of Griffing (1956b) the fixed effect model was more appropriate in the present case since 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_1S expressed as general and specific combining ability. In Griffing’s approach GCA represents additive variance (perhaps modified by apistatis) whereas SCA represents non-additive effects.

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 sums, the sum of square of GCA, SCA were all computed from these table. The GCA of any parents was estimated as the difference between its array mean and the overall mean.

3.16. GCA and SCA effects

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

GCA effects (Gi) $=\frac{1}{n+2}\sum[\mathrm{Y}i.+\mathrm{Y}ii)-\frac{2}{n}(Y..)]$ Restricted to $\sum_1^n \mathrm{G}i=0$

SCA effects (Sij) = $\mathrm{Y}ij-\frac{1}{n+2}\sum[\mathrm{Y}i.-\mathrm{Y}ii+Yj.+Yjj)+\frac{2}{(n+1)(n+2)}Yjj]$(i<j)

3.17. Calculation of heterosis

For estimation of heterosis in each character the main value of the 36 F_1S have been compared with mid parent (MP) for heterosis over mid parental value. Percent heterosis was calculated as-

$$\text{H (MP)} = \frac{\overline{F}-\overline{MP}}{\overline{MP}} \times 100$$

The significant test for heterosis was done by using standard error of the value of and mid parent as-

$$\text{SE (MP)} = \sqrt{3/2xMSE/r}$$

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Combining ability variance

The analysis of variance showed highly significant differences among the treatments for all characters studied (Appendix 4.).The mean square of GCA and SCA were highly significant for all the characters indicating that both additive and non-additive types of gene effects were involved for the expression of these traits (Appendix 3.).

The relative portion of additive to non-additive components were more than uniformity for plant height at last harvest and fruit breadth suggested preponderance of additive gene action in the expression of these traits. Nataranjan (1992) reported the predominance of additive gene action for number fruit set per cluster. Wang *et al.* (1998a) also reported that additive gene action appeared to be more important non-additive gene action for the fruits per plant, average fruit weight and fruit breadth in tomato. Whereas, Bhatt *et al.* (2001b) opined that predominance of non-additive gene action for fruits per cluster and fruits per plant and Shrivastava *et al.* (1998) also mentioned same comments for fruits per plant and individual fruit weight.

But for rest of the characters viz. days to 1st flowering, days to 50% flowering, number of flower cluster per plant, number of fruits per plant, individual fruit weight, yield per plant, number of seed per fruit, fruit length, TSS%, locules per fruit and fruit yield per plant, non-additive gene action were prominent. Dhaliwal *et al.* (2000) also reported that non-additive gene action appeared more important than additive gene effect on days to flowering, yield per plant and TSS% Shrivastava *et al.* (1998) observed that non-additive gene action appear more important than additive gene effect in tomato. On the other hand, the results of these findings supported the Nataranjan (1992) findings. Dod *et al.* (1995) for TSS% and locules per fruit in tomato.

4.2. Combining ability effects

The results of GCA effects for 13 different characters and the SCA effects of 36 F_1 crosses for the same characters were estimated and presented from table 2 to table 14.

4.2.1. Days to first flowering

The estimate of the GCA and SCA effects for this trait is given table 2. Among the nine parent studies five parents P_1, P_2, P_3, P_4 and P_5 showed significant positive GCA effects (4.13 **, 3.10 **, 3.43 **, 3.43 **, 4.67 ** respectively) for days to 1st flowering. On the other hand the parent P_8 showed the highest significant negative GCA effect (-5.51**) followed by the parent P_9 (-5.20**) suggesting that these parents were good general combiners for earliness.

Out of 36 cross combinations 16 crosses showed negative SCA effects, there were 15 crosses showed significant negative effect. The highest significant negative SCA effect was observed in the cross $P_7 \times P_8$ (-22.81 **) followed by $P_6 \times P_9$ (-21.15 **) and $P_6 \times P_8$ (-20.65 **). So these crosses were the best specific combiner for earliness.

Table 2. Estimates of GCA and SCA effects in tomato for days to 1st flowering

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-1.48 *	-5.15 **	-5.48 **	-0.73 ns	5.38 **	5.22 **	5.79 **	3.48 **	4.13 **
P_2		-5.45 **	-4.45 **	-4.36 **	3.41 **	3.59 **	6.48 **	6.51**	3.10 **
P_3			-3.45 **	-6.03 **	5.75 **	5.59 **	7.48 **	5.51 **	3.43 **
P_4				-4.70 **	5.41 **	6.92 **	5.48 **	5.18 **	3.43 **
P_5					4.50 **	3.34 **	6.91 **	8.27 **	4.67 **
P_6						-9.21 **	-20.65 **	-21.15 **	-4.10 **
P_7							-22.81 **	-20.57 **	-3.94 **
P_8								-18.20 **	-5.51 **
P_9									-5.20 **
S.E.								0.64	
S.E.									0.48
5%								1.31	1.75
1%								1.76	1.61

*Significant at 5% level of probability
** Significant at 1% level of probability
ns = non-significant

4.2.2. Days to 50% flowering

The estimate of the GCA and SCA effects for days to 50% flowering are given Table 3. The parent P_6, P_7, P_8, P_9 showed significant positive GCA effects (3.38 **, 4.04 **, 5.89 ** and 6.47 ** respectively). The parent P_9 showed the highest significant positive GCA effect (6.47 **) followed by the parent P_8 (5.89**). The highest significant negative GCA effect was obtained by and the parent P_2 (-4.71 **) followed by parent P_3 (-4.47 **). Thus the parent P_2 and P_3 were the best general combiners which may be used in crosses for earliness. El-Mahady *et al.* (1990) reported highly negative significant GCA effect for early yield in certain lines. Chadha *et al.* (1997) also found a line as a good general combiner for earliness.

There were 15 F_1 showed positive SCA effect for this trait on which 13 showed significant positive SCA effects. Remaining 21 crosses showed negative SCA effects for days to 50% flowering. Cross $P_1 \times P_9$ showed the highest significant negative SCA effects (-10.21 **) followed by $P_5 \times P_8$ (-8.12 **) and $P_2 \times P_7$ (-7.85 **). Thus, $P_1 \times P_9$, $P_5 \times P_8$, $P_2 \times P_7$ and $P_2 \times P_6$ were good specific combination for earliness. The result is fully supported by the findings of Chadha *et al.* (1997)

Table 3. Estimates of GCA and SCA effects in tomato for days to 50% flowering

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	4.30 **	2.73 **	-0.21 ns	5.21 **	-3.45 **	-3.79 **	-4.64 **	-10.21 **	-4.11 **
P_2		2.33 **	2.06 **	0.48 ns	-7.52 **	-7.85 **	-5.70 **	-5.27 **	-4.71 **
P_3			4.82 **	1.24 ns	-6.42 **	-5.76 **	-6.94 **	-5.52 **	-4.47 **
P_4				2.64 **	-4.03 **	-4.70 **	-7.21 **	-7.12 **	-3.53 **
P_5					-5.27 **	-4.94 **	-8.12 **	-5.36 **	-2.96 **
P_6						10.06 **	17.88 **	19.30 **	3.38 **
P_7							20.21 **	21.97 **	4.04 **
P_8								19.79 **	5.89 **
P_9									6.47 **
S.E. (Sij)								0.71	
S.E. (Gi)									0.53
5%								1.44	1.23
1%								1.95	1.78

** Significant at 1% level of probability ns = non-significant

4.2.3. Plant height at last harvest

The results of GCA and SCA effects for plant height at last harvest has been presented in table 4. Among 9 parents three parent showed significant positive GCA effects. The highest significant negative GCA effect was observed in P_1 (-35.86 **). The highest significant positive GCA was found from P_9 (53.98**) followed by P_5 (30.55**) and P_6 (27.12**). Thus, parent P_9 was the best general combiner which may be used for increasing plant height during harvest. If dwarfness is desired then parent P_1 showed best GCA effect.

Among 36 cross combinations 15 crosses showed significant positive SCA effect for plant height at last harvest. The highest significant positive effect was obtained from the cross combination of $P_8 \times P_9$ (47.87 **) followed by $P_2 \times P_4$ (43.31 **) and $P_7 \times P_9$ (42.39**). The highest significant negative SCA was observed on $P_1 \times P_5$ (-59.78**). The significant positive SCA effect of $P_8 \times P_9$, $P_2 \times P_4$ and $P_7 \times P_9$ indicated that these cross combinations were good specific combiner for better plant height at last harvest. Positive heterosis for this trait was reported by Dod and Kale (1992) and Ahmad *et al*. (2011). The SCA effect of $P_8 \times P_9$, $P_2 \times P_4$ and $P_7 \times P_9$ indicated that the cross combination $P_1 \times P_5$ was best specific combiner for dwarfness.

Table 4. Estimates of GCA and SCA effects in tomato for Plant height at last harvest

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-16.31 **	0.76 **	-9.94 **	-59.78 **	-6.35 **	-17.83 **	-17.62 **	37.79 **	-35.86 **
P_2		-27.18 **	43.31 **	-0.73 **	-32.30 **	-12.38 **	-14.56 **	-2.15 **	-20.92 **
P_3			-15.62 **	29.35 **	29.78 **	-13.30 **	20.51 **	0.92 **	-11.99 **
P_4				16.84 **	-46.73 **	-1.81 **	-5.00 **	-5.59 **	-21.48 **
P_5					10.23 **	27.15 **	23.96 **	-34.62 **	30.55 **
P_6						-6.82 **	7.39 **	35.47 **	27.12 **
P_7							-42.02 **	42.39 **	-15.80 **
P_8								47.87 **	-5.61 **
P_9									53.98 **
S.E. (Sij)								0.21	
S.E. (Gi)									0.16
5%								0.43	0.36
1%								0.58	0.53

** Significant at 1% level of probability

4.2.4. Number of flower cluster per plant

The estimates of the GCA and SCA effects for number of flower cluster per plant are given Table 5. Among 9 parents 4 parents showed significant positive GCA effect for this trait. The highest significant negative GCA was observed in the parent P_3 (-5.62 **). On the other hand the highest significant positive GCA was obtained from the parent P_9 (10.00 **) followed by P_8 (5.20 **) and P_7 (5.17 **) which indicated that the parent P_9 is the best general combiner for number of flower cluster per plant and the parents P_8 and P_7 were good general combiner for this trait.

Out of 36 crosses 14 crosses showed significant positive SCA effect for this trait. The highest significant positive SCA effect was found in cross combination of $P_7 \times P_9$ (38.87 **) followed by $P_6 \times P_9$ (37.12 **) and $P_8 \times P_9$ (25.42 **). So the cross combination $P_7 \times P_9$ was the best and cross combination $P_6 \times P_9$ and $P_8 \times P_9$ were good specific combiner for number of flower cluster per plant.

Table 5. Estimates of GCA and SCA effects in tomato for number of flower cluster per plant

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	3.41 **	6.72 **	6.10 **	7.42 **	-3.28 **	-8.68 **	-9.31 **	-8.71 **	-5.28 **
P_2		5.55 **	0.93 ns	5.46 **	-5.24 **	-4.44 **	-4.08 **	-9.27 **	-4.51 **
P_3			0.64 ns	6.17 **	-6.13 **	-3.53 **	-9.57 **	-11.57 **	-5.62 **
P_4				1.95 **	-4.35 **	-4.15 **	-3.79 **	-8.98 **	-5.21 **
P_5					-4.23 **	-7.63 **	-5.19 **	-11.69 **	-4.73 **
P_6						7.62 **	15.71 **	37.12 **	4.97 **
P_7							21.60 **	38.87 **	5.17 **
P_8								25.42 **	5.20 **
P_9									10.00 **
S.E. (Sij)								0.92	
S.E. (Gi)									2.31
5%								1.26	1.07
1%								1.68	1.55

ns = non-significant

** Significant at 1% level of probability

4.2.5. Number of fruits per plant

The GCA effect for number of fruits per plant were significant all the 9 parents (Table 6.). The highest significant negative GCA was found in P_3 (-21.26 **) followed by P_4 (-20.66 **) and P_5 (-19.25 **). The highest significant positive GCA was observed in P_6 (27.19 **) followed by P_9 (25.77 **). Thus, these parents were good general combiner for this trait. Chadha *et al.* (1997); De-Araujo and De-Campos (1990) and Bhuiyan (1982) reported some good general combiners for number of fruit per plant.

Out of 36 crosses fourteen cross combinations showed significant positive SCA effect for this trait (table 6.). All the crosses showed significant SCA effect. The highest significant negative SCA effect was found in $P_1 \times P_9$ (-53.43 **) followed by $P_2 \times P_9$ (-38.04 **) and $P_4 \times P_9$ (-34.09 **). On the other hand the highest significant positive SCA effect was observed in $P_6 \times P_9$ (134.74 **) followed by $P_8 \times P_9$ (126.41 **) and $P_7 \times P_9$ (114.80 **) which indicated that these cross combinations were good specific combiner for increasing number of fruits per plant in tomato crops. Bhuiyan (1982) and Ahmad (2002) also found significant positive SCA effects in some hybrids in tomato.

