STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO (*Lycopersicon esculentum* Mill.)

A Thesis

By

MD. SALEH AHMED

REG NO: 25301/00402

A Thesis

Submitted to the Faculty of Agriculture,

Sher-e-Bangla Agricultural University, Dhaka,

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

IN

HORTICULTURE

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JUNE, 2006

CERTIFICATE

This is to certify that the thesis entitled **"STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO (*Lycopersicon esculentum* Mill.)"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in HORTICULTURE** embodies the result of a piece of *bonafide* research work carried out by **Md. Saleh Ahmed, Registration No. 25301 / 00402,** under my supervision and guidance. No part of this thesis has been submitted for any other degree in any other institutions.

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

Dated:

Joydebpur, Bangladesh

Dr. Shahabuddin Ahmad
Principal Scientific Officer
Horticulture Research Centre
Bangladesh Agricultural Research Institute (BARI)
Supervisor

Dedicated to
All of My
Teachers

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ABSTRACT

STUDY ON COMBINING ABILITY AND HETEROSIS IN TOMATO (*Lycopersicon esculentum* Mill.)

By

MD. SALEH AHMED

To asses the combining ability a genetically diverse seven parent diallel set (without reciprocal) of tomato (*Lycopersicon esculentum* Mill.) was grown in order to reveal the nature and magnitude of various gene action involved and test the percent heterosis in the expression of yield and its components.

Both General Combining Ability (GCA) and Specific Combining Ability (SCA) were estimated for eleven morphological and reproductive characters. The variances due to GCA and SCA were highly significant for almost all the characters indicating the predominance of both additive and non-additive gene actions. The parent P3 appeared as the best general combiner for early flowering, fruits per cluster and fruits per plant, P7 for plant height at 50% flowering, fruits per cluster, fruits per plant, individual fruit weight, yield per plant and brix%, P1 for plant height at 50% flowering, plant height at last harvest, individual fruit weight, fruit breath, brix% and locules per plant and P2 for individual fruit weight, yield per plant, fruit length, fruit breath and locules per plant. The cross combinations P3xP6, P1xP3 and P3xP7 were the superior for earliness as these showed significant negative SCA effects, P2xP6, P4xP7 and P6xP7 for fruits per cluster, P4xP7, P2xP7, P2xP6 and P3xP5 for fruits per plant, P1xP7, P1xP2, P3xP7 and P3xP6 for individual fruit weight, P4xP7 and P2xP6 for yield per plant, P1xP7 and P3xP6 for brix%.

Considerable heterosis over the better parent was found in a number of characters in many hybrids. Highest significant positive heterobeltosis for fruits per cluster was observed in the cross P4xP6 (23.73%), for fruits per plant cross P4xP7 (83.88%), for individual fruit weight cross P1xP7 (16.67%), for fruit yield per plant cross P4xP7 (62.31%) and for brix% highest heterosis was observed in the cross P1xP7 (31.89%).

CHAPTER I

INTRODUCTION

Tomato is used as vegetable worldwide. It is a very popular and important vegetable in the world. Tomato (*Lycopersicon esculentum* Mill.) is under Solanaceae family. Its chromosome no. 2n = 24 (Jenkins, 1948). Usually it is found to be a self- fertilized annual crop. The Genus *Lycopersicon* is derived from a Greek word meaning wolf's peach. There are nine species of this genus. Among them only two are cultivated. They are *Lycopersicon esculentum* (common tomato) and *Lycopersicon pimpinellifolium*.

Specialists considered that tomato has originated in the new world (The America) i.e., the Andean region which includes part of Bolivia, Chili, Colombia, Ecuador and Peru. It is evident that tomato was originally domesticated in Mexico (Jenkins, 1948) because of its diversity of cultivated type, culinary uses as well as its abundance of native names of the tomato fruits. Tomato gradually spread from its native land to European countries and rest of the world (Heisar, 1969). Wild cultivars of tomato were found in the tropical rain forests of South America as well as in the arid regions of the native Mexico. So, it is clear that tomato is an introduced crop in Bangladesh.

With the passage of time, tomato is considered as the most important and popular vegetable in Bangladesh for its good taste as well as nutritional value. Because of its diversified use, the area and production is increasing day by day. A wide range of latitude, soil types and methods of cultivation is suitable for tomato production. A night temperature of 15°C to 20°C ensures optimum fruit setting (Charles and Harris, 1972; Verkerk, 1955; Schiable, 1962). So, winter is preferable for tomato cultivation in Bangladesh.

We can use tomato as fresh or in processed form. Its demand is increasing day by day. In the world, it ranks is the first among of all canned vegetables (Rashid, 1999). Tomato is used as salad, soup, pickles, puree sauces, ketchup, jelly and in many other food items. Tomato improves the flavor and other characteristics of other foods.

Tomato provides us vitamin A and vitamin C. It supplies the highest amount of vitamins and minerals as we consume it both in fresh and processed conditions.

Our family's daily diets nutrition can be maintained by growing tomatoes in home garden. For farmers it is also be a good source of earning money cultivating tomatoes in a large scale for urban markets and processing industries. So, tomato production is profitable to farmers.

Combining ability is an important term for successful heterosis breeding. It helps to identify the best combiner that may be used in crosses either to exploit heterosis or to accumulate fixable genes. Breeder can easily design effective breeding plan for future upgradation of the existing materials by finding genetic architecture of various characters from combining ability. The performance of various hybrid combinations helps the breeder to obtain the genetic improvement of the existing tomato genotypes.

For improving valuable economic characters, heterosis is a basic, highly effective breeding method. The heterosis effect in tomatoes was first observed by Hedrick and Booth (1907). Subsequently, heterosis for yield and its component has been demonstrated by many workers (Wellington, 1912; Power, 1945; Larson and Currence 1944; Burdick, 1954; Daskalof *et al.*, 1967b). Larson and Currence (1944) observed that average yield of all tested F1 hybrids was 39% above the average yield of the parental lines. Power (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. The best hybrid surpassed the best market cultivar by almost 300%. In recent year heterosis and combining ability in tomato has also been reported by Singh and Singh (1993), Singh *et al.* (1995), Vidyasagar *et al.* (1997), Susic (1998), Bhatt *et al.* (2001a), Bhatt *et al.* (2001b) and many other authors. In Bangladesh Bhuiyan (1982) first time studied the heterosis and combining ability in tomato for yield and yield contributing characters. He reported better parent heterosis in fruit yield per plant up to 124.5% in the cross Fujuki x World champion.

As exotic varieties do not have good adaptability for yield potential in our climatic condition, we should have to develop our own high yielding variety. At present we have some released varieties of tomato with good yield potential. But these are all open pollinated types. More over, we also need widely adapted disease resistant as well as high yielding variety. So, utilization of hybrid vigor is the most important to meet our demand. Many countries have developed lots of high yielding varieties by exploiting hybrid vigor in tomato, but in Bangladesh such studies are still insufficient. We do not have locally developed hybrid varieties of tomato for winter season. So every year we import exotic varieties at the cost of our hard earned foreign currency.

Considering the above facts, the present study has been undertaken to generate some breeding information with the following objectives-

1. To determine the Combining Ability (GCA and SCA) of the parents used in the crosses.
2. To generate information on the nature and magnitude of some gene actions involved in the inheritance of different characters.
3. To determine the heterosis of the crossed material.

CHAPTER II

REVIEW OF LITERATURE

Throughout the world Tomato (*Lycopersicon esculentum* Mill.) is one of the most important and popular vegetable crops. Many attempts were conducted by the breeders to develop its varieties. Available information in the literature belonging to the combining ability, mode of gene action and heterosis have been reviewed and presented chronologically and character wise in this chapter.

Combining Ability

Sprague and Tatum (1942) introduced the term combining ability when they used general combining ability (GPA) 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'. To review those early studies an effort has been made on combining ability of tomato are directly related to the present investigation.

Days of 50% flowering

Ray and Syamal (1998) studied on days to fruiting in partial diallel involving seven parents in tomato. They concluded that additive gene-action involved for days to fruiting in tomato. E1-Mahdy *et al.* (1990) in a study of complete diallel of 6 lines under heat stress observed highly significant general and specific combining ability for early yield. The additive gene effects appeared more important than non-additive gene effects for the trait. Some maternal effects were detected. Each of the used parents, CL 5915-206 D4-2-5, KF1 and Peto 86 were found good general combiners for early yield. Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for days to flowering, due to less than unity of the ratio of general to specific combining ability.

Dhaliwal *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. Analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the character days to flowering. The non-additive gene effects were more pronounced for days to flowering. Bhatt *et al.* (2001b) crossed fourteen varieties of tomato in a half diallel fashion and evaluated the resulting 91 F_1s and the parents and observed that variances of general combining ability(GCA) and specific combining ability (SCA) were significant for days to first harvest. Results showed the predominance of non-additive gene action. Sweet-72 exhibited highly significant negative GCA for early maturity. Punjab chhuhara was a good combiner and gave the highest per se value for earliness. Arka Saurabh x NDT3 showed the highest negative SCA for earliness. Shrivastava *et al.* (1993) collected information on combining ability from 9 cultivars and their F1 and F2 hybrids and found that Pusa Ruby X Money Maker was best combination for earliness.

Chadha *et al.* (1997) studied combining ability of tomatoes in a set of eight determinate lines X three indeterminate testers and found that line Sonali was good general combiners for days to 50% flowering. Out of the 24 F1s studied, one cross-combination was found to be good specific combiner for days to 50% flowering. Ahmad (2002) using a diallel cross of 8x8 excluding reciprocals observed highly significant GCA and SCA effects for two different sowing (May sowing and July sowing) for days to 50% flowering. He reported highest significant negative GCA effect in the parent TM026 in first sowing (-1.36) and second sowing (-0.57) and largest negative SCA values in the crosses TM051 x TM017, TM053 x TM026, TM025 x TM041, TM025xTM044.

Ghosh *et al.* (1996) from a 9 x 9 diallel cross and graphical analysis of tomato reported the partial dominance for days to first flowering. Perera and Liyanaarachchi (1993) in a 13 x 13 half diallel cross observed significant additive gene effects for days to flowering indicating significant differences between the parents. Brahma *et al.* (1991) in three parents and their F1, F2, BC1 and BC2 generations in 2 crosses (Jap X K7 and Jap X CT1) and reported pronounced dominance effects for days to flowering in the cross Jap X CT1.

Plant height (cm)

Ray and Syamal. (1998) studied on plant height in partial diallel involving seven parents in tomato. They concluded that non-additive gene-action for plant height involved in tomato. Bhuiyan (1982) studied on combining ability of tomato in a diallel set (without reciprocal) and observed significant GCA and SCA value for plant height indicating that both additive and non-additive gene action were involved in the inheritance of this trait. The GCA and SCA ratio was more than one, indicating that the plant height was predominantly under the additive genetic control. Among the seven parents Fujuki and Anobik showed highly significant negative GCA effect indicating that they were good combiner for dwarfness. The crosses Fujuki x CL. 8d-0-7-1-0-0, Fujuki x Japanese, 499 F.R. x World champion, 499 F.R. x Japanese, 499 F.R. x Big cherry, World champion x Big cherry, CL. 8d-0-7-1-0-0 x Japanese, and Anobik x Big cherry showed highly significant negative SCA effects. Ahmad (2002) in a 8 x 8 diallel set of tomato without reciprocal in May and July sowing and found predominance additive gene effects for this trait and highest significant positive GCA effects (24.56 and 19.37) in the parent TM017 in both the sowing. Eleven cross combinations showed significant positive SCA effects.

Shrivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for length of plant, due to less than unity of the ratio of general to specific combining ability. Bhatt *et al.* (2001b) crossed fourteen varieties of tomato in a half diallel fashion and evaluated the resulting 91 F_1s and the parents and observed that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for plant height. Results showed the predominance of non-additive gene action.

Brahma *et al.* (1991) evaluated three parents and their F1, F2, BC1 and BC2 generations in 2 crosses (Jap X K7 and Jap X CT1) and reported pronounced dominance effects for plant height in the cross Jap X CT1. Chandrasekhar and Rao (1989) evaluated F1 progenies and parental genotypes Pusa Early Dwarf, Pusa Ruby, Druzoa 1300, Topaz, Slava VF and Ogosta for GCA and SCA for plant height and reported that the variations due to GCA and SCA were significant. SCA effects were significant and positive in 6 crosses for plant height.

Fruits per cluster

Bhatt *et al.* (2001b) crossed fourteen varieties of tomato in a half diallel fashion and evaluated the resulting 91 F_1s and the parents and observed that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for fruits per truss. Results showed the predominance of non-additive gene action. Punjab Chuhara showed highly significant desirable GCA effects for fruits per truss. Pubjab chuhara was a good combiner and gave the highest per se value for fruits per truss.

Resende *et al.* (2000) in a study of diallel cross of tomato for number of frutis in the 1^{st}, 2^{nd} and 3^{rd} trusses found significant general combining ability (GCA) effects in a group of parents for fruit number in the 1^{st} and 2^{nd} trusses. Natarajan (1992) evaluated the parents and F1 hybrids from a diallel cross involving 6 homozygous lines under moisture stress and reported that additive gene action were important for number of fruits set/cluster. LE75 ranked first for this trait.

Fruits per plant

Bhatt *et al.* (2001b) crossed fourteen varieties of tomato in a half diallel fashion and evaluated the resulting 91 F_1s and the parents and observed that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for fruits per plant. Results showed the predominance of non-additive gene action. Punjab Chuhara showed highly significant desirable GCA effects for fruits per plant. Punjab chuhara was a good combiner and gave the highest per se value for fruits per plant. Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruits per plant. A predominance of variance due to GCA over SCA was observed for fruits per plant indicating that additive gene action plays an important role in inheritance of these characters.

Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for number of fruits, due to less than unity of the ratio of general to specific combining ability. Bhutani and Kalloo (1988) in an eight parent's diallel set of 28 F1 and 28 F2 evaluated for genetical studies for number of fruits in tomato. From the study they concluded that non-additive type of gene actions were involved for the control of number of fruits in tomato (*Lycopersicon esculentum* Mill.) as evidence by combining ability analysis, component analysis and graphical analysis.

Natarajan (1992) evaluated information on combining ability in the parents and F1 hybrids from a diallel cross involving 6 homozygous lines under moisture stress and reported that both additive and non-additive gene action were important for the number of fruits/plant. LE76 was the best combiner for number of fruits/plant. Dhaliwal *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. Analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the character marketable fruit number, total fruit number. The non-additive gene effects were more pronounced for marketable fruit number, total fruit number.

Chadha *et al.* (1997) studied combining ability of tomatoes in a set of eight determinate lines X three indeterminate testers and found that lines BWR-5 (HR), LE79-5 (W) and EC 129156 were good general combiners for marketable fruits/plant. Out of the 24 F_1s studied, four for marketable fruits/plant showed significant positive SCA effects. Bhuiyan (1982) studied on combining ability of tomato in a diallel set (without reciprocal) and found that mean squares of number of fruits per plant due to both general combining ability and specific combining ability was highly significant indicating that both additive and non-additive gene actions were responsible for the character number of fruits per plant. Parent Big cherry showed highly significant value indicating that it was best general combiner, where the cross Fujuki x CL. 8d-0-7-1-0-0 was the best positive specific combiner.

Ahmad (2002) reported highest significant GCA effects in the parents TM051 (12.44 and 11.03) for May and July sowing. He also found that eleven combinations in both the sowings showed highly significant positive SCA values. 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 all hybrids with Roma VFN as one of parents showed high SCA for total number of commercial fruits.