Table 6. Estimates of GCA and SCA effects in tomato for number of fruit per plant

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	12.11 **	-3.00 ns	20.99 **	13.58 **	10.42 **	13.22 **	-6.51 **	-53.43 **	-2.31 *
P_2		12.00 **	5.46 **	9.05 **	-15.38 **	-15.32 **	-4.38 **	-38.04 **	-15.78 **
P_3			14.34 **	21.93 **	-33.10 **	-3.83 **	-23.30 **	-30.81 **	-21.26 **
P_4				13.26 **	-26.51 **	-4.11 **	-22.70 **	-34.09 **	-20.66 **
P_5					-21.91 **	-11.85 **	-23.88 **	-31.90 **	-19.25 **
P_6						14.12 **	57.66 **	134.74 **	27.19 **
P_7							-18.61 **	114.80 **	11.12 **
P_8								126.41 **	15.18 **
P_9									25.77 **
S.E. (Sij)								1.34	
S.E. (Gi)									1.002
5%								2.73	2.31
1%								3.67	3.36

*Significant at 5% level of probability

ns = non-significant

** Significant at 1% level of probability

4.2.6. Individual fruit weight

The estimates of the GCA and SCA effects for individual fruit weight are given table 7. Six parents showed significant positive GCA effect for individual fruit weight. The highest significant negative GCA was observed in P_8 (-15.66 **). The highest significant positive GCA was obtained from P_5 (15.73 **) followed by P_9 (9.17 **) and P_4 (6.14 **) which indicated that P_5 was the best general combiner and P_9 and P_4 were good general combiner which may be used in crosses for improvement of individual fruit weight in tomato. The findings of Bhuiyan (1982), Chadha *et al.* (1997) and Ahmad (2002) also supported the result.

There were 19 cross combination showed positive SCA effect, on which 14 cross combinations showed significant positive SCA effect for individual fruit weight. The highest significant negative SCA effect was observed in $P_6 \times P_9$ (-49.18 **) followed by $P_7 \times P_9$ (-46.45 **) and $P_8 \times P_9$ (-44.22 **). The highest significant positive SCA was obtained from $P_5 \times P_7$ (18.05 **) followed by $P_3 \times P_8$ (16.58 **) and $P_1 \times P_7$ (11.78 **). So cross combinations $P_5 \times P_7$, $P_3 \times P_8$ and $P_1 \times P_7$ was good specific combiner for improvement of this trait. Chadha *et al.* (1997) selected some hybrids for this trait.

Table 7: Estimates of GCA and SCA effects in tomato for Individual fruit weight

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	3.44 **	-1.28 ns	-8.57 **	-1.92 *	6.69 **	11.78 **	5.11 **	3.74 **	2.35 **
P_2		5.57 **	1.21 ns	-13.05 **	6.45 **	5.97 **	1.23 ns	0.79 ns	3.15 **
P_3			-7.64 **	-8.13 **	1.52 ns	-6.59 **	16.58 **	-11.78 **	3.43 **
P_4				-17.15 **	4.69 **	-2.46 **	9.76 **	-2.17 **	6.14 **
P_5					4.54 **	18.05 **	1.40 ns	8.95 **	15.73 **
P_6						-13.26 **	-24.72 **	-49.18 **	-11.00 **
P_7							-21.65 **	-46.45 **	-13.30 **
P_8								-44.22 **	-15.66 **
P_9									9.17 **
S.E. (Sij)								0.79	
S.E. (Gi)									0.59
5%								1.60	1.36
1%								2.15	1.97

*Significant at 5% level of probability ns = non-significant

** Significant at 1% level of probability

4.2.7. Number of seed per fruit

There were three 3 parents showed significant positive GCA effect and six parents showed negative GCA effect, on which four parents showed significant negative GCA effect for number of seed per fruit (Table 8.). The highest significant negative GCA was observed in P_9 (-22.76 **). The highest significant positive GCA was obtained from followed by P_5 (29.65 **) indicated that P_5 is the best general combiner for increasing number of seed per fruit.

Among 36 cross combinations 19 crosses showed significant positive SCA effect for number of seed per plant. The highest significant negative SCA was observed on $P_2 \times P_8$ (-16.67 **) followed by $P_5 \times P_9$ (-16.67 **) and $P_3 \times P_5$ (-14.31 **). On the other hand the highest significant positive effect was obtained from $P_5 \times P_8$ (24.89 **) followed by $P_1 \times P_5$ (24.13 **) and $P_7 \times P_8$ (23.07**). The significant positive SCA effect of $P_5 \times P_8$, $P_1 \times P_5$ and $P_7 \times P_8$ indicated that these cross combinations are good specific combiner for increasing number of seed per fruit.

Table 8: Estimates of GCA and SCA effects in tomato for number of seed per fruit.

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-13.73 **	-12.04 **	18.55 **	24.13 **	-5.70 **	-3.64 **	10.65 **	10.76 **	-7.50 **
P_2		16.69 **	22.52 **	10.90 **	0.19 ns	0.85 **	-16.67 **	5.46**	-3.40 **
P_3			-5.80 **	-14.31 **	1.35 **	-9.83 **	-6.88 **	-7.81 **	-0.07 ns
P_4				2.90 **	-3.84 **	8.70 **	0.70 **	-11.23 **	2.93 **
P_5					3.89 **	4.33 **	24.89 **	-16.62 **	29.65 **
P_6						-2.09 **	3.87 **	-2.26 **	2.18 **
P_7							23.07 **	-6.39 **	-0.27 ns
P_8								-1.52 **	-0.77 **
P_9									-22.76 **
S.E. (Sij)								0.25	
S.E. (Gi)									0.19
5%								0.51	0.43
1%								0.68	0.63

ns = non-significant

** Significant at 1% level of probability

4.2.8. Fruit length

There were five parent showed significant positive GCA effects and three parents showed significant negative GCA effect for this trait. The highest significant negative GCA effect was observed in P_1 (-0.20 **) followed by P_3 (-0.19 **). The highest significant positive GCA is found in P_9 (0.24 **) followed by P_2 (0.09 **). Thus, the parent P_9 was the best general combiner which may be used for improvement of fruit length (Table 9). Susic (1998) and Ahmad (2002) also reported some good general combiner for fruit length.

Among 36 cross combinations 16 crosses showed positive SCA effect on which 15 parent's significant positive SCA effect and 19 parents showed significant negative SCA effect for fruit length trait. The highest significant positive effect was obtained from P_2 × P_8 (0.89 **) followed by P_3 × P_4 (0.80 **) and P_2 × P_7 (0.77 **). The highest significant negative SCA was recorded from P_1 × P_4 (-0.75 **) followed by P_2 × P_5 (-0.49 **). The significant positive SCA effect of P_2 × P_8, P_3 × P_4 and P_2 × P_7 indicated that these cross combinations are good specific combiner for improvement of fruit length. Susic (1998) and Ahmad (2002) also reported SCA for fruit length in tomato.

Table 9: Estimates of GCA and SCA effects in tomato for Fruit length

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-0.14 **	-0.44 **	-0.75 **	-0.17 **	-0.24 **	0.19 **	0.38 **	0.00 ns	-0.20 **
P_2		-0.30 **	-0.44 **	-0.49 **	-0.06 **	0.77 **	0.89 **	-0.26 **	0.09 **
P_3			0.80 **	0.45 **	0.01 **	0.22 **	-0.41 **	-0.25 **	-0.19 **
P_4				0.07 **	-0.21 **	-0.36 **	0.08 **	0.57 **	-0.01 **
P_5					0.31 **	0.18 **	-0.17 **	-0.42 **	0.04 **
P_6						-0.33 **	-0.44 **	-0.32 **	0.02 **
P_7							0.33 **	0.11 **	0.01 **
P_8								-0.00 ns	-0.00 ns
P_9									0.24 **
S.E. (Sij)								0.003	
S.E. (Gi)									0.003
5%								0.01	0.01
1%								0.01	0.01

ns = non-significant

** Significant at 1% level of probability

4.2.9. Fruit breadth

The fruit breadth of four parents out of nine parents showed significant positive GCA effects and five parents showed significant negative GCA effect. The highest significant negative GCA effect was observed in P_6 (-0.74 **) followed by P_1 (-0.51 **). The highest significant positive GCA was found from P_9 (0.90 **) followed by P_4 (0.60 **) and P_5 (0.52 **). So the parent P_9, P_4 and P_5 were the best general combiner which could be used for improvement of fruit breadth (Table10). Susic (1998) and Ahmad (2002) also reported some GCA for fruit breadth.

The SCA of 19 crosses showed positive effect, on which 18 cross combinations showed significant positive SCA effect for fruit breadth. The highest significant negative SCA was observed on $P_4 \times P_5$ (-1.13 **) followed by $P_8 \times P_9$ (-0.92 **) and $P_3 \times P_9$ (-0.84 **). On the other hand the highest significant positive effect was obtained from $P_4 \times P_8$ (1.18 **) followed by $P_4 \times P_9$ (1.09 **) and $P_5 \times P_7$ (0.89 **). So $P_4 \times P_8$, $P_4 \times P_9$ and $P_5 \times P_7$ cross combinations are good specific combiner for improvement of fruit breadth. Susic (1998) reported good specific combiners for fruit breadth in tomato. Superior hybrids for fruit breadth were also reported by Ahmad (2002).

Table 10: Estimates of GCA and SCA effects in tomato for fruit breadth

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-0.75 **	0.40 **	-0.27 **	0.70 **	0.01 **	-0.35 **	-0.29 **	0.83 **	-0.51 **
P_2		0.22 **	0.15 **	-0.08 **	-0.04 **	0.37 **	-0.34 **	0.35 **	-0.23 **
P_3			0.33 **	0.18 **	0.44 **	0.35 **	-0.09 **	-0.84 **	0.16 **
P_4				-1.13 **	0.00 ns	-0.19 **	1.18 **	1.09 **	0.60 **
P_5					-0.22 **	0.89 **	0.25 **	-0.76 **	0.52 **
P_6						-0.45 **	0.48 **	-0.04 **	-0.74 **
P_7							-0.38 **	0.15 **	-0.39 **
P_8								-0.92 **	-0.32 **
P_9									0.90 **
S.E. (Sij)								0.002	
S.E. (Gi)									0.001
5%								0.002	0.003
1%								0.001	0.004

ns = non-significant

** Significant at 1% level of probability.

4.2.10. Number of locules

Among 9 parents 2 parents showed significant positive GCA effect 7 parents showed significant negative GCA effect for number of locules (Table 11). The highest significant positive GCA was obtained from P_9 (1.63 **) followed by P_5 (0.58 **). On the other hand highest significant negative GCA was observed in P_6 (-0.55 **) followed by (-0.52 **) indicated that P_6 and P_7 were the best general combiner for increasing number of locules. Bhutani and Kallo (1991) and Dod *et al.* (1995) reported some good general combiner parents for decreasing locules per fruit.

Among 36 cross combinations 20 crosses showed positive SCA effect on which 19 parents showed significant positive SCA for number of locules. 16 parents showed negative SCA effect on which 15 parents showed significant negative SCA effect for this trait. The highest significant positive effect was obtained from $P_2 \times P_6$ (1.26 **) followed by $P_7 \times P_9$ (1.24 **) and $P_1 \times P_6$ (0.89 **). On the other hand the highest significant negative SCA was observed on $P_6 \times P_9$ (-2.26 **) followed by $P_3 \times P_4$ (-1.05 **) and $P_3 \times P_5$ (-0.91 **). The significant negative SCA effect of $P_6 \times P_9$, $P_3 \times P_4$ and $P_3 \times P_5$ indicated that these cross combinations are good specific combiner for decreasing number of locules.

Table 11. Estimates of GCA and SCA effects in tomato for number of locules per fruit

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-0.91 **	0.04 *	0.61 **	0.26 **	0.89 **	-0.51 **	0.24 **	0.69 **	-0.38 **
P_2		-0.11 **	0.00 ns	0.13 **	1.26 **	-0.77 **	-0.02 ns	0.74 **	-0.12 **
P_3			-1.05 **	0.08 **	0.32 **	-0.49 **	0.06 **	0.79 **	-0.07 **
P_4				-0.50 **	0.43 **	-0.60 **	-0.60 **	-0.42 **	-0.29 **
P_5					-0.10 **	0.52 **	-0.72 **	0.59 **	0.58 **
P_6						-0.34 **	0.41 **	-2.26 **	-0.55 **
P_7							-0.31 **	1.24 **	-0.52 **
P_8								0.66 **	-0.27 **
P_9									1.63 **
S.E. (Sij)								0.02	
S.E. (Gi)									0.02
5%								0.04	0.037
1%								0.06	0.05

*Significant at 1% level of probability ** Significant at 5% level of probability ns = non-significant

4.2.11. Pericurp thickness (mm)

Out of nine parents three parents showed significant positive GCA effects and six parents showed significant negative GCA effect for this trait (Table 12.). The highest significant negative GCA effect was observed in P_6 (-0.03 **) followed by P_1, P_4, P_7 and P_8 which showed (-0.02 **) significant negative effect. The highest significant positive GCA is found from P_9 (0.07 **) followed by P_2 (0.02 **). So the parent P_9 was the best general combiner which may be used for improvement of pericurp thickness (mm).

There were 13 crosses among 36 crosses showed significant positive SCA effect and 22 parents showed negative SCA effect, on which 19 parents showed significant negative SCA effect for this trait. The highest significant positive effect was obtained from $P_1 \times P_5$ (0.18 **) followed by $P_3 \times P_6$ (0.08 **). The highest significant negative SCA was observed on $P_1 \times P_3$ (-0.18 **) followed by $P_1 \times P_6$ (-0.16 **). The positive SCA effect of $P_1 \times P_5$ and $P_3 \times P_6$ indicated that these cross combinations are good specific combiner for improvement of pericurp thickness of tomato. Ahmad (2000) found positive GCA and SCA effects.

Table 12: Estimates of GCA and SCA effects in tomato for Pericurp thickness (mm)

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-0.09 **	-0.18 **	-0.12 **	0.18 **	-0.16 **	0.03 **	-0.00 ns	0.03 **	-0.02 **
P_2		0.05 **	-0.02 **	-0.01 **	-0.08 **	0.03 **	0.06 **	0.03 **	0.02 **
P_3			0.06 **	-0.09 **	0.08 **	-0.10 **	-0.00 **	0.05 **	-0.01 **
P_4				-0.12 **	0.02 **	0.05 **	-0.02 **	-0.02 **	-0.02 **
P_5					-0.04 **	-0.07 **	-0.03 **	-0.10 **	0.01 **
P_6						-0.03 **	-0.05 **	0.04 **	-0.03 **
P_7							-0.08 **	0.00 ns	-0.02 **
P_8								-0.04 **	-0.02 **
P_9									0.07 **
S.E. (Sij)								0.001	
S.E. (Gi)									0.001
5%								0.001	0.002
1%								0.003	0.002

ns = non-significant

** Significant at 1% level of probability

4.2.12. TSS%

Results of GCA and SCA effects are shown in Table 13. Among 9 parents none of them showed significant GCA effects which indicated that there was no significant difference among the parents for TSS%. Dod *et al.* (1995) and Shrivastava (1998a) also reported some parents acted as good general combiner for TSS% without showing any differences.

It revealed from table 13 that among 36 cross combinations eight parents showed positive SCA effects on which none of the cross combination showed significant positive SCA effect for TSS%. Rest of 28 parents showed negative SCA effect on which only 2 cross combination P_6 × P_8 (-2.36**) and P_2 × P_8 (-2.09*) showed significant negative SCA effect.

Table 13: Estimates of GCA and SCA effects in tomato for TSS%

Parent	TSS								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	-0.37 ns	-0.57 ns	-0.17 ns	-0.27 ns	1.06 ns	-0.68 ns	-1.05 ns	-0.61 ns	-0.60 ns
P_2		0.69 ns	-0.20 ns	-0.31 ns	-0.78 ns	0.28 ns	-2.09 *	0.69 ns	-0.56 ns
P_3			-0.91 ns	-0.52 ns	0.82 ns	-0.43 ns	-1.20 ns	-0.85 ns	-0.36 ns
P_4				0.49 ns	-0.17 ns	0.28 ns	-1.29 ns	-1.84 *	-0.37 ns
P_5					0.22 ns	-0.03 ns	-1.20 ns	-1.95 *	-0.26 ns
P_6						-0.19 ns	-2.36 **	-1.32 ns	-0.10 ns
P_7							-1.30 ns	-0.86 ns	-0.35 ns
P_8								13.44 **	1.02 ns
P_9									1.58 *

*Significant at 5% level of probability ns = non-significant

** Significant at 1% level of probability

4.2.13. Fruit yield per plant

The estimates of the GCA and SCA effects for fruit yield per plant are given Table 14. Among nine parents three parents showed significant positive GCA effect, six parents showed significant negative GCA effect for fruit yield per plant. The highest significant negative GCA was observed in P_3 (-0.39 **) followed by P_8 (-0.33 **) and P_4 (-0.27 **). The highest significant positive GCA was obtained from followed by P_1 (0.61 **) followed by P_6 (0.40 **) and P_5 (0.27 **) indicated that these cross combinations were the best general combiner for increasing fruit yield per plant. Similarly Chandrasekhar and Rao (1989), Dhaliwal *et al.* (2000), Nataranjan (1992) and Sharma *et al.* (1999) reported some good general combiners for this trait.

Among 36 cross combinations 16 crosses showed significant positive SCA effect for fruit yield per plant. The highest significant positive effect were obtained from two cross combinations those were $P_1 \times P_6$ (1.53 **) and $P_1 \times P_7$ (1.53 **) followed by $P_5 \times P_9$ (0.46 **). The highest significant negative SCA was observed on $P_3 \times P_6$ (-1.02 **) followed by $P_1 \times P_9$ (-0.94 **) and $P_1 \times P_3$ (-0.81 **). The significant positive SCA effect of $P_1 \times P_6$, $P_1 \times P_7$ and $P_5 \times P_9$ indicated that these

Table 14: Estimates of GCA and SCA effects in tomato for fruit yield per plant

Parent	SCA								GCA
	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
P_1	0.43 **	-0.81 **	0.29 **	0.32 **	1.53 **	1.53 **	0.24 **	-0.94 **	0.61 **
P_2		0.30 **	-0.28 **	-0.66 **	0.15 **	-0.37 **	0.24 **	0.30 **	-0.11 **
P_3			-0.08 **	0.32 **	-1.02 **	-0.39 **	-0.05 **	-0.22 **	-0.39 **
P_4				-0.58 **	-0.52 **	-0.16 **	-0.24 **	-0.05 **	-0.27 **
P_5					-0.25 **	0.34 **	-0.72 **	0.46 **	0.27 **
P_6						0.05 **	0.06 **	-0.36 **	0.40 **
P_7							-0.67 **	0.27 **	-0.09 **
P_8								0.03 **	-0.33 **
P_9									-0.11 **
S.E. (Sij)									
S.E. (Gi)									
5%									
1%									

*Significant at 5% level of probability ns = non significant

** Significant at 1% level of probability

cross combinations are good specific combiner for increasing fruit yield per plant. Several workers like Bhatt *et al.* (2001a; 2001b), Dhaliwal *et al.* (2000) and Sharma *et al.* (1999) reported some hybrids superior for yield per plant.

The above results discussed earlier indicated that among the nine parents P_2, P_5, P_8 and P_9 was good general combiner early flowering. The parent P_9 was good general combiner for plant height at last harvest, number of flower cluster per plant, fruit length, pericurp thickness and TSS%. The parent P_9, P_5 both were identified as good combiners for individual fruit weight and number of locules per fruit. Also the parent P_5 was also good general combiner for seed per fruit. Parent P_9, P_5 and P_4 were good general combiner for fruit breadth. The parent P_6 was the best general combiner for number of fruits per plant and fruit yield per plant. As yield of tomato is a complicated parameter, which is generally influenced by earliness, number of fruits per plant, fruit breadth and fruit weight. Considering all these traits the parents P_9, P_5 and P_6 may be used in a crossing programmed for higher yield in tomato.

The maximum SCA effect was observed in the cross combination $P_7 \times P_8$, $P_1 \times P_9$, $P_6 \times P_9$, $P_5 \times P_8$, $P_2 \times P_7$ for earliness; $P_8 \times P_9$, $P_2 \times P_4$ $P_7 \times P_9$ for highest plant height at last harvest; $P_7 \times P_9$, $P_6 \times P_9$, $P_8 \times P_9$ for number of flower per cluster; $P_6 \times P_9$, $P_8 \times P_9$, $P_7 \times P_9$ number of fruits per plant; $P_5 \times P_7$, $P_3 \times P_8$ and $P_1 \times P_7$ for improvement of individual fruit weight; $P_5 \times P_8$, $P_1 \times P_5$ and $P_7 \times P_8$ for number of seed per fruit; $P_2 \times P_8$, $P_3 \times P_4$ and $P_2 \times P_7$ for fruit length; $P_4 \times P_8$, $P_4 \times P_9$ and $P_5 \times P_7$ for fruit breadth; $P_2 \times P_6$, $P_7 \times P_9$ and $P_1 \times P_6$ for number of locules; $P_1 \times P_5$ and $P_3 \times P_6$ for increasing Pericurp thickness (mm); $P_8 \times P_9$, $P_1 \times P_6$, $P_1 \times P_7$ and $P_5 \times P_9$ fruit yield per plant. It is revealed that a combination of the two best general combiners may not be the best combination and poor × poor may not be the poor one (Singh *et al.*, 1965). Poor combining parent may lacked the additive effects of good parent but were highly responsive to heterozygosity in the way of non-additive effects (Darrah and Hallaner, 1972). Thus cross between good × good combinations may give transgressive segregants in the subsequent generation (Longhum, 1961).

4.3. Heterosis

The estimates of percent heterosis observed in F_1 generation over mid parents are presented through Table 15.1 to Table 15.4.The mean performance of parents and F_1S are presented in Appendix 5.1-5.4.

4.3.1. Days to 1st flowering

Among 36 cross combinations 24 cross combinations showed negative heterosis over mid parent for days to 1st flowering on which six hybrids showed significant negative heterosis that indicated earliness than their respective mid parent (Table 15.1). Heterosis for this trait ranged from -78.80 to 5.96 percent. None of the F_1 showed positive heterosis for days to 1st flowering traits. The highest negative heterosis effect was observed in cross $P_7 \times P_8$ (-78.80%) which is desirable for early flowering.

4.3.2. Days to 50% flowering

Out of 36 cross combination 29 showed negative heterosis over mid parent for days to 50% flowering, on which ten hybrids showed significant negative heterosis that indicated earliness than their respective mid parent (Table 15.1). Heterosis for this trait ranged from -12.43 to 62.61 percent. The highest positive heterosis effect was observed in the cross $P_7 \times P_9$ (62.61 %) The highest negative heterosis effect was observed in cross $P_2 \times P_5$ (-12.43%) for this trait which indicted earliness Singh (1993) and Kumar (1997) also reported negative heterosis for days to 50% flowering.

4.3.3. Plant height at last harvest

In the case of plant height at last harvest, 20 cross combination among 36 showed negative heterosis and remaining 16 cross combination showed significant positive heterosis over mid parent for this trait, among them 19 hybrids showed significant negative heterosis (Table 15.1). Heterosis for this trait range from -53.02 to 56.52 percent. The highest negative heterosis effect was observed in cross $P_1 \times P_5$ (-53.02 %). The highest positive heterosis effect was observed in the cross $P_8 \times P_9$ (56.52 %)

Table 15.1. Percent heterosis over mid parent of 36 tomato hybrids for three morphological characters.

Crosses	Characters		
	Days To First Flower	Days To 50% Flowering	Plant Height At Last Harvest (cm)
$P_1 \times P_2$	2.86 ns	-4.40 ns	-46.64 **
$P_1 \times P_3$	-4.96 ns	-5.64 ns	-14.77 **
$P_1 \times P_4$	-5.34 ns	-10.79 **	-36.16 **
$P_1 \times P_5$	5.96 ns	-1.44 ns	-53.02 **
$P_1 \times P_6$	1.06 ns	-1.50 ns	-20.53 **
$P_1 \times P_7$	0.00 ns	0.00 ns	-41.38 **
$P_1 \times P_8$	0.36 ns	-1.47 ns	-31.41 **
$P_1 \times P_9$	-5.30 ns	-10.26 *	31.72 **
$P_2 \times P_3$	-7.14 ns	-9.30 *	-32.71 **
$P_2 \times P_4$	-4.66 ns	-9.71 *	18.88 **
$P_2 \times P_5$	-3.18 ns	-12.43 **	-8.40 **
$P_2 \times P_6$	-4.63 ns	-11.76 **	-31.53 **
$P_2 \times P_7$	-4.93 ns	-10.39 *	-28.39 **
$P_2 \times P_8$	0.36 ns	-6.32 ns	-21.01 **
$P_2 \times P_9$	-0.36 ns	-4.60 ns	8.36 **
$P_3 \times P_4$	-2.49 ns	-3.47 ns	-15.23 **
$P_3 \times P_5$	-6.67 ns	-9.71 *	26.86 **
$P_3 \times P_6$	0.35 ns	-8.33 *	23.08 **
$P_3 \times P_7$	-0.70 ns	-5.11 ns	-12.27 **
$P_3 \times P_8$	2.51 ns	-6.98 ns	30.13 **
$P_3 \times P_9$	-2.47 ns	-3.49 ns	26.92 **
$P_4 \times P_5$	-3.52 ns	-7.30 ns	9.38 **
$P_4 \times P_6$	0.00 ns	-4.09 ns	-37.00 **
$P_4 \times P_7$	2.46 ns	-3.24 ns	-12.81 **
$P_4 \times P_8$	-1.44 ns	-7.43 ns	-5.50 **
$P_4 \times P_9$	-2.84 ns	-6.29 ns	13.13 **
$P_5 \times P_6$	-0.70 ns	-6.36 ns	5.73 **
$P_5 \times P_7$	-3.81 ns	-3.79 ns	15.76 **
$P_5 \times P_8$	2.84 ns	-9.04 *	21.21 **
$P_5 \times P_9$	4.90 ns	-3.39 ns	-0.54 ns
$P_6 \times P_7$	-47.74 **	39.21 **	-9.88 **
$P_6 \times P_8$	-74.29 **	51.76 **	6.63 **
$P_6 \times P_9$	-75.07 **	55.29 **	33.87 **
$P_7 \times P_8$	-78.80 **	58.46 **	-37.52 **
$P_7 \times P_9$	-73.78 **	62.61 **	44.84 **
$P_8 \times P_9$	-71.41 **	56.90 **	56.52 **
Heterosis mean	**-12.85**	**3.78**	**-3.44**

*Significant at 5% level of probability ns = non-significant

** Significant at 1% level of probability

for plant height at last harvest traits. If dawrfness is considerable then cross combination $P_1 \times P_5$ would be desirable. On the other hand if better plant height is desirable then cross combination $P_8 \times P_9$ is acceptable. Kumar (1995b) and Ahmed *et al.* also recorded appreciable heterosis for plant height. Shrivastava *et al.* (1998) and Bhat *et al.* (2001b) reported predominance of non-additive gene action for plant.