Ratan and Saini (1976) genetically analyzed a diallel set of 12 tomato lines for number of fruits per plant. In full diallel the graphical analysis indicated partial dominance for number of fruits per plant. Exploitation of non-additive genetic variation was suggested by developing F1 hybrids. Sahrigy *et al.* (1970) have reported the importance of dominance effects in the inheritance of number of fruits per plant. Brahma *et al.* (1991) evaluated three parents and their F1, F2, BC1 and BC2 generations in 2 crosses (Jap X K7 and Jap x CT1) and reported pronounced dominance effects for fruits/plant in the cross Jap X CT1. They also found important of additive X dominance effects for fruits/plant. In both crosses only dominance X dominance interaction was positive. Perera and Liyanaarachchi (1993) 13 X 13 half diallel cross observed significant additive gene effects for fruit number indicating significant differences between the parents. Ghosh *et al.* (1996) from a 9 X 9 diallel cross and graphical analysis of tomato reported the partial dominance for number of fruits/plant.

Average individual fruit weight (g)

Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruit weight. A predominance of variance due to GCA over SCA was observed for fruit weight indicating that additive gene action plays an important role in inheritance of these characters. Kumar *et al.* (1997) grew nine parents and their 18 F1 hybrids of tomato and reported that for average fruit weight selection is more rewarding due to the prevalence of additive gene action.

Singh *et al.* (1999) evaluated twelve tomato (*Lycopersion esculentum*) parents and their 66 F1 hybrids produced in a diallel fashion. From the combining ability, components of variation they reported the importance of both additive and non-additive gene effects for fruit weight with the magnitude of the former being greater. Bhuiyan (1982) studied on combining ability of tomato in a diallel set (without reciprocal) and found highly significant variances due to general combining and specific combing ability for individual fruit weight indicating that both additive and non-additive gene actions were involved in the expression of the character. The ratio of GCA and SCA was considerably high indicating that additive nature of genetic system was largely operative in the inheritance of fruit weight. Parent Japanese was the best general combiner showed highly significant positive GCA effects. Hybrids, Fujuki X World champion, Fujuki X CL. 8d-0-7-1-0-0, 499 F.R. X World champion ,499 F.R. x Big cherry, World champion X Big cherry, CL. 8d-0-7-1-0-0-x Japanese, CL. 8d-0-7-1-0-0 x Anobik and Japanese X Big cherry showed highly significant positive SCA effects and the highest SCA effects was recorded in World champion X Big cherry.

Dhaliwal *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. Analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the character fruit weight. The additive gene effects were more pronounced for fruit weight. Chandrasekhar and Rao (1989) evaluated F1 progenies and parental genotypes for fruit weight and reported that the variations due to GCA and SCA were significant. SCA effects were significant and positive in 8 crosses for fruit weight. Natarajan (1992) evaluated information on combining ability in the parents and F1 hybrids from a diallel cross involving 6 homozygous lines under moisture stress and reported that both additive and non-additive gene action were important for fruit weight LE76 was the best general combiner for fruit weight. Perera and Liyanaarachchi (1993) a 13 X 13 half diallel cross observed significant additive gene effects for fruit weight indicating significant differences between the parents. They also observed directional dominance effects and significant epistatic effects for fruit weight.

Ahmad (2002) Crossed a 8 x 8 diallel set of tomato with out reciprocal in May and July sowing and found highest significant positive GCA effects in both the sowing in the parent TM025 (7.03 and 7.40). Out of 28 F1's nine F1's gave significantly larger positive SCA values in both the sowing. Ghosh *et al.* (1996) from a 9 x 9 diallel cross and graphical analysis of tomato reported the partial dominance for fruit weight. Chadha *et al.* (1997) studied combining ability of tomatoes in a set of eight determine lines X three indeterminate testers and found that lines BT-10, BWR-5 (HR) and EC 191540 were good general combiners for average fruit weight. Out of the 24 F1s studied, five for average fruit weight showed significant positive SCA effects.

Yield per plant (kg)

Bhutani and Kallo (1988) reported that non-additive type of gene actions were involved for the control of yield per plant in tomato (*Lycopersicon esculentum* Mill) as evidence by combing ability analysis, component analysis and graphical analysis. Singh *et al* (1999) reported the importance of both additive and non-additive gene effects for total yield with the magnitude of the former being greater. Khalf Allah (1970) has reported that non-additive gene action was involved in the inheritance of yield.

Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for crop yield, due to less than unity of the ratio of general to specific combining ability. Bhuiyan (1982) studied on combining ability to tomato in a diallel set (without reciprocal) and found that additive and non-additive genetic components played a significant role in bringing out heterotic effects but non-additive gene action was predominance in the inheritance of fruit yield per plant. Parent Fujuki and Japanese showed significant positive GCA effects. The crosses Fujuki X World champion, Fujuki x CL. 8d-0-7-1-0-0 and Japanese x Big cherry exhibited high significant SCA effects. Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for plant yield. A predominance of variance due to SCA over GCA was observed for plant yield, indicating a role of non-additive gene action in the expression of this character. Dharmati *et al.* (1999) estimated the general combining ability (GCA) of 15 parents and specific combining ability (SCA) of 50 crosses in summer tomato using a line X tester analysis and found that GCA-SCA ratios were less than unity for fruit yield per plant, indicating the role of non-additive gene action. The parents 20/2, 20/4 and 20/6 Alcobasa were the best general combiners for fruit yield per plant. High positive and significant SCA effects for fruit yield per plant was shown by the crosses 20/6 Alcobasa X L58, 20/2 Alcobasa X L15 and 20/5 Alcobasa X N229-8MF6. They also noticed that, high heterosis was in the crosses with parents having high GCA.

Bhatt *et al.* (2001a) studied the combining ability on a 15 x 15 diallet set of tomato excluding reciprocals and found that the magnitude of variance due to general as well as specific combining ability was highly significant indicating the importance of both additive and non-additive gene action. They observed prevalence of non-additive gene effects. Cross combinations EC 818703 x EC 13042 (0.88) was the best specific combiner for yield per plant. Bhatt *et al.* (2001b) crossed fourteen varieties of tomato in a half diallel fashion and evaluated the resulting 91 F1s and the parents and observed that variances of general combining ability (GCA) and specific combining ability (SCA) were significant for yield/plant. Results indicated the predominance of non-additive gene action for yield/plant. Punjab Chuhara showed highly significant desirable GCA effects for yield per plant. The highest significant SCA effect for yield/plant was observed in the cross Punjab Chuhara x Azad Kranti.

Natarajan (1992) evaluated the parents and F1 hybirds from a diallel cross involving 6 homozygous lines under moisture stress and reported that both additive and non-additive gene action were important for yield/plant. LE76 was the best general combiner for yield. The hybirds LE75 X LE76 and LE22x LE76 produced the highest yield/plant under the stress condition. Dhaliwal *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. Analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the character total yield, whereas only non-additive gene effects seem to play a predominant role for marketable yield. The non-additive gene effects were more pronounced for total yield. Parents C 122, S 286, S 281, I 979 and

X 331 were good combiners for yield. A large number of hybrids exhibited significant specific combining ability (SCA) effects for yield. Chandrasekhar and Rao (1989) evaluated F1 progenies and parental genotypes for yield and reported that the variations due to GCA and SCA were significant. SCA effects were significant and positive in 7 crosses for yield. Pusa Early Dwarf was the best general combiner for yield. Sharma *et al.* (1999) studied the general (GCA) and specific (SCA) combining ability in tomato through line X tester analysis involving 12 lines (females) and 2 tester (males) and found that the variances due to lines and crosses were significant for yield per plant. The mean square due to testers and lines x testers was significant for yield per plant. Among parents, the lines BTL-33 and BTL-11 and tester Roma proved the best general combiners for yield. The best specific cross-combinations were BTN-46 X Roma, BTL-11 X AC-402 and BTR-49 X Roma. The best cross-combinations did not necessarily involve good general combiners as their parents. Ahmad (2002) crossed a 8 X 8 diallel set of tomato with out reciprocal in May and July sowing and found highest significant positive GCA effects in the parent TM051 (539.41 and 429.73) in two sowing. The cross combinations TM051 X TM017 exhibited highest significant and positive SCA effects. Sahrigy *et al.* (1970) have reported the importance of dominance effects in the inheritance of yield. Ghosh *et al.* (1996) from a 9 X 9 diallel cross and graphical analysis of tomato reported the partial dominance for yield/plant.