4.3.4. Number of flower cluster per plant

Out of 36 cross combinations 27 cross combination showed positive heterosis over mid parent, among these 7 cross combination showed significant positive heterosis (Table 15.2). Range of mid parent heterosis was ranges from -40.62 to 600.81 percent. Figure 1. showed number of flower cluster per plant (mid parent) in tomato. The highest negative heterosis effect was observed in cross $P_3 \times P_4$ (-40.62 %). The highest positive heterosis effect was observed in the cross $P_7 \times P_9$ (600.81%) for number of flower cluster per plant traits. Ahmad (2000a) found positive heterosis for this trait.

4.3.5 Number of fruits per plant

There were 23 cross combination out of 36 cross combinations showed positive heterosis over mid parent, among these 11 cross combination showed significant positive heterosis (Table 15.2). Range of mid parent heterosis was-28.17 to 577.49 percent. Figure 2. showed number of flower cluster per plant in tomato. The highest negative heterosis effect was observed in cross $P_3 \times P_8$ (-28.17 %). The highest positive heterosis effect was observed in the cross $P_7 \times P_9$ (577.49 %) for number of flower cluster per plant traits. Heterosis for fruit per plant also reported by several workers like Bhatt *et al.* (1990), Dev *et al.* (1994), Sekar (2001) and Vidyasagar *et al.* (1997).

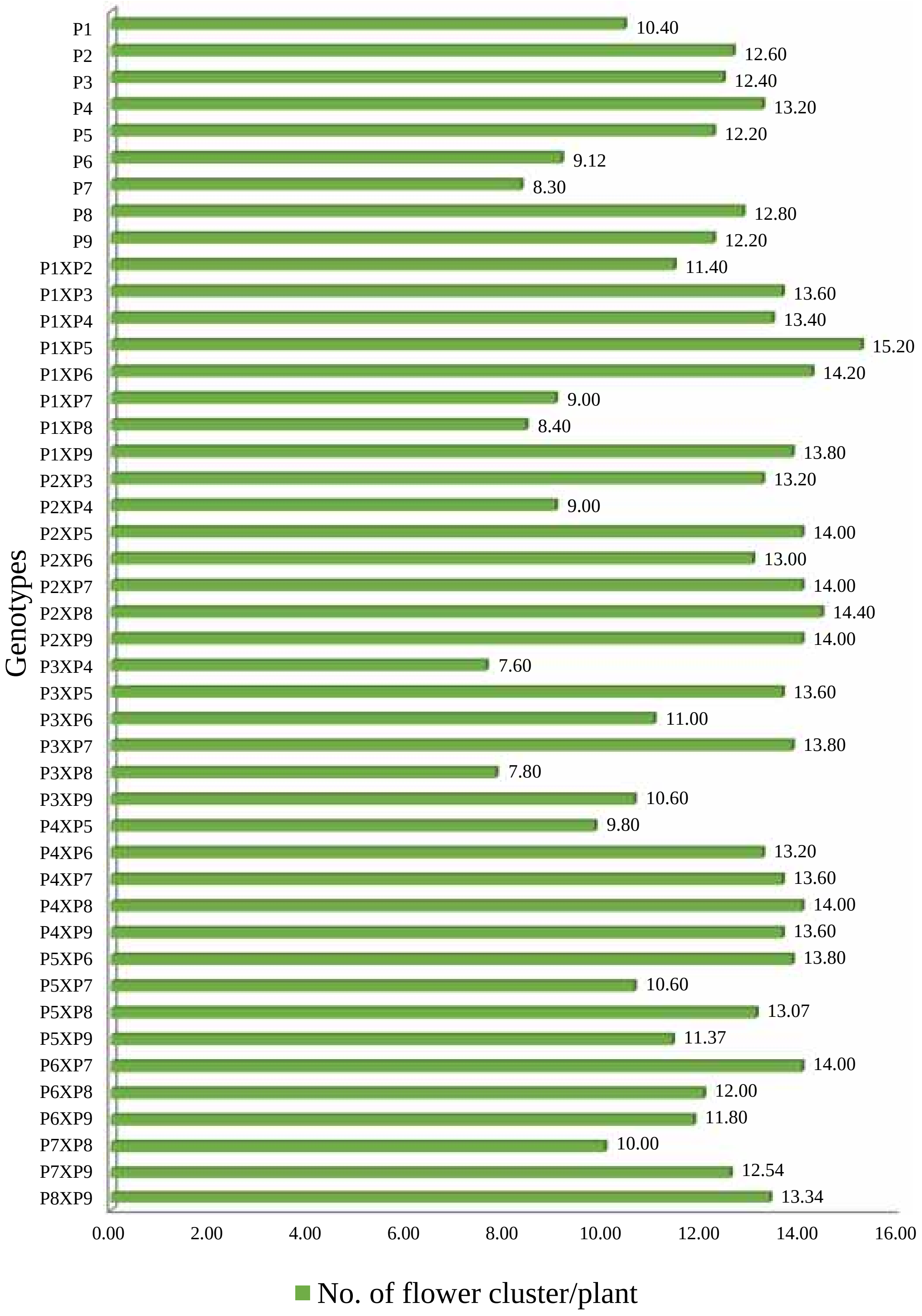


Figure 1. Number of flower cluster per plant in 9 parents and 36 crosses of tomato.

Table 15.2. Percent heterosis over mid parent of 36 tomato hybrids for four yield component characters.

Crosses	Characters			
	Number of flower cluster/plant	Number of fruits/plant	Individual fruit weight (gm)	Fruit yield /plant
$P_1 \times P_2$	-0.87 ns	10.13 ns	20.42 **	34.83 **
$P_1 \times P_3$	19.30 ns	-25.20 **	0.87 ns	-22.34 **
$P_1 \times P_4$	13.56 ns	30.53 **	-14.29 **	17.58 **
$P_1 \times P_5$	34.51 ns	15.46 ns	1.40 ns	23.40 **
$P_1 \times P_6$	45.49 *	74.15 **	-7.43 ns	62.42 **
$P_1 \times P_7$	-3.74 ns	76.11 **	5.28 ns	89.25 **
$P_1 \times P_8$	-27.59 ns	30.65 **	-8.12 ns	21.53 **
$P_1 \times P_9$	22.12 ns	-12.07 ns	-27.04 **	-17.98 **
$P_2 \times P_3$	5.60 ns	-17.16 ns	8.76 *	-9.33 **
$P_2 \times P_4$	-30.23 ns	-25.84 **	-2.14 ns	-25.85 **
$P_2 \times P_5$	12.90 ns	-16.48 ns	-16.11 **	-28.33 **
$P_2 \times P_6$	19.71 ns	11.11 ns	-10.49 *	-1.00 ns
$P_2 \times P_7$	33.97 ns	-4.00 ns	-8.37 ns	-11.99 **
$P_2 \times P_8$	13.39 ns	16.07 ns	-18.10 **	-4.76 **
$P_2 \times P_9$	12.90 ns	0.74 ns	-31.07 **	-16.20 **
$P_3 \times P_4$	-40.62 *	-12.99 ns	-21.67 **	-31.44 **
$P_3 \times P_5$	10.57 ns	5.99 ns	-16.03 **	-10.45 **
$P_3 \times P_6$	2.23 ns	-28.31 **	-25.47 **	-46.32 **
$P_3 \times P_7$	33.33 ns	15.83 ns	-36.67 **	-26.75 **
$P_3 \times P_8$	-38.10 *	-28.17 **	-0.80 ns	-27.98 **
$P_3 \times P_9$	-13.82 ns	14.14 ns	-46.49 **	-30.43 **
$P_4 \times P_5$	-22.83 ns	-7.44 ns	-28.63 **	-34.01 **
$P_4 \times P_6$	18.28 ns	-9.90 ns	-22.88 **	-29.18 **
$P_4 \times P_7$	26.51 ns	23.77 *	-31.64 **	-14.97 **
$P_4 \times P_8$	7.69 ns	-21.61 *	-14.91 **	-31.46 **
$P_4 \times P_9$	7.09 ns	14.75 ns	-38.08 **	-22.33 **
$P_5 \times P_6$	29.46 ns	0.33 ns	-16.61 **	-13.95 **
$P_5 \times P_7$	3.41 ns	5.60 ns	3.45 ns	9.59 **
$P_5 \times P_8$	4.53 ns	-22.80 *	-20.07 **	-36.45 **
$P_5 \times P_9$	-6.83 ns	22.54 ns	-23.63 **	0.77 ns
$P_6 \times P_7$	308.19 **	132.03 **	-69.28 **	3.51 **
$P_6 \times P_8$	298.45 **	197.28 **	-91.42 **	-9.34 **
$P_6 \times P_9$	555.57 **	529.17 **	-94.79 **	-19.81 **
$P_7 \times P_8$	371.66 **	52.48 **	-89.34 **	-31.02 **
$P_7 \times P_9$	600.81 **	577.49 **	-94.14 **	6.62 **
$P_8 \times P_9$	367.31 **	528.05 **	-94.15 **	-16.55 **
Heterosis mean	**74.83**	**59.79**	**-27.21**	**-8.35**

*Significant at 5% level of probability ns = non-significant

** Significant at 1% level of probability

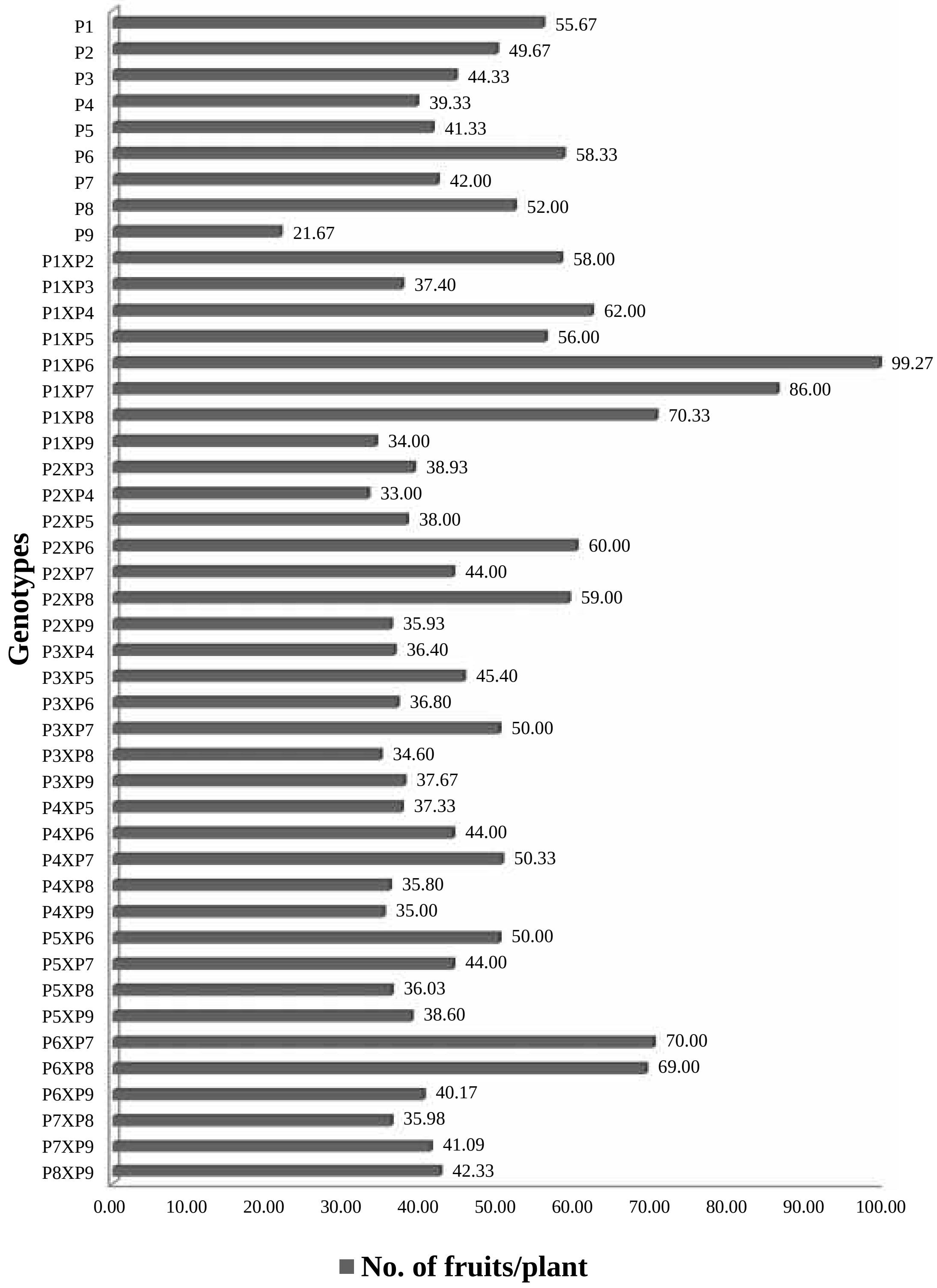


Figure 2. Number of fruits per plant in 9 parents and 36 crosses of tomato

4.3.6. Individual fruit weight (gm)

Six cross combination out of 36 showed positive heterosis over mid parent, among them 2 cross combination showed significant positive heterosis (Table 15.2).Range of mid parent heterosis was -94.79 to 20.42percent. The highest positive heterosis effect was observed in the cross $P_1 \times P_2$ (20.42%) for Individual fruit weight (gm) traits. Figure 3. showed the variation of Individual fruit weight (gm) among the genotypes. It is clear from the figure that higher individual fruit weight in a particular F_1 does not necessarily show high heterosis because of higher performance by parental line. The highest negative heterosis effect was observed in cross $P_6 \times P_9$ (-94.79 %). Kumar *et al.* (1995a; 1995b), Singh *et al.* (1995), and Vidyasagar *et al.* (1997) also reported heterosis for this trait.

4.3.7. Fruit yield /plant

Ten cross combination out of 36 showed positive heterosis over mid parent, among them 9 cross combination showed significant positive heterosis (Table 15.2).Range of heterosis over mid parent was -46.32 to 89.25 percent. Figure 6 numbers of locules per fruit. The highest negative heterosis effect was observed in cross $P_3 \times P_6$ (-46.32%). The highest positive heterosis effect was observed in the cross $P_1 \times P_7$ (89.25 %) for number of locules per fruit trait. Kurian and Peter (2001) also identified heterotic hybrids for locule number in tomato.

4.3.8. Number of seed per fruit

There were 24 cross combination out of 36 showed positive heterosis over mid parent, among them 20 cross combination showed significant positive heterosis (Table 15.3). Range of mid parent heterosis was -23.85 to 39.19 percent. Figure 4. showed number of seed per tomato fruit. The highest negative heterosis effect was observed in cross $P_3 \times P_9$ (-23.85 %). The highest positive heterosis effect was observed in the cross $P_2 \times P_4$ (39.19 %) for number of seed/fruit traits. Heterosis for number of seed/fruit also reported by several workers like Dev *et al.* (1994), Sekhar (2001) and Vidyasagar *et al.* (1997).

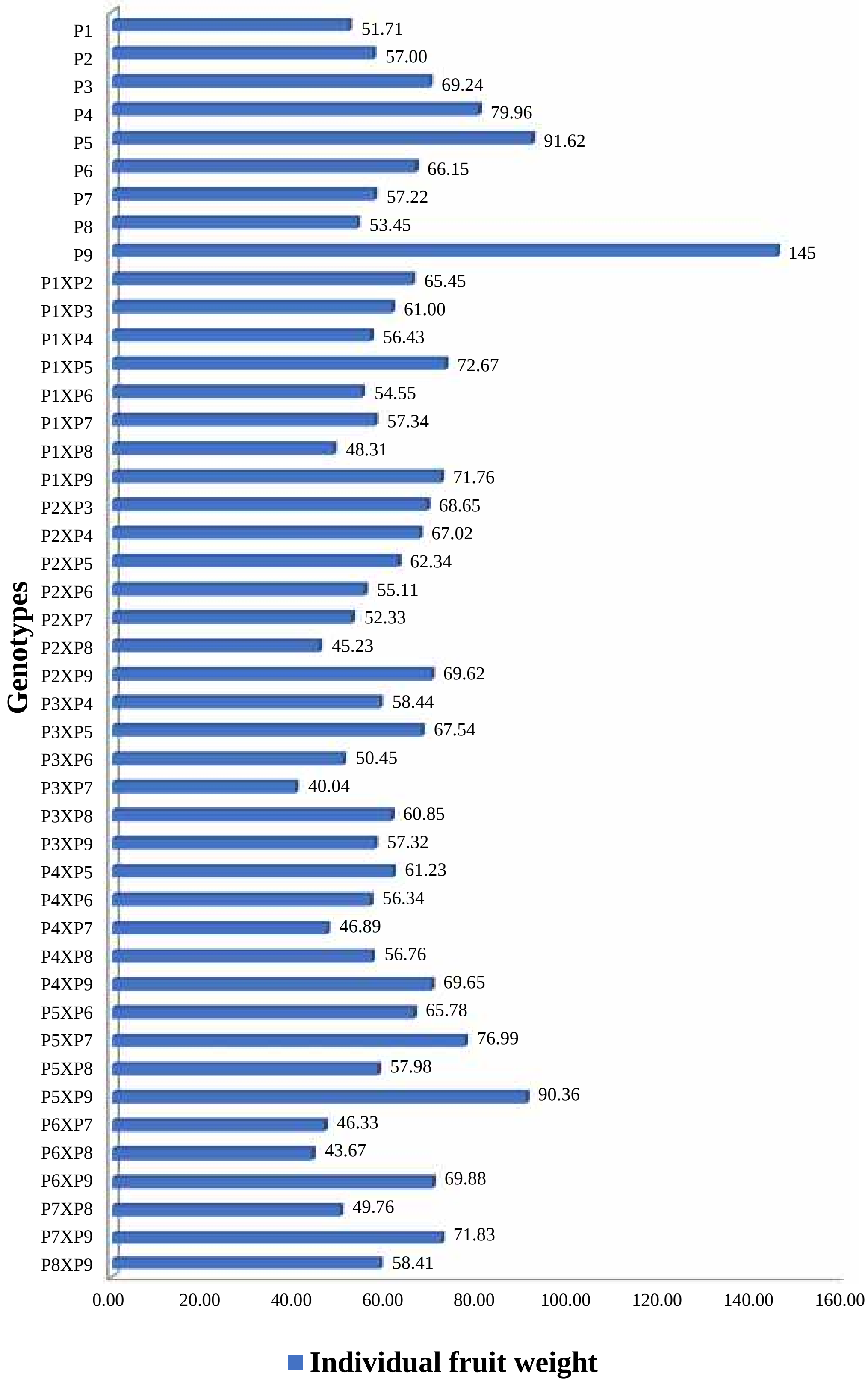


Figure 3. Individual fruit weight in 9 parents and 36 crosses of tomato.

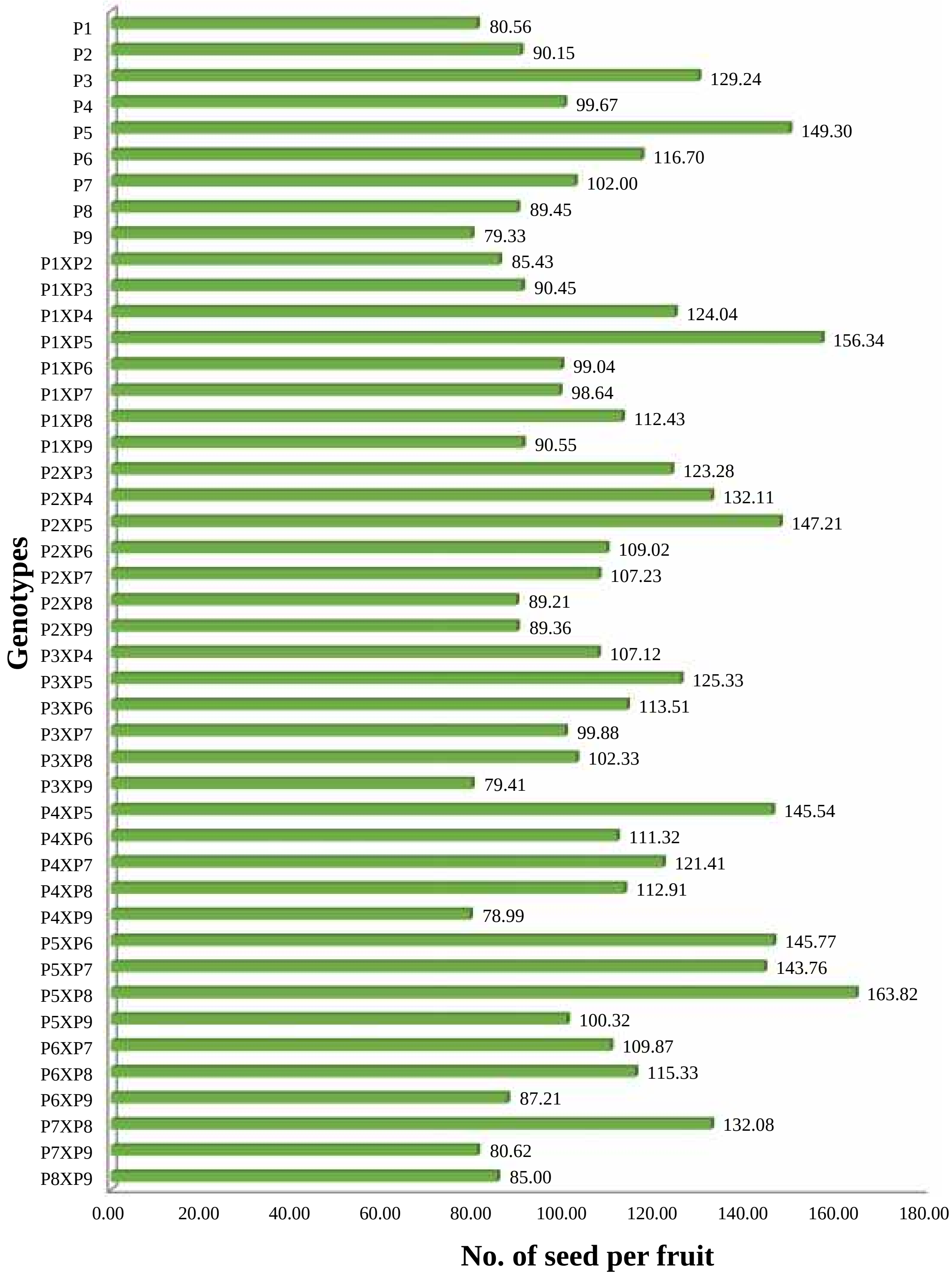


Figure 4. Number of seed per fruit in 9 parents and 36 crosses of tomato.

Table 15.3. Percent heterosis over mid parent of 36 tomato hybrids for three fruit characters

Crosses	Characters		
	Number of seed/fruit	Fruit length	Fruit breadth
$P_1 \times P_2$	0.08 ns	-7.61 **	-14.46 **
$P_1 \times P_3$	-13.78 **	-13.00 **	14.50 **
$P_1 \times P_4$	37.64 **	-19.25 **	1.61 **
$P_1 \times P_5$	36.03 **	-8.99 **	13.00 **
$P_1 \times P_6$	0.41 ns	-14.24 **	2.84 **
$P_1 \times P_7$	8.06 **	3.31 **	-3.90 **
$P_1 \times P_8$	32.26 **	4.53 **	-5.10 **
$P_1 \times P_9$	13.26 **	-7.16 **	14.46 **
$P_2 \times P_3$	12.38 **	-5.15 **	8.31 **
$P_2 \times P_4$	39.19 **	-8.77 **	7.13 **
$P_2 \times P_5$	22.96 **	-9.57 **	-2.41 **
$P_2 \times P_6$	5.41 **	-6.43 **	-0.54 **
$P_2 \times$ P7	11.61 **	19.41 **	8.98 **
$P_2 \times P_8$	-0.66 ns	19.05 **	-7.57 **
$P_2 \times P_9$	5.45 **	-6.71 **	4.55 **
$P_3 \times P_4$	-6.41 **	14.07 **	14.75 **
$P_3 \times P_5$	-10.01 **	7.52 **	6.21 **
$P_3 \times P_6$	-7.69 **	-5.01 **	15.30 **
$P_3 \times P_7$	-13.61 **	10.13 **	13.61 **
$P_3 \times P_8$	-6.41 **	-4.34 **	2.56 **
$P_3 \times P_9$	-23.85 **	-6.54 **	-9.64 **
$P_4 \times P_5$	16.91 **	-0.88 **	-13.58 **
$P_4 \times P_6$	2.90 **	-9.84 **	6.49 **
$P_4 \times P_7$	20.40 **	-2.71 **	3.57 **
$P_4 \times P_8$	19.41 **	3.40 **	25.44 **
$P_4 \times P_9$	-11.74 **	6.09 **	19.62 **
$P_5 \times P_6$	9.60 **	-1.08 **	-4.06 **
$P_5 \times P_7$	14.41 **	7.51 **	16.43 **
$P_5 \times P_8$	37.23 **	-1.18 **	3.13 **
$P_5 \times P_9$	-12.25 **	-10.17 **	-11.70 **
$P_6 \times P_7$	0.48 ns	-6.57 **	-7.09 **
$P_6 \times P_8$	11.89 **	-10.47 **	10.84 **
$P_6 \times P_9$	-11.02 **	-12.42 **	-0.43 **
$P_7 \times P_8$	37.98 **	15.01 **	-6.27 **
$P_7 \times P_9$	-11.08 **	4.40 **	3.53 **
$P_8 \times P_9$	0.72 ns	0.35 ns	-15.61 **
Heterosis mean	**7.45**	**-1.7**	**3.18**