Fruit length (cm)

Susic (1998) crossed seven phenotypiclly divergent genotypes (MLS49, V100, D150, NO-10, 93/10 and R38) in a full diallel without backcross after investigating the parent and F1 hybrids. The line 93/10 characterized by greatest fruit length showed the best general combining ability (GCA). The highest specific combining ability (SCA) values for fruit length were recorded in the hybrid obtained by crossing D150 and NO-10. Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruit length. A predominance of additive gene action was observed for fruit length.

Ahmad (2002) crossed a 8 X 8 diallel set of tomato with out reciprocal in May and July sowing and found predominance of additive gene effects and highest significant positive GCA effects in the parent TM002 in both sowings (0.64 and 0.61). Six cross combinations showed significant positive SCA effects in both sowing. Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for length of fruit, due to less than unity of the ratio of general to specific combining ability.

Fruit breadth (cm)

Ahmad (2002) crossed a 8 X 8 diallel set of tomato without reciprocal in May and July sowing and found significant positive GCA effects in the parent TM025 (0.45 and 0.27) in both the sowings. He also reported that nine combinations showed significant positive SCA effects in both sowing. The graphical analysis suggested complete dominance in addition to the interaction for this trait. 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. Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male), they reported the predominance of non-additive variance for width of fruit due to less than unity of the ratio of general to specific combining ability.

Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for fruit width. A predominance of variance due to GCA over SCA was observed for fruit width, indicating that additive gene action plays an important role in inheritance of these characters. Ghosh *et al.* (1996) from a 9 X 9 diallel cross and graphical analysis of tomato reported the partial dominance for equatorial fruit diameter and polar fruit diameter.

Susic (1998) crossed seven phenotypiclly divergent genotypes (MLS49, V100, D150, NO-10, 93/10 and R38) in a full diallel without backcross after investigating the parents and F1 hybrids he reported that partial dominance was the mode of inheritance for fruit width in the F1 generation. The line 93/10 characterized by greatest fruit width showed the best general combining ability (GCA). The highest specific combining ability (SCA) values for fruit width were recorded in the hybrid obtained by crossing D150 and NO-10.

Brix%

Bhatt *et al.* (2001a) studied the combining ability on a 15 X 15 diallel set of tomato excluding reciprocals and found that the magnitude of variance due to general as well as specific combining ability was highly significant indicating the importance of both additive and non-additive gene action. They observed prevalence of non-additive gene effects. Cross combinations KS-10 x Pant T-3 (1.66) was the best specific combiners for total soluble solids. Dhaliwal *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. Analysis of variance for combining ability revealed 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 I 181 was good combiner for TSS.

Shrivastava (1998a) crossed nine superior varieties of tomato in a diallel fashion and found higher GCA and SCA ratio indicating additive gene effects in both the generations for fruit total soluble solids (TSS) suggesting their exploitation through simple breeding methods. Among parents Pusa Ruby was the best combiner for TSS (0.84, 0.70). The best specific combiner was Pusa Ruby X Money Maker for TSS.
Wang *et al.* (1998a) crossed 5 processing tomato cultivars in a complete diallel fashion and found that general combining ability (GCA) and specific combining ability (SCA) were highly significant for Soluble Solids content. A predominance of variance due to SCA over GCA was observed for soluble solids, indicating a role of non-additive gene action in the expression of this character. Kumar *et al.* (1997) grew nine parents and their 18 F1 hybrids of tomato and observed that for inheritance of processing character TSS non-additive gene action was predominant. Thus, they recommended heterosis breeding for the improvement of this character. Zhou and Xu (1990) studied Soluble Solids Content (SSC) in fruits from 20 hybrid combinations

from a 5 X 4 diallel without reciprocals and observed 74.15% GCA and 25.85% SCA variance for SSC. Singh *et al.* (1998) grew sixty-six F_1 hybrids produced in a diallel fashion and their 12 parents and suggested that both fixable and non-fixable gene effects were involved in the inheritance of total soluble solids. Ahmad (2002) crossed a 8 X 8 diallel set of tomato without reciprocal in May and July sowing and found highest significant positive GCA value (0.21 and 2.20) in the parent TM002 in tow sowings respectively. Out of 28 F_1s three cross combinations TM017 x TM044, TM017 X TM026 and TM053 X TM017 exhibited significant positive SCA values in both sowing. Ghosh *et al.* (1996) from a 9 X 9 from 9 X 9 diallel cross and graphical analysis of tomato reported the dominance for total soluble solids.

Dod *et al.* (1995) studied combining ability of tomato in a 12 parents diallel (excluding reciprocals) for TSS and found significant GCA and SCA variances indicating the importance of both additive and non-additive genetic components. The magnitude of GCA compared with SCA was higher indicating a predominant role for additive gene action. AC238, Punjab Chhuhara and Pusa Ruby were the best general combiner. E1-Madhy *et al.* (1990) in a study of compete diallel of 6 lines under heat stress observed highly significant general and specific combining ability for TSS% .The additive gene effects appeared more important than non-additive gene effects for the trait.

Locules per fruit

Dhaliwal *et al.* (2000) studied in tomato the combining ability of genetic male sterile (pollen abortive type) parents in combination with superior performing male parents. Analysis of variance for combining ability revealed that both, the additive and the non-additive gene effects governed the inheritance of the character number of locules. The additive gene effects were more pronounced for number of locules.

Singh *et al.* (1998) grew sixty-six F_1 hybrids produced in a diallel fashion and their 12 parents and suggested that both fixable and non-fixable gene effects were involved in the inheritance of locule number. Ghosh *et al.* (1996) from a 9 X 9 diallel cross and graphical analysis of tomato reported the partial dominance for number of locules/fruit. Srivastava *et al.* (1998) carried out combining ability analysis in a field experiment through line x tester method using fifteen lines (female) and three testers (male). They reported the predominance of non-additive variance for number of locules, due to less than unity of the ratio of general to specific combining ability.

Dod *et al.* (1995) studied combining ability of tomato in a 12 parent's diallel (excluding reciprocals) for numbers of locules/plant and found significant GCA and SCA variances indicating the importance of both additive and non-additive genetic components. The magnitude of GCA compared with SCA was higher indicating a predominant role for additive gene action. AC238, Punjab Chhuhara and Pusa Ruby were the best general combiner. Bhutani and Kalloo (1991) analyzed 8-parent diallel cross including 28 F1s and 28 F2s 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. They concluded that a desirable higher locule number can be brought about by simple selection.

HETEROSIS

Hetersosis in Crop Plants-Early History

The dominance of hybrids over their parents is called heterosis. It observed that hybrids often possess comparatively increased vigor from their parents (Sprague, 1983). In 1876 Darwin reviewed earlier literature and also recoded his own experiments in several crop species. 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 'harmful' (Allard, 1960).

Tested a series of hybrids between maize varieties and found that 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).

In 1900 Mendel's laws were rediscovered and drew the attention of the biological world on problems of heredity and led to renewed interest in hybrid vigor as one aspect of quantitative inheritance. Establishment of widespread understanding heterosis was laid by Shull 1908, 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, F1 yields exceeded those of the parental varieties. The term heterosis was coined by Shull and first proposed in 1914 (Hayes, 1952).