*Significant at 5% level of probability ns = non-significant

** Significant at 1% level of probability

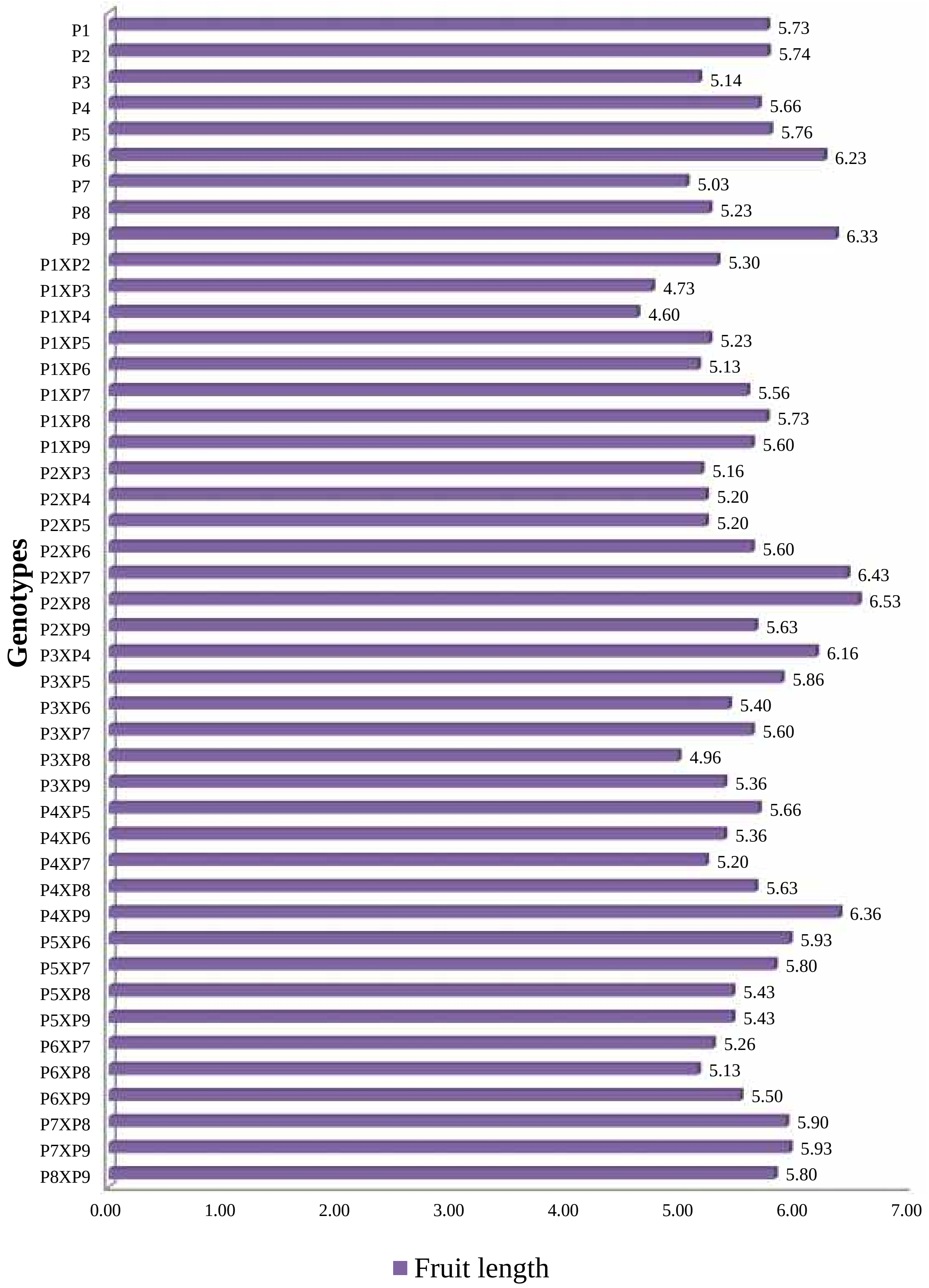


Figure 5. Fruit length of 9 parents and 36 crosses of tomato

4.3.9. Fruit length

The heterotic effect of fruit length revealed that 20 cross combination out of 36 showed positive heterosis over mid parent, among them 16 cross combination showed significant positive heterosis (Table 15.3).Range of mid parent heterosis was -19.25 to 68.83 percent. Figure 5. showed fruit length. The highest negative heterosis effect was observed in cross P_1 × P_4 (-19.25). The highest positive heterosis effect was observed in the cross P_2 × P_7 (19.41) for fruit length trait.

4.3.10. Fruit breadth (cm)

In the case of fruit breadth, 22 crosses exhibited significant positive mid parent heterosis, rest of the cross combinations showed negative heterosis (Table 15.3).Range of mid parent heterosis was -15.61 to 25.44 percent. The highest negative heterosis effect was observed in cross P_8 × P_9 (-15.61 %). The highest positive heterosis effect was observed in the cross P_4 × P_8 (25.44 %) for Fruit breadth (cm) trait. Heterosis for Fruit breadth (cm) also reported by Chaudhury and Khanna (1972), Susic (1998) and Wang *et al.* (1998b).

4.3.11. Number of locules per fruit

Out of 36 cross combinations 13 showed positive heterosis over mid parent, on them 12 cross combination showed significant positive heterosis (Table 15.4.). Range of mid parent heterosis was -45.45 to 68.83 percent. The highest negative heterosis effect was observed in cross P_3 × P_4 (-45.45 %). The highest positive heterosis effect was observed in the cross P_1 × P_6 (68.83%) for number of locules per fruit trait. Kurian and Peter (2001) also identified heterotic hybrids for locule number in tomato.

4.3.12. Pericurp thickness (mm)

In the case of Pericurp thickness (mm), only five crosses exhibited significant positive mid parent heterosis, rest of the cross combinations showed negative heterosis (Table 15.4). Range of mid parent heterosis was confined as -46.32 to 3.90 percent, that indicated non-additive gene action is prominent than additive gene action. The highest

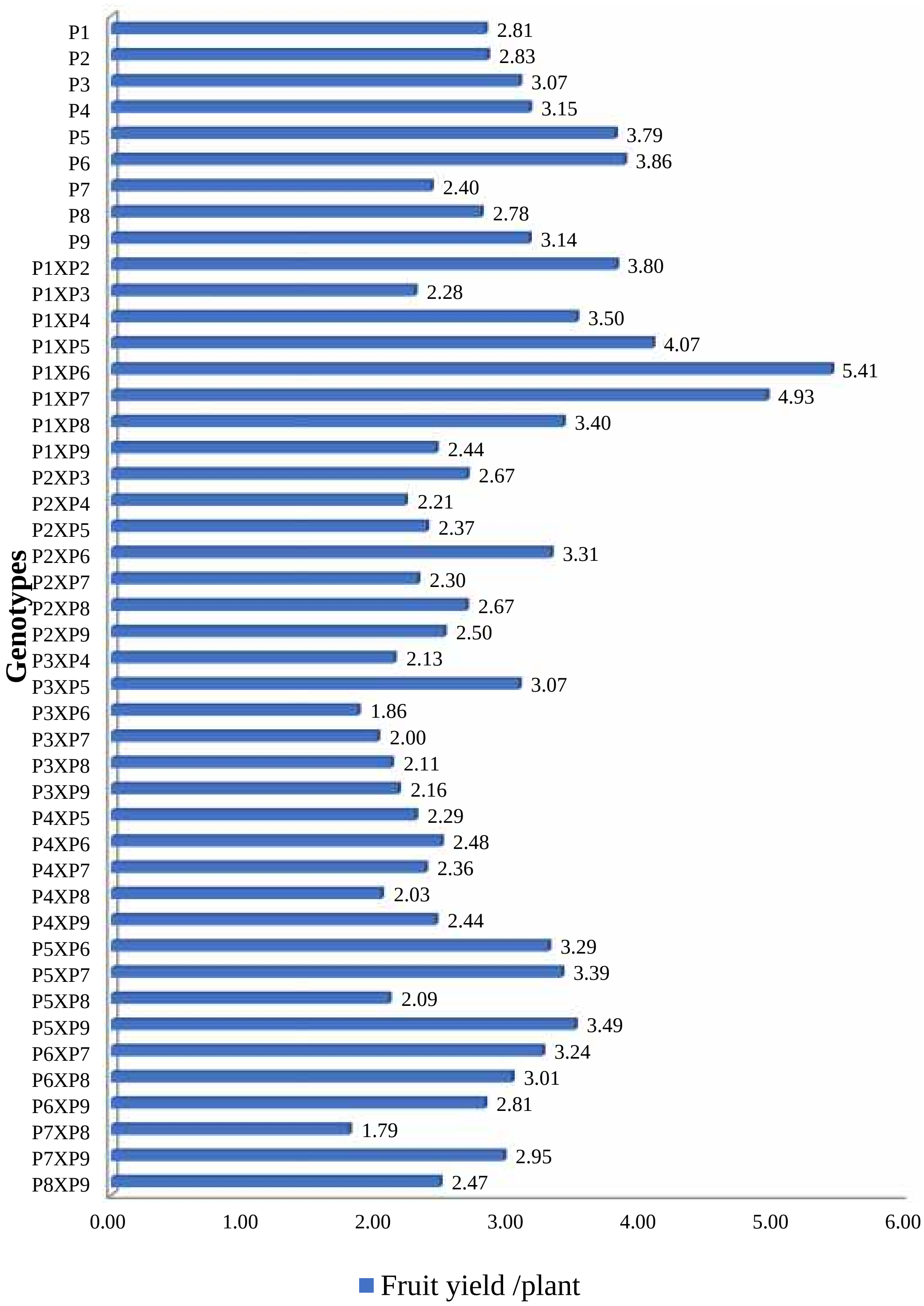


Figure 6. Fruit yield per plant in 9 parents and 36 crosses of tomato

negative heterosis effect was observed in both crosses P_1 × P_3 and P_1 × P_6 (-46.32%). The highest positive heterosis effect was observed in the cross P_1 × P_5 (3.90 %) for Pericurp thickness trait. Ahmad (2000) observed positive heterosis for this trait.

4.3.13. TSS%

The heterotic results indicated that all the cross combinations showed insignificant heterosis.

Table 15.4 Percent heterosis over mid parent of 36 tomato hybrids for three fruit characters.

Crosses	Characters		
	Number of locules	Pericurp thickness (mm)	TSS%
$P_1 \times P_2$	-20.00 **	-28.57 **	-37.98 ns
$P_1 \times P_3$	10.23 **	-46.32 **	-39.02 ns
$P_1 \times P_4$	13.98 **	-38.42 **	-33.75 ns
$P_1 \times P_5$	20.31 **	3.90 **	-34.38 ns
$P_1 \times P_6$	68.83 **	-46.32 **	-5.36 ns
$P_1 \times P_7$	-20.00 **	-14.74 **	-40.98 ns
$P_1 \times P_8$	20.00 **	-19.47 **	-19.73 ns
$P_1 \times P_9$	39.89 **	-7.80 **	1.25 ns
$P_2 \times P_3$	-3.47 ns	2.23 **	-17.22 ns
$P_2 \times P_4$	-12.92 **	-11.17 **	-36.54 ns
$P_2 \times P_5$	7.38 **	-13.40 **	-37.11 ns
$P_2 \times P_6$	60.00 **	-22.91 **	-41.98 ns
$P_2 \times P_7$	-33.33 **	-2.79 **	-24.74 ns
$P_2 \times P_8$	0.00 ns	2.23 **	-42.47 ns
$P_2 \times P_9$	30.67 **	3.61 **	-3.29 ns
$P_3 \times P_4$	-45.45 **	-3.33 **	-46.43 ns
$P_3 \times P_5$	1.35 ns	-29.23 **	-38.05 ns
$P_3 \times P_6$	14.27 **	-1.67 **	-10.71 ns
$P_3 \times P_7$	-27.68 **	-28.33 **	-35.19 ns
$P_3 \times P_8$	-2.85 ns	-13.33 **	-22.64 ns
$P_3 \times P_9$	26.50 **	3.08 **	-4.85 ns
$P_4 \times P_5$	-23.02 **	-35.38 **	-23.08 ns
$P_4 \times P_6$	1.87 ns	-13.33 **	-31.03 ns
$P_4 \times P_7$	-41.94 **	-6.67 **	-25.00 ns
$P_4 \times P_8$	-34.69 **	-18.33 **	-27.27 ns
$P_4 \times P_9$	-9.14 **	-10.77 **	-26.67 ns
$P_5 \times P_6$	3.57 ns	-24.62 **	-23.08 ns
$P_5 \times P_7$	7.38 **	-27.69 **	-29.20 ns
$P_5 \times P_8$	-19.46 **	-21.54 **	-24.32 ns
$P_5 \times P_9$	23.01 **	-24.29 **	-27.34 ns
$P_6 \times P_7$	-20.00 **	-21.67 **	-28.57 ns
$P_6 \times P_8$	20.00 **	-25.00 **	-41.82 ns
$P_6 \times P_9$	-41.80 **	-3.08 **	-12.01 ns
$P_7 \times P_8$	-23.00 **	-28.33 **	-24.53 ns
$P_7 \times P_9$	33.21 **	-6.15 **	-4.85 ns
$P_8 \times P_9$	25.36 **	-13.85 **	-4.85 ns
Heterosis mean	1.36	-16.48	-17.20

*Significant at 5% level of probability ns = not significant

** Significant at 1% level of probability

Parent P_1 **Parent P_2**

Parent P_3 **Parent P_4**

Plate 1.1. Photograph showing Tomato plants of different parents (P_1 –P_4) at fruiting stage

Parent P_5

Parent P_6

Parent P_7

Parent P_8

Parent P_9

Plate 1.2. Photograph showing Tomato plants of different parents (P_5 – P_9) at fruiting stage

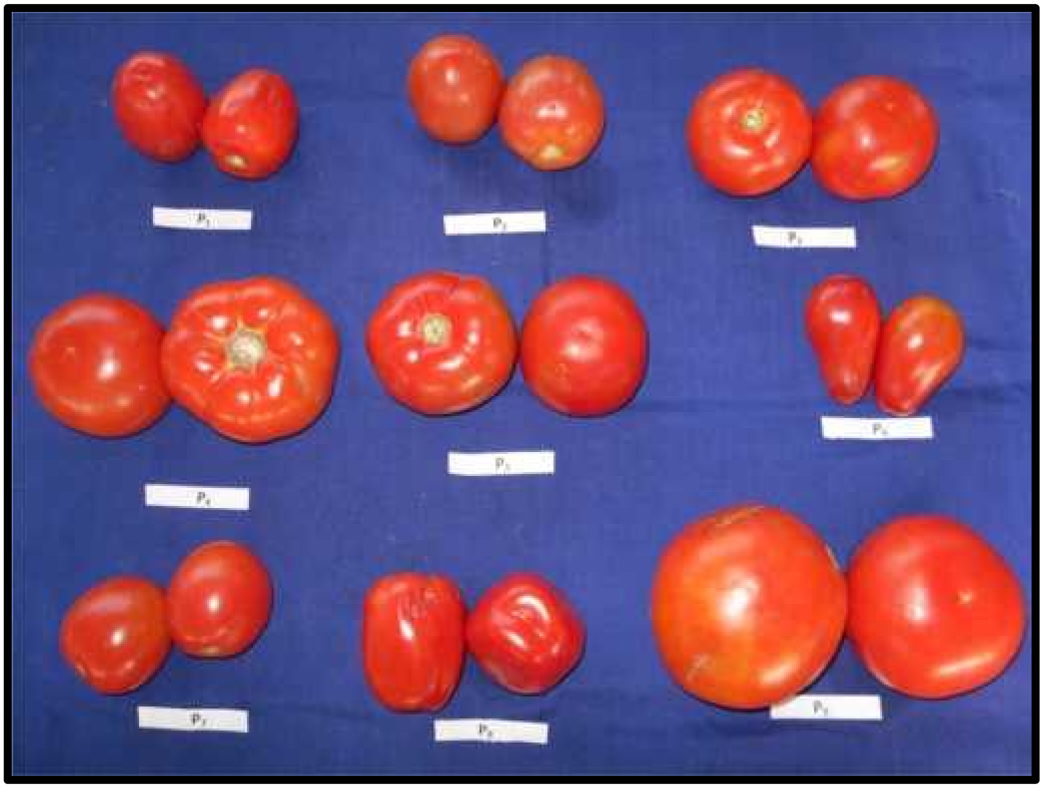


Plate 2. Photographs showing fruits in nine parents which were used in the study

$P_1 \times P_5$

$P_1 \times P_6$

$P_2 \times P_5$

$P_2 \times P_8$

Plate 3.1. Photographs showing tomato plants of the cross combinations of some selected crops at fruit bearing stage

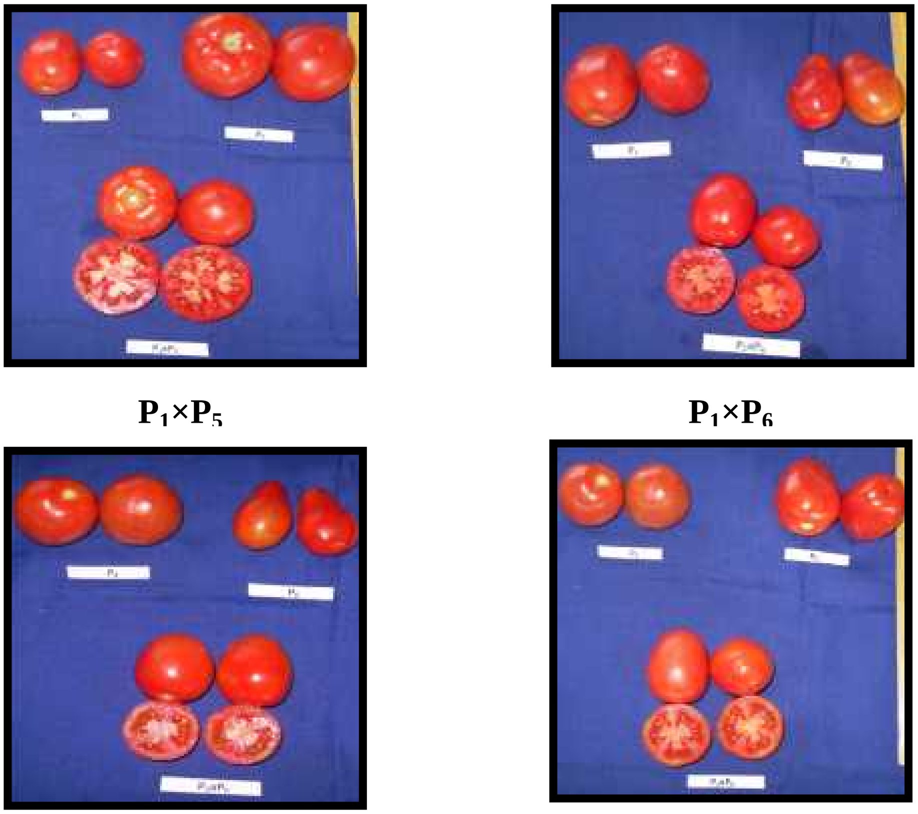
$P_4 \times P_8$

$P_5 \times P_7$

$P_6 \times P_9$

$P_7 \times P_8$

Plate 3.2. Photographs showing tomato plants of the cross combinations of some selected crops at fruit bearing stage



$P_1 \times P_5$

$P_1 \times P_6$

$P_2 \times P_5$

$P_2 \times P_8$

Plate 4.1. Photographs showing fruits of some selected crosses

$P_4 \times P_8$

$P_5 \times P_7$

$P_6 \times P_9$

$P_7 \times P_8$

Plate 4.2. Photographs showing fruits of some selected crosses

CHAPTER V

SUMMARY AND CONCLUSION

5.1. Summary

An investigation was carried out to study the combining ability and heterosis in tomato during winter season of 2013-2014 at the experimental field of Olericulture Division, Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Using 36 cross combinations involving nine parents combining ability, nature of gene action and heterotic performance for eleven parameters were evaluated.

The mean square of GCA and SCA were highly significant for all the characters indicating that additive and non- additive types of gene actions were involved for the expression of these traits. The relative proportion of additive to non-additive components suggested preponderance of additive gene expression of plant height at last harvest, fruit breadth. but rest of the characters days to 1st flower, days to 50% flowering, number of cluster per plant, days to first harvest, number of fruits per plant, harvest duration, individual fruit weight, yield per plant, fruit length, fruit breadth, TSS%, locules per plant, pericurp thickness, number of seed per fruit non-additive gene effects were found more prominent.

The parents P_2, P_5, P_8 and P_9 were good general combiner early flowering. The P_9 was good general combiner for plant height at last harvest, number of flower cluster per plant, fruit length, pericurp thickness and TSS%. The P_9, P_5 both were identified as good combiners for individual fruit weight and number of locules per fruit. Also the parent P_5 is also good general combiner for seed per fruit. Parent P_9, P_5 and P_4 were good general combiner for fruit breadth. The parent P_6 was the best general combiner for number of fruits per plant and fruit yield per plant. Considering all these traits the parents P_9, P_5 and P_6 could be used in a hybridization programme to improvement those characters by simple selection in segregating generations.

The highest SCA effect was observed in the cross combination $P_7 \times P_8$ followed by $P_1 \times P_9$ and $P_6 \times P_9$, $P_5 \times P_8$, for earliness; $P_8 \times P_9$ for the highest plant height at last harvest; $P_7 \times P_9$ for number of flower per cluster; $P_6 \times P_9$ number of fruits per plant; $P_5 \times P_7$ for improvement of individual fruit weight; $P_5 \times P_8$ for number of seed per fruit; $P_2 \times P_8$ for fruit length; $P_4 \times P_8$ for fruit breadth; $P_2 \times P_6$ for number of locules; $P_1 \times P_5$ and $P_3 \times P_6$ for increasing Pericurp thickness (mm); $P_8 \times P_9$ for TSS% and $P_1 \times P_6$ and $P_1 \times P_7$ fruit yield per plant. Therefore earliness, higher yield and higher quality the hybrids $P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_8$, $P_4 \times P_8$ $P_5 \times P_7$, $P_6 \times P_9$, $P_7 \times P_8$ may be selected for further trial.

Heterotic responses over mid parent were calculated and significant heterosis was found. The highest significant positive heterosis over mid parent for early flowering was observed in the cross $P_7 \times P_8$ and $P_2 \times P_5$; the highest heterosis for plant height at last harvest was $P_8 \times P_9$ followed by $P_7 \times P_9$ and $P_6 \times P_9$; the highest heterosis for number of flower cluster per plant was $P_7 \times P_9$ followed by $P_6 \times P_9$ and $P_7 \times P_8$; the highest heterosis for number of fruits per plant $P_7 \times P_9$ followed by $P_6 \times P_9$ and $P_8 \times P_9$; Individual fruit weight was observed in the cross $P_1 \times P_2$ followed by $P_2 \times P_3$; the highest heterosis for number of seed per fruit in the cross $P_2 \times P_4$ followed by $P_7 \times P_8$ and $P_1 \times P_4$;the highest heterosis for fruit length in $P_2 \times P_7$ followed by $P_2 \times P_8$ and $P_7 \times P_8$; the best heterotic cross for Fruit breadth was in $P_4 \times P_9$ followed by $P_5 \times P_6$ and $P_5 \times P_8$; the highest heterosis for locules per fruit was in $P_1 \times P_6$ followed by $P_2 \times P_6$; the highest heterosis for pericurp thickness was in $P_1 \times P_5$; the highest heterosis for TSS% was found in cross $P_8 \times P_9$; the highest heterosis for fruit yield per plant was in $P_1 \times P_7$ followed by $P_1 \times P_6$. Cross combination $P_1 \times P_6$ showed the highest heterotic effects for two characters.\

5.2. Conclusion

From result of the present investigation, the following conclusion may be drawn.

- Genetic analysis involving 9 × 9 half-diallel cross indicated that both additive and non-additive gene actions are important in governing yield. Its attributing components and quality indicating the possibility of improving the crop by direct selection of individual plant as by selective mating.

- The parent P_9 was the best general combiner for plant height at last harvest number of flower cluster per plant, fruit length, and fruit breadth, number of locules and pericurp thickness. Parent P_5 was best general combiner for individual fruit weight, number of seed per fruit. Parent P_6 was best for number of fruit per plant, parent P_2 and P_8 were best general combiner for earliness and parent P_1 was best for fruit yield per plant.

- The cross combinations $P_7 \times P_8$ and $P_1 \times P_9$ showed highest SCA effect for earliness; $P_8 \times P_9$ for highest plant height at last harvest; $P_7 \times P_9$ for number of flower per cluster; $P_6 \times P_9$ number of fruits per plant; $P_5 \times P_7$ for improvement of individual fruit weight; $P_5 \times P_8$ for number of seed per fruit; $P_2 \times P_8$ for fruit length; $P_4 \times P_8$ for fruit breadth; $P_2 \times P_6$ for number of locules; $P_1 \times P_5$ and $P_3 \times P_6$ for increasing Pericurp thickness (mm); $P_1 \times P_6$ and $P_1 \times P_7$ fruit yield per plant. Therefore earliness, higher yield and higher quality the hybrids $P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_8$, $P_4 \times P_8$, $P_5 \times P_7$, $P_6 \times P_9$, $P_7 \times P_8$ may be selected for further trial.

- Considering heterosis over mid some of the important characters are earliness, fruits per cluster and fruits per plant, individual fruit weight, fruit yield per plant, fruit diameter and TSS%. Both $P_7 \times P_9$ and $P_8 \times P_9$ cross combinations exhibited highest mid parent heterosis over mid parent for 2 different characters, cross combination $P_7 \times P_9$ exhibited highest heterosis over mid parent for number of flower cluster per plant and number of fruits per plant. The cross combination $P_8 \times$

P_9 showed the highest mid parent heterosis over mid parent for plant height at last harvest including early flowering.

The promising 9 crosses ($P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_8$, $P_4 \times P_8$, $P_5 \times P_7$, $P_6 \times P_9$, $P_7 \times P_8$) may be forwarded for further investigation and regional yield trial.

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APPENDICES

Appendix 1. Weather data of the experimental site during the period of October, 2013 to April, 2014

Month	Air temperature (^oC)			Relative Humidity (%)		Total Rainfall (mm)
	Maximum	Minimum	Mean	9:00 am	2:00 pm	
October	32.12	23.54	27.83	77.74	71.10	393.3
November	29.40	19.51	24.455	74.63	53.20	63.0
December	26.08	13.82	19.95	73.10	51.19	0
January	25.20	12.51	18.85	76.87	46.90	0
February	31.46	18.23	24.84	75.03	43.31	0
March	33.72	20.24	26.98	69.80	40.80	0
April	33.63	22.83	28.23	78.76	63.03	97.24

Source: Meteorological department, BARI.