Commercial exploitation of heterosis in crop plants

The agriculture of 20^{th} century blessed by commercial utilization of heterosis plays a vital role in the breeding and development of crop hybrids, although the genetic basis of the phenomenon remained unclear (Sinha and Khanna, 1975; Mc Daniel, Rood *et al.* 1988). Probably Hayes and Jones in 1916 first suggested that hybrid vigor be exploited in vegetables (Hayes, 1952). The commercial exploitation of heterosis, however, first occurred in 1930's. The economic impact of hybrid maize was so great that by 1944 more than 80 percent of acreage in the USA was sown to hybrids, and by 1960 virtually the entire maize gown in the USA was hybrid varieties. Today, most of the world's sugar is produced by hybrid sugarcane or hybrid sugar beets. Hybrid sorghum, sunflower, tomato, cucumber, onion, capsicum, eggplant, watermelon, cabbage, cauliflower, broccoli, radish and several other horticultural and forage crops are frequently grown on a large scale. F1 hybrid eggplants were commercially used in Japan before 1952 (Kakizaki, 1930). Hybrid rice is now being grown on an increasing area in China. In short, the economic importance of hybrid varieties can be seen in Gardner's (1968) statement. Development and use of heterosis has been the most important practical achievement of genetics so far.

Occurrence of heterosis in tomato

Heterosis effect in tomatoes was first observed by Hedrick and Booth (1907). Subsequently, heterosis for yield and its component has been demonstrated by many workers (Wellington, 1912; Power, 1945; Larson and Currence 1944; Burdick, 1954; Daskalof *et al.*, 1967; Singh and Singh, 1993). 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.

Days to 50% flowering

Ahmad (2002) crossed a 8 X 8 diallel set of tomato without reciprocal in May and July sowing and found highest heterobeltiotic effects in both the sowing in the hybrid TM051 X TM017 (-21.76% and –13.43% respectively). Heterosis over better parent was also reported by Ahmed *et al.* (1988) and Singh and Singh (1993).

Vidyasagar *et al.* (1997) examined a line (8) X tester (3) of tomatoes involving bacterial wilt (*Ralstonia Solanacearum*) resistant parents and observed that 12 F1s each exhibited superiority to their respective better parents for days to 50% (early) flowering. Kumar *et al.* (1995a) studied on seven tomato lines, their 21 F1s and three commercial hybrid standards and observed greatest heterosis over superior parents for early yield (41.6%). Jamwal *et al.* (1984) crossed 10 foreign lines and 3 local testers and observed heterosis.

Plant height (cm)

Ahmad (2002) found highest heterosis over better parent in the cross TM026X TM025 which were 32.24% and 26.90% respectively for May and July sowing. Similar result was also reported by Ahmed *et al.* (1988). Kumar *et al.* (1995b) studied on seven tomato lines, their 21 F1s and three commercial hybrids showed greatest heterosis (%) over superior parents for plant height (24.54). Dod *et al.* (1992) and Bhatt *et al.* (1999) from diallel cross observed pronounced heterosis for plant height.

Bhuiyan (1982) studied on heterosis of tomato in a 7X7 diallel set (without reciprocal) and found maximum – 45.40 per cent heterosis for plant height in the cross Japanese X Anobik over parental value.

Fruits per cluster

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 truss.

Bhatt *et al.* (1999) evaluated ninety-one F1 crosses of tomato in a diallel set involving 14 percents (excluding reciprocals) to study heterosis for number of fruit/truss and found appreciable heterosis over best parental lines.

Fruits per plant

Ahmad (2002) found highest heterosis over better parent in the cross TM041 X TM044 which were 159.70 and 181.36 percent respectively for May and July sowing. Resende *et al.* (2000) found higher heterosis values in the hybrids than the standard cultivar Santa Clara for number of marketable fruits. Vidyasagar *et al.* (1997) in a line (8) X tester (3) analysis observed better parents heterosis in 5 F1s for marketable fruits/Plant.

Sekar (2001) observed more than 10% heterosis over the best parent for the number of fruits per plant and yield per plant. Dev *et al.* (1994) in a line X tester analysis observed heteriosis over the better parent 115.7% for the number of fruits per plant.

Ahmed *et al.* (1988) also reported heterosis over the better parent for fruit per plant. Bhatt *et al.* (1999) recorded appreciable heterosis over best parental lines. Jamwal *et al.* (1984) crossed 10 foreign lines and 3 local testers and observed heterois for fruit number per plant. Bhuiyan (1982) observed maximum better parent heterosis (113.92 percent) for number of fruits per plant in the cross Fujuki X CL. 8d-0-7-1-0-0. Kumar *et al.* (1995a) observed greatest heterosis over superior parent's fruit numbers (143.1%). Chaudhury and Khanna (1972) reported heterosis in 17 hybrids out of 28 hybrids for fruit number and with maximum increases over the better parent of 49.93% under high temperature growing environment.

Average individual fruit weight (g)

Ahmad (2002) reported better parent heterosis for average fruit weight in the cross TM051 X TM017 (44.61 and 30.81% for May and July sowing respectively). Kumar *et al.* (1995a) and Kumar *et al.* (1995b) observed greatest heterosis over superior parents for average fruit weight (30.8% and 32.27%) respectively.

Vidyasager *et al.* (1997) in a line (8) X tester (3) analysis observed superiority of 3 F1S to their respective better parents for fruit weight. Singh *et al.* (1995) observed heterosis in some crosses for weight of fruit. Ahmed *et al.* (1988) also reported heterosis over the better parent for fruit weight.

Scott *et al.* (1986) and E1-Madhy *et al.* (1990) also reported heterosis for the trait fruit weight under high temperature environments. Alvarez (1985) reported that hybrid INCA 21X INCA 3 was superior to the better parent for average weight in summer. Bhuiyan (1982) observed maximum better parent heterosis (8.45 percent) for individual fruit weight in the cross Fujuki X World champion.

Yield per plant (kg)

Ahmad (2002) reported 200.17% and 241.70%, Singh *et al.* (1996) observed 31.1% to 57.9%, Sidhu and Singh (1993) reported 71.7%, Chaudhury and Khanna (1972) reported 73.77%, Bhuiyan (1982) observed 124.15 % and Hegazi *et al.* (1995) reported 58.5% and Kumar *et al.* (1995b) reported 87.06% heterobeltiosis for yield per plant.

Bhatt (2001a) in a 15 X 15 diallel set of tomato excluding reciprocals found positive high significant heterosis for yield (41.97, 157.84 and 28.94%) over the top, the better parent and the commercial control, respectively. Bhatt *et al.* (1999) observed maximum heterosis (63.79) in the cross Punjab Chhuhara x Punjab Kesari over the top parent Punjab Chhuhara for total yield per plant.

Sherif and Hussein (1992) observed significant heterosis for fruit yield/plant, as reflected by differences in the highest yields of parents and F1 hybrids: 845.6 and 2084.7 g/plant for Yellow Pear Sweet 100 X Yellow Pear, respectively. 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 450g to 800g.

Opena *et al.* (1987), Scott *et al.* (1986), Ahmed *et al.* (1988), Jamwal *et al.* (1984) reported heterosis over better parent in yield per plant or total yield in tomato. The heterosis for yield has also been reported by Anelsson, 1954; Choudhury *et al.* ,1965 Choudhury, 1966; Culkov, 1965; Gottle and Darley, 1956; Singh, 1965; Swadiak, 1966; Tesi *et al.*, 1970; Zonic and Dumanovic, 1954, Zurkov, 1995. E- Metwally *et al.* (1996) and Resende *et al.* (2000)

Fruit length (cm)

Ahmad (2002) found highest better parent heterosis in the cross TM051 X TM025 (22.25 percent in May sowing and 2.87 percent in July sowing) for fruit length. Susic (1998) in a full diallel without backcrosses involving seven parents recorded maximum heterosis for fruit length (4.62%) in the hybrid V100 X 93/10.

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. Singh *et al.* (1995) observed heterosis in some crosses for length of fruit. Scott *et al.* (1986) and Chaudhury and Khanna (1972) reported heterosis over better parent for fruit size in few cases in tomato.