Appendix 2. The results of the chemical analysis of soil sample of BARI, Joydebpur, and Gazipur

Soil properties	2014	Critical limit
Soil p^H	6.58	-
Organic matter (%)	0.75	-
Total nitrogen (%)	0.067	0.12
Available P (µg/ml)	20	14
Exchangeable K (meq/100ml)	0.19	0.2
Boron (µg/ml)	0.21	0.2

Source: Soil resources, soil survey project, Bangladesh.

Appendix 3. Analysis of variance for genotypes (parents and crosses)

Source of variation	df	Mean sum of squares			
		Days to 1st flowering	Days to 50% flowering	Plant height at last harvest	Number of flower cluster per plant
Block	2	1.274	2.230*	0.741	0.031
Genotypes	44	6.666**	15.659*	7598.864*	12.210*
Error	88	0.744	1.305	0.923	0.052

* Significant at 5% level of significant

Appendix 3. Cont'd

Source of variation	df	Mean sum of squares			
		Number of fruits/plant	Individual fruit weight (g)	Yield per plant (kg)	Number of seed/ fruit
Block	2	1.261*	0.715	0.011	3.265*
Genotypes	44	652.365*	845.337*	1.768*	1587.550*
Error	88	0.592	0.431	0.002	1.292

* Significant at 5% level of significant

Appendix 3. Cont'd

Source of variation	df	Mean sum of squares				
		Fruit length (cm)	Fruit breadth (cm)	TSS%	Locules per plant	Pericarp thickness
Block	2	0.001	0.001	16.294*	0.022	0.001
Genotypes	44	0.570*	2.695*	19.991*	4.351*	0.026
Error	88	0.001	0.001	0.001	0.010	0.000

* Significant at 5% level of significant

Appendix 4. Analysis of variance for combining ability in tomato

Source of variation	df	Mean sum of squares			
		Days to 1st flower	Days to 50% flowering	Plant height at last harvest	Number of flower cluster per plant
GCA	8	222.49**	253.85**	9890.45**	423.43**
SCA	36	109.56**	105.51**	897.96**	203.10**
Error	88	2.84	3.50	0.31	2.64*
GCA/SCA	-	0.19	0.22	1.002	0.19

* Significant at 5% level of significant

** Significant at 1% level of significant

Appendix 4. Cont'd

Source of variation	df	Mean sum of squares			
		Number of fruits/plant	Individual fruit weight (g)	Yield per plant (kg)	Number of seed/ fruit
GCA	8	4483.50 **	1291.70**	1.34	2033.81**
SCA	36	2303.54 **	488.37**	105.51**	194.82**
Error	88	12.42	4.28	0.001	0.43
GCA/SCA	-	0.1774	0.24	0.287	0.95

* Significant at 5% level of significant

** Significant at 1% level of significant

Appendix 4. Cont'd

Source of variation	df	Mean sum of squares				
		Fruit length (cm)	Fruit breadth (cm)	TSS%	Locules per plant	Pericarp thickness
GCA	8	0.2014	3.5318**	6.415**	5.3711**	0.0
SCA	36	0.1876	0.3133	6.7191**	0.5789	0.008
Error	88	0.0001	0	5.4549	0.0032	0
GCA/SCA	-	0.0976	1.0249	0.069	0.847	0.12

* Significant at 5% level of significant

** Significant at 1% level of significant

Appendix 5.1. Mean performance of three morphological characters of nine parents and 36 cross combinations of tomato

Genotypes	Days to 1st Flowering	Days to 50% flowering	Plant height at last harvest
P_1 X P_2	65.45	54.33	62.00
P_1 X P_3	61.00	53.00	88.00
P_1 X P_4	56.43	51.00	67.80
P_1 X P_5	72.67	57.00	70.00
P_1 X P_6	54.55	54.67	120.0
P_1 X P_7	57.34	55.00	65.60
P_1 X P_8	48.31	56.00	76.00
P_1 X P_9	71.76	51.00	191.0
P_2 X P_3	68.65	52.00	75.00
P_2 X P_4	67.02	52.67	136.0
P_2 X P_5	62.34	51.67	144.0
P_2 X P_6	55.11	50.00	109.0
P_2 X P_7	52.33	50.33	86.00
P_2 X P_8	45.23	54.33	94.00
P_2 X P_9	69.62	55.33	166.0
P_3 X P_4	58.44	55.67	86.00
P_3 X P_5	67.54	52.67	183.0
P_3 X P_6	50.45	51.33	180.0
P_3 X P_7	40.04	52.67	94.00
P_3 X P_8	60.85	53.33	138.0
P_3 X P_9	57.32	55.33	178.0
P_4 X P_5	61.23	55.00	161.0
P_4 X P_6	56.34	54.67	94.00
P_4 X P_7	46.89	54.67	96.00
P_4 X P_8	56.76	54.00	103.0
P_4 X P_9	69.65	54.67	162.0
P_5 X P_6	65.78	54.00	203.0
P_5 X P_7	76.99	55.00	177.0
P_5 X P_8	57.98	53.67	184.0
P_5 X P_9	90.36	57.00	185.0
P_6 X P_7	46.33	52.33	139.6
P_6 X P_8	43.67	51.33	164.0
P_6 X P_9	69.88	52.67	251.7
P_7 X P_8	49.76	53.33	71.67
P_7 X P_9	71.83	55.00	215.7
P_8 X P_9	58.41	54.00	231.3
P_1	51.71	55.67	108.0
P_2	57.00	58.00	124.4
P_3	69.24	56.67	98.50
P_4	79.96	58.67	104.4
P_5	91.62	60.00	190.0
P_6	66.15	55.33	194.0
P_7	57.22	54.33	115.8
P_8	53.45	58.00	113.6
P_9	145.0	58.00	182.0
CV (%)	**1.85**	**2.10**	**0.71**

Appendix 5.2. Mean performance of three morphological characters of nine parents and 36 cross combinations of tomato

Genotypes	Number of Flowers Cluster per Plant	Number of Fruits per Plant	Individual fruit weight (gm)	Fruit yield /plant
P_1 X P_2	11.40	58.00	65.45	3.80
P_1 X P_3	13.60	37.40	61.00	2.28
P_1 X P_4	13.40	62.00	56.43	3.50
P_1 X P_5	15.20	56.00	72.67	4.07
P_1 X P_6	14.20	99.27	54.55	5.41
P_1 X P_7	9.000	86.00	57.34	4.93
P_1 X P_8	8.400	70.33	48.31	3.39
P_1 X P_9	13.80	34.00	71.76	2.44
P_2 X P_3	13.20	38.93	68.65	2.67
P_2 X P_4	9.000	33.00	67.02	2.21
P_2 X P_5	14.00	38.00	62.34	2.37
P_2 X P_6	13.00	60.00	55.11	3.31
P_2 X P_7	14.00	44.00	52.33	2.30
P_2 X P_8	14.40	59.00	45.23	2.67
P_2 X P_9	14.00	35.93	69.62	2.50
P_3 X P_4	7.600	36.40	58.44	2.13
P_3 X P_5	13.60	45.40	67.54	3.07
P_3 X P_6	11.00	36.80	50.45	1.86
P_3 X P_7	13.80	50.00	40.04	2.00
P_3 X P_8	7.800	34.60	60.85	2.11
P_3 X P_9	10.60	37.67	57.32	2.16
P_4 X P_5	9.800	37.33	61.23	2.28
P_4 X P_6	13.20	44.00	56.34	2.48
P_4 X P_7	13.60	50.33	46.89	2.35
P_4 X P_8	14.00	35.80	56.76	2.03
P_4 X P_9	13.60	35.00	69.65	2.44
P_5 X P_6	13.80	50.00	65.78	3.29
P_5 X P_7	10.60	44.00	76.99	3.39
P_5 X P_8	13.07	36.03	57.98	2.09
P_5 X P_9	11.37	38.60	90.36	3.49
P_6 X P_7	14.00	70.00	46.33	3.24
P_6 X P_8	12.00	69.00	43.67	3.01
P_6 X P_9	11.80	40.17	69.88	2.81
P_7 X P_8	10.00	35.98	49.76	1.79
P_7 X P_9	12.54	41.09	71.83	2.95
P_8 X P_9	13.34	42.33	58.41	2.47
P_1	10.40	55.67	51.71	2.81
P_2	12.60	49.67	57.00	2.83
P_3	12.40	44.33	69.24	3.07
P_4	13.20	39.33	79.96	3.14
P_5	12.20	41.33	91.62	3.78
P_6	9.12	58.33	66.15	3.86
P_7	8.30	42.00	57.22	2.40
P_8	12.80	52.00	53.45	2.78
P_9	12.20	21.67	145.0	3.14
CV (%)	**1.89**	**1.63**	**1.04**	**1.69**

Appendix 5.3. Mean performance of three morphological characters of nine parents and 36 cross combinations of tomato

Genotypes	Number of seed per fruit	Fruit Length	Fruit Breadth
P_1 X P_2	85.43	5.30	4.16
P_1 X P_3	90.45	4.73	5.70
P_1 X P_4	124.0	4.60	5.46
P_1 X P_5	156.3	5.23	6.36
P_1 X P_6	99.04	5.13	4.40
P_1 X P_7	98.64	5.56	4.40
P_1 X P_8	112.4	5.73	4.53
P_1 X P_9	90.55	5.60	6.86
P_2 X P_3	123.3	5.16	5.80
P_2 X P_4	132.1	5.20	6.16
P_2 X P_5	147.2	5.20	5.86
P_2 X P_6	109.0	5.60	4.63
P_2 X P_7	107.2	6.43	5.40
P_2 X P_8	89.21	6.53	4.76
P_2 X P_9	89.36	5.63	6.66
P_3 X P_4	107.1	6.16	6.73
P_3 X P_5	125.3	5.86	6.50
P_3 X P_6	113.5	5.40	5.50
P_3 X P_7	99.88	5.60	5.76
P_3 X P_8	102.3	4.96	5.40
P_3 X P_9	79.41	5.36	5.86
P_4 X P_5	145.5	5.66	5.63
P_4 X P_6	111.3	5.36	5.50
P_4 X P_7	121.4	5.20	5.66
P_4 X P_8	112.9	5.63	7.10
P_4 X P_9	78.99	6.36	8.23
P_5 X P_6	145.8	5.93	5.20
P_5 X P_7	143.8	5.80	6.66
P_5 X P_8	163.8	5.43	6.10
P_5 X P_9	100.3	5.43	6.30
P_6 X P_7	109.9	5.26	4.06
P_6 X P_8	115.3	5.13	5.06
P_6 X P_9	87.21	5.50	5.76
P_7 X P_8	132.1	5.90	4.56
P_7 X P_9	80.62	5.93	6.30
P_8 X P_9	85.00	5.80	5.30
P_1	80.56	5.73	4.48
P_2	90.15	5.74	5.24
P_3	129.2	5.14	5.47
P_4	99.67	5.66	6.26
P_5	149.3	5.76	6.77
P_6	116.7	6.23	4.07
P_7	102.0	5.03	4.67
P_8	89.45	5.23	5.06
P_9	79.33	6.33	7.50
CV (%)	**1.03**	**0.29**	**0.17**

Appendix 5.4. Mean performance of three morphological characters of nine parents and 36 cross combinations of tomato

Genotypes	Number of Locules	Pericurp Thickness (cm)	TSS%
P_1 X P_2	2.00	0.45	3.10
P_1 X P_3	3.00	0.34	3.10
P_1 X P_4	3.35	0.39	3.50
P_1 X P_5	3.88	0.71	3.50
P_1 X P_6	3.37	0.34	5.00
P_1 X P_7	2.00	0.54	3.00
P_1 X P_8	3.00	0.51	4.00
P_1 X P_9	5.36	0.63	5.00
P_2 X P_3	3.11	0.61	4.40
P_2 X P_4	3.00	0.53	3.50
P_2 X P_5	4.00	0.56	3.50
P_2 X P_6	4.00	0.46	3.20
P_2 X P_7	2.00	0.58	4.00
P_2 X P_8	3.00	0.61	3.00
P_2 X P_9	5.66	0.67	5.00
P_3 X P_4	2.00	0.58	3.00
P_3 X P_5	4.00	0.46	3.50
P_3 X P_6	3.11	0.59	5.00
P_3 X P_7	2.33	0.43	3.50
P_3 X P_8	3.13	0.52	4.10
P_3 X P_9	5.76	0.67	5.00
P_4 X P_5	3.21	0.42	4.50
P_4 X P_6	3.00	0.52	4.00
P_4 X P_7	2.00	0.56	4.20
P_4 X P_8	2.25	0.49	4.00
P_4 X P_9	4.34	0.58	4.00
P_5 X P_6	3.34	0.49	4.50
P_5 X P_7	4.00	0.47	4.00
P_5 X P_8	3.00	0.51	4.20
P_5 X P_9	6.220	0.53	4.00
P_6 X P_7	2.00	0.47	4.00
P_6 X P_8	3.00	0.45	3.20
P_6 X P_9	2.23	0.63	4.80
P_7 X P_8	2.31	0.43	4.00
P_7 X P_9	5.77	0.61	5.00
P_8 X P_9	5.43	0.56	5.00
P_1	2.00	0.67	4.76
P_2	3.00	0.59	5.23
P_3	3.44	0.60	5.40
P_4	3.89	0.60	5.80
P_5	4.45	0.70	5.90
P_6	2.00	0.60	5.80
P_7	3.00	0.60	5.40
P_8	3.00	0.60	5.20
P_9	5.66	0.70	5.11
CV (%)	**2.87**	**0.80**	**0.40**