Fruit breadth (cm)

Ahmad (2002) found highest better parent heterosis in the cross TM051 X TM017 (22.65% in May sowing and 15.97% in July sowing) for fruit breadth. Susic (1998) in a full diallel without backcrosses involving seven parents recorded maximum heterosis for fruit width (4.56%) in the hybrid D150 X NO-10.

Wang *et al.* (1998b) using five lines and two cultivars observed higher heterosis for fruit length. Chaudhruy and Khanna (1972) reported heterosis for fruit size, with maximum increases over the better parent of 6.82%. Alvarez (1985) reported heterosis for equatorial diameter in the tomato.

Brix %

Ahmad (2002) reported better parent heterosis for brix% in the cross TM017 X TM044 (21.00%) and TM017 X TM026 (13.54%) for May and July sowing respectively. Bhatt (2001a) in a 15 X 15 diallel set of tomato excluding reciprocals obtained positive high significant heterosis for TSS (25.97, 11.93 and 19.02%) over the top, the better parent and the commercial control, respectively.

Kurian *et al.* (2001) observed the highest significant heterobeltiosis in the F1 hybrids of LE206 X St 64 for TSS in tomato. Shrivastava (1998b) found maximum heterosis in the crosses NT-3 X HS-101 (23.59%) for total soluble solids. El-Mahdy *et al.* (1990) reported significant heterosis over the mid-parent for TSS% in tomato under heat stress condition in Egypt.

Locules per fruit

Kurian and Peter (2001) studied on heterosis using line x tester analysis between bacterial wilt (*Ralstonia solanacearum*) – resistant/tolerant accessions (Sakthi, LE 214 and LE 206) and processing cultivars (HW 208F, St 64, Ohio 8129, Fresh Market 9 and TH 318) and identified heteroic hybrids for locule number (LE 206 X Ohio 8129 and LE 214 X St 64).

Chapter III

MATERIALS AND METHODS

Experimental site

The study was carried out in the research farm of Olericulture Division of Horticultural Research Center (HRC) of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur during the winter season of 2005-2006. The location of the site is 24.00^{0}N latitude and 90.26^0 E longitudes at an elevation of 8.4 meters from sea level (Anon., 1995).

Climate of the experimental Site

The experimental site is situated under the sub-tropical climatic zone which was characterized by heavy rainfall during May to September (scanty during the rest of the year). The monthly average minimum and maximum temperature during the crop period was 12.00^{0}C and 32.69^{0}C respectively. The monthly mean minimum and maximum relative humidity was 48.41% and 97.63%, respectively. The monthly average rainfall during the crop period was 17.59 mm. The meteorological data (air temperature, relative humidity and rainfall) as recorded by Metrological Department, BARI, Joydebpur, Gazipur during the study period are presented in Appendix 1.

Soil

The soil of the experimental field was characterized by sandy clay loam in texture having a pH around 6.0. The soil belongs to the Chita soil series of red brown terrace (Anon., 1998; Brammer, 1971 and Shaheed, 1984). The soil was later developed for vegetable research purpose by riverbed silt.

Plant material used

Seeds of 7 parental lines and their 21 cross combinations from a diallel cross without reciprocals were obtained from Olericulture Division of HRC. The parental lines were:

P1= TM(S)-011

P2= TM(S)-017

P3 = TM(S)-013

P4= TM(S)-015

P5= TM(S)-003

P6 = VRT-001

P7 = VRT-002

The parents were selected based on their performance of genetic diversity. These 7 parents and 21F_1·s were the planting materials of the present study.

Raising seedling

Seeds of 21 collected genotypes were sown densely on 15th October, 2005 in the primary seedbed. Ten days after sowing, the young seedlings at the cotyledonary stage were transplanted in the secondary seedbed at a spacing of 5 X 5 cm.

Land preparation

The land was first ploughed in September, 2005. Six ploughing and cross- ploughing followed by laddering was done to have a good tillage and the weeds and other unwanted plants were removed thoroughly. Pits were prepared for transplanting seedling.

Application of Manures and Fertilizer

The following doses of fertilizers (Razzaque *et al.*, 2000) were applied in the plots-

Cow dung-10 ton/hectare

Urea- 550 kg/ hectare

TSP- 450 kg/hectare

MP-250 kg/ hectare

Half of the quantity of Cow dung and the entire amount of TSP were applied during final land preparation. The remaining Cow dung and half of MP were applied before 3 days of planting. The whole Urea and half MP were applied in 3 equal splits as top dressing after 15, 30 and 50 days of transplanting respectively.

Layout and Design

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 4m X 1 m accommodating 20 plants in a plot having row to row and plant to plant spacing of 60cm X 40 cm. The unit plot and blocks were separated by 50 cm and 1m. respectively. Treatment was randomly allotted in each block.

Transplanting of seedling

Thirty one days old seedlings were transplanted in the main experimental field on 15th November, 2005.

Intercultural operation and after care

The field was weeded and mulched when necessary. Then top dressing and irrigation were done at 15 days of interval.

Pruning, stacking and plant protection measures

Pruning was done by removing some of the lateral branches below the 1st inflorescence during the early stage of growth to allow the plants more sunlight and to reduce the incidence of insect infestation. Stacking was done with bamboo stick in such a way that necessary records could be taken from individual plant without much difficulty. The insecticide Diazinon was sprayed to prevent the damage of the plants by the fruit borer and white fly, the vector of TYLCV.

Harvesting

Harvesting continued for one month and 14 days because fruits of different parents and hybrids matured progressively at different dates and over long time.

Observation and collection of data

Five plants from each unit plot were randomly selected. Data on the following parameters were recorded:

1. **Days to 50% flowering:** Number of days required from sowing to first flower opening of the 50% plants of each replication.
2. **Plant heights at 50% flowering (cm):** The average of length of the main stem from the ground level to the tip, measured in centimeters at 50% flowering of the 5 selected plants.
3. **Plant heights at last harvest (cm):** The average of length of the main stem from the ground level to the tip, measured in centimeters at the time of last harvest of the 5 selected plants.
4. **Fruits per cluster:** The average value of total number of fruits in the fruited clusters was counted and was taken as fruits per cluster.
5. **Fruits per plant:** Average value of number of mature fruits harvested from the 5 selected plants.
6. **Individual fruit weight (g):** Individual fruit weight in gram was calculated based on the twenty representative fruits.
7. **Fruit yield per plant (kg):** Total weight of fruits (kg) per 5 plants was recorded and yield per plant was calculated from the average value.
8. **Fruit length (cm):** Fruit length was measured with a digital slide calipers from the neck of the fruit to the bottom of the same from ten representative fruits and their average was taken as the length of the fruit.
9. **Fruit breadth (cm):** Fruit breadth was measured along the equatorial part of the same ten representative fruits taken for fruit length by digital slide calipers and their average was taken as the breadth of the fruit.
10. **Brix %:** Total soluble solid content was recorded by a hand refractometer.
11. **Locule number per fruit:** Total number of locules presents in fruit was counted by cutting ten mature fruits and their average was taken as locules per fruit.

STATISTICAL ANALYSIS

Analysis of variance (ANOVA)

The collected data for various characters were statistically analized using MSTAT-C program to find out the variation among the different genotypes by F-test as it was a single factor experiment. The variances of each character were partitioned into block, genotype and error differences. Treatment means were compared by Duncan's Multiple Range Test (DMRT) and coefficient of variation (CV %) were also estimated as suggested by Gomez and Gomez (1984). As the purpose of the experiment was to evaluate the performance of the hybrids and their parents, data were recorded fro all (28) the genotypes.

Statistical Procedure Used for Combining Ability Analysis

Combining abiltiy analysis of the traits with significant genotypic differneces was done according to the model 1 (fixed genotypic effects) and method 2 (half diallel) of Griffing (1956a,b).The fixed effect model was more appropriate in the present case since the parent selected was self pollinated lines and the parents and F1s 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 F1's expressed as general and specific combining abilities. In Griffing's approach GCA represents additive variance (perhaps modified by epistatis) where SCA represents non-additive effects.

The mathematical model used in this analysis was as follows:

$$Yij = m + Gi + Gj + Sij + 1/bc\sum \sum eijkl$$

Where,

Yij = is the mean of i x jth genotype over k and l

i ,j = 1,2,.........., n

k = 1,2,..........., b

l = 1,2,............., c

m = population mean

Gi = GCA effects of the ith parent

Gj = GCA effects of the jth parent

eijkl = environmental effects

1/bc $\sum \sum$ eijkl = mean error effect

The significant differences within each of the component effects were tested by F – test. Diallel tables were prepared by computing the averages over the 3 replications of all the parents and F1's in the appropriate cells. The row sums, columns sums, the sums of the squares of GCA, SCA were all computed from this table. The GCA of any parent is estimated as the difference between its array mean and the overall mean. The analysis of variance of combining ability and expectation of mean squares using Griffing's (1956) model 1 method 2.

The general form of ANOVA for combining ability was as follows :

Source of variation	df	Sum of squares	Mean sum squares	F-test	Expected mean squares
GCA	6	SSg	MSg	MSg/MSe	$\sigma^2 e + \frac{(n+2)}{(n-1)} \Sigma G^2 i$
SCA	21	SSs	MSs	MSs/MSe	$\sigma^2 e + \frac{2}{n(n-1)} \sum\sum_{i<j} S^2 ij$
Error	54	SSe	MSe		$\sigma^2 e$

GCA and SCA effects

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

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

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

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

Calculation of heterosis:

For estimation of heterosis in each character the mean values of the 21 F_1's have been compared with better parent (BP) for heterobeltosis and with mid parent (MP) for heterosis over mid parental value. Percent heterosis was calculated as –

$$H (BP) = \frac{(\overline{F_1} - \overline{BP})}{\overline{BP}} X 100$$

$$H (MP) = \frac{(\overline{F_1} - \overline{MP})}{\overline{MP}} X 100$$

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

$SE (BP) = (3/2 X MSE/r)^{1/2}$

$SE (MP) = (2 X MSE/r)^{1/2}$

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Combining Ability

The analysis of variances for general combining ability (GCA) and specific combining ability (SCA) were found significant for most of the characters studied (Table 1) indicating both additive and non-additive gene actions for the expression of these characters. The general combining ability (GCA) variances for all the characters studied higher in the magnitude than the specific combining ability variances indicating the predominance of the additive effect for these characters. The general combining ability (GCA) variances for the characters fruits per cluster, fruits per plant, individual fruit weight and fruit breadth were higher in the magnitude than the specific combining ability (SCA) variances indicating that additive gene effect is predominant for these characters. Bhuiyan (1982) and Wang *et al.* (1998a) also reported that additive gene action appear more important than non-additive gene effects for the fruits per plant, average fruit weight and fruit breadth in tomato.

The GCA component is primarily a function of the additive genetic variance. GCA variances with each parent plays significant role in the choice of parents. A parent with higher positive significant GCA effects is considered as a good general combiner. The magnitude and direction of the significant effects for the seven parents provide meaningful comparisons and would give indications to the future breeding programme. The results of GCA effects for eleven different characters and the SCA effects of 21 F1 crosses for the same characters were estimated and presented from the table 2 to table 12. The SCA effects signify the role of non-additive gene action in the expression of the characters. It indicates the highly specific combining ability leading to highest performance of some specific cross combinations. That is why it is related to a particular cross. High GCA may arise not only in crosses involving high combiners but also in those involving low combiners. Thus in practice, some of the low combiners should also be accommodated in hybridization programme.

Table 1. Analysis of variance for combining ability in tomato

Source of variation	df	Mean sum of squares				
		Days to 50% flowering	Plant height at 50% flowering(cm)	Plant height at last harvest (cm)	Fruits per cluster	Fruits per plant
GCA	6	57.331**	105.148**	4492.426**	1.419*	191.172**
SCA	21	4.822	81.539**	1019.570**	0.301	46.860**
Error	27	2.784	5.369	10.590	0.327	3.170

Table 1. Cont'd

Source of variation	df	Mean sum of squares					
		Individual fruit weight (g)	Yield per plant (kg)	Fruit length (cm)	Fruit breadth (cm)	Brix %	Locules per fruit
GCA	6	1372.671**	0.625**	0.759*	0.835**	2.270**	1.244**
SCA	21	97.249**	0.327**	0.049	0.078	0.478*	0.207*
Error	27	22.465	0.035	0.066	0.072	0.122	0.09

* Significant at 5% level

* * Significant at 1% level

4.1.1 Days to 50% flowering

The mean square for GCA was significant but SCA was insignificant for days to 50% flowering which suggest the presence of additive and absence of non-additive genetic variance in the population for this character (Table 1). Here higher magnitude of GCA variance than SCA variance indicated pre dominance of additive gene action.

Srivastava *et al.* (1998); Dhaliwal *et al.* (2000) and Bhatt *et al.* (2001b) also reported the predominance of non-additive variance for days to flowering. Where El-Mahdy *et al.* (1998) and Natarajan (1992) reported that additive gene effects appeared more important than non-additive gene effects.

Table2. Estimates of GCA and SCA effects in tomato for days to 50% flowering

Parent	SCA						
	P2	P3	P4	P5	P6	P7	GCA
P1	3.319**	-2.181*	-0.403	1.431	0.375	-0.736	1.960**
P2		-0.958	-0.181	1.653	0.597	-0.514	-0.262
P3			-0.181	-0.847	-2.903*	-2.014*	-4.762**
P4				-0.069	-0.625	0.264	-1.040*
P5					2.708*	3.597**	-0.373
P6						0.542	2.683**
P7							1.794**
S.E.(Gi)							0.515
S.E.(Gi-Gj)							0.787
S.E (Sij)						1.274	
S.E.(Sii-Sjj)						1.759	
5%						2.170	0.877
1%						3.151	1.274

* Significant at 5% level

* * Significant at 1% level

The estimate of GCA effects for this trait is given in (table 2). Among the seven parent studies the parent P3 showed higher significant negative GCA effect (-4.762**) than the parent P4 (-1.04*) for days to 50% flowering. On the other hand three parents P6, P1, P7 sowed significant positive value (2.683**, 1.96** and 1.794** respectively). So the parent P3 was the best general combiner for earliness. El Maḥdy *et al.* (1990) reported highly significant GCA effect for early yield in certain lines under heat stress in tomato. E-Metawally *et al.* (1996) also found such effect in heat tolerance tomato lines. Chadha *et al.* (1997) also found a lines performing as a good general combiner.

Among the 21 F1s only three F1s P3xP6 (-2.903*), P1xP3 (-2.181*) and P3xP7 (-2.014*) showed significant negative SCA values. Suggesting these F1s were good specific combiner for earliness. On the other hand three F1s showed significant positive SCA. Among them P5 x P7(3.597**) showed comparatively the highest positive SCA than P1xP2 (3.319**) and P5 x P6 (2.708*). Shrivastava *et al.* (1993) also reported a hybrid as a best combination for earliness. Chadha *et al.* (1997) found a hybrid as a good specific combiner for days to 50% flowering.

4.1.2 Plant height at 50% flowering

The mean square for GCA and SCA were highly significant for this trait which suggests the presence of both additive and non-additive gene action for this character (Table 1).

Among the seven parent studies the parent P1 and P7 showed the significant positive GCA effects. The GCA value of P1 (5.397**) was higher than P7 (3.830**). On the other hand P3 (-3.392**), P4 (-2.725**), and P6 (-2.392**) showed significant negative GCA effect. So the parent P1 was the best general combiner for plant height at 50% flowering (Table 3).

Among the 21 cross combinations 10 crosses P3xP6 (15.481**), P4xP6 (11.414**), P1xP4 (10.325**), P1xP3 (8.892**), P2xP6 (7.414**), P3xP5 (6.381**), P1xP5 (6.292**), P3xP7 (4.458**), P4xP7 (3.992*), and P2xP7 (3.092*) showed significant positive SCA effects. Thus these 10 crosses were good specific combiner for plant height at 50% flowering. The cross P3xP6 was the best specific combiner. On the other hand only P3xP4 (-3.486*) showed significant negative SCA effects.

Table 3. Estimates of GCA and SCA effects in tomato for plant height at 50% flowering (cm)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	1.625	8.892**	10.325**	6.292**	-0.908	0.769	5.397**
P2		0.114	2.747	0.914	7.414**	3.092*	0.475
P3			-3.486*	6.381**	15.481**	4.458**	-3.392**
P4				-1.686	11.414**	3.992*	-2.725**
P5					-0.819	2.358	-1.192
P6						-2.942	-2.392**
P7							3.830**
S.E.(Gi)							0.715
S.E.(Gi-Gj)							1.092
S.E.(Sij)						1.770	
S.E.(Sii-Sjj)						2.442	
5%						3.014	1.218
1%						4.377	1.768

* Significant at 5% level

* * Significant at 1% level

4.1.3 Plant height at last harvest

The mean squares for GCA and SCA were highly significant for plant height at last harvest indicating that both additive and non-additive gene effects are important in contributing for this trait (Table 1). Chandrasekhar and Rao (1989) also reported significant GCA and SCA variation for plant height. But there was pre dominance of noOn-addiditive gene action due to higher SCA component than GCA component. Ray and Syamal (1998); Shrivastava *et al.* (1998) and Bhatt *et al.*(2001 b) also reported non-additive gene action,. On the other hand Bhuiyan (1982) reported pre dominance type of additive gene action.

Table 4. Estimates of GCA and SCA effects in tomato for plant height at last harvest (cm)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	44.620**	47.279**	36.677**	29.984**	6.371**	29.584**	48.271**
P2		-5.923*	-0.196	3.027	15.349**	3.127**	-3.107**
P3			-7.447**	-5.225*	10.497**	-3.710	-20.020**
P4				-17.832**	21.640**	-4.732*	-1.748*
P5					-11.728**	15.325**	-10.470**
P6						-2.787	-11.857**
P7							-1.070
S.E.(Gi)							1.004
S.E.(Gi-Gj)							1.534
S.E.(Sij)						2.485	
S.E.(Sii-Sjj)						3.430	
5%						4.232	1.710
1%						6.145	2.483

* Significant at 5% level

* * Significant at 1% level

Among the seven parents only P1 (48.271**) showed significant positive GCA value. So the parent P1 appeared the best general combiner to be used in crosses for improvement of the plan height. On the other hand five parents showed significant negative GCA value. Among them P3 (-20.02**) showed the highest negative GCA value followed by P6 (-11.857**), P5 (-10.47**), P2 (-3.107**) and P4 (-1.748*). So P3 can be used as the best general combiner in a crossing programme for the producing short plant type. Good general combining ability for plant height was also reported by Bhuiyan (1982) and Ahmad (2002).

Out of 21 cross combinations 11 crosses showed significant positive SCA effects and 6 crosses showed significant negative SCA effects. The highest significant positive SCA effect was obtain by the cross P1xP3 (47.279**) followed by P1xP2 (44.62**), P1xP4 (36.677**) and P1xP5 (29.984**). The highest significant negative SCA effect was obtained by the crossP4xP5 (-17.832**) followed by P5xP6 (-11.728**), P3xP4 (-7.447**) and P2xP3 (-5.923*). The crosses with highest positive SC are considered as the best specific combiners for this trait.

4.1.4 Fruits per Cluster

The analysis of variance for fruits per cluster indicated the importance of both additive and non-additive gene action as the variance due to GCA and SCA were significant (Table 1). But the higher magnitude of GCA variances to SCA variances suggested the pre dominance of additive gene action for this character. Natarajan (1992) reported the pre dominance of additive gene action for number of fruits set per cluster. Contrary Bhatt *et al.* (2001 b) reported predominance of non-additive gene action.

Table 5 represents the GCA and SCA effects for fruits per cluster. Among the seven parents 3 showed positive GCA effects and only P7 (0.505**) showed highest significant positive effects followed by P3 (0.394*). The other parent P1 (0.171) did not show significant value. Thus P7 and P3 was good general combiner for fruits per cluster and the parent P7 was the best general combiner for fruits per cluster. On the other hand among four negative GCA value showing parents only the parent P2(-

0.64**) showed negative significant GCA value. Resende *et al.* (2000) also reported significant general combining ability (GCA) effects in a group of parents.

Table 5. Estimates of GCA and SCA effects in tomato for fruits per cluster

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	-0.214	0.153	0.275	-0.169	-0.036	-0.158	0.171
P2		-0.036	-0.314	-0.558	0.875*	0.253	-0.640**
P3			0.053	0.208	-0.158	-0.081	0.394*
P4				-0.269	0.664	0.842*	-0.129
P5					-0.281	0.497	-0.284
P6						0.831*	-0.017
P7							0.505**
S.E.(Gi)							0.177
S.E.(Gi-Gj)							0.270
S.E.(Sij)						0.437	
S.E.(Sii-Sjj)						0.603	
5%						0.744	0.301
1%						1.081	0.438

* Significant at 5% level

* * Significant at 1% level

10 cross combinations out of 21 showed positive SCA effect for this character, among them only three crosses exhibited significant positive SCA effect. The highest significant positive SCA effect was obtained by the cross P2xP6 (0.875*) followed by P4xP7 (0.842*) and P6xP7 (0.831*). The crosses with highest positive SCA are considered as the best specific combiners for this trait. There was no parent showing negative significant SCA value.

4.1.5 Fruits per Plant

The mean square for GCA and SCA were highly significant for this trait which suggests the presence of both additive and non-additive gene action for this character (Table 1). Bhuiyan (1982) and Natarajan (1992) supported the result in tomato. However considerably higher GCA component compared to the SCA component suggested that the additive portion of genetic variance was substantial. Wang *et al.* (1998 a) also reported important role of additive gene action.

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

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	-3.732**	1.568	-4.888**	-0.893	0.313	-0.671	-8.302**
P2		0.785	-0.221	0.524	8.529**	4.146**	-1.118*
P3			2.579*	9.024**	-0.471	2.246	3.882**
P4				0.518	4.524**	19.540**	5.437**
P5					-4.232**	-4.265**	-0.357
P6						-4.010**	-2.263**
P7							2.721**
S.E.(Gi)							0.549
S.E.(Gi-Gj)							0.839
S.E.(Sij)						1.360	
S.E.(Sii-Sjj)						1.877	
5%						2.316	0.935
1%						3.363	1.358

* Significant at 5% level

* * Significant at 1% level

Bhuiyan (1982) reported predominance of additive and additive x additive gene actions for this character. On the other hand Bhutani and Kalloo (1988); Srivastava *et al.* (1998) and Bhatt *et al.* (2001 b) observed non-additive control for this character.

The parent P4 showed highly significant positive GCA effects (5.437**) followed by P3 (3.882**) and P7 (2.721**). The highest significant negative value was obtained by the parent P1 (-8.302**) followed by P6 (-2.263**) and P2 (-1.118*). Thus P4, P3 and P7 were the best general combiners which could be used in crosses for the increasing number of fruits per plant and in this trait P4 is the best for increasing number of fruits per plant. Chadha *et al.* (1997); De-Araujo and De-Campos (1991) and Natarajan (1992) reported some good general combiners for number of fruits per plant.

Out of 21 cross combinations 12 crosses showed positive SCA effects but 6 showed significant positive SCA effects. The highest significant positive effect was observed in the cross P4xP7 (19.540**) followed by P3xP5 (9.024**), P2xP6 (8.529**) and P2xP7 (4.146**). So these crosses were the best specific combiner for increasing fruits per plant. The cross P4 and P7 was the best specific combiner for this trait. Significant negative SCA effects was observed in P1xP4 (-4.888**) followed by P5xP7 (-4.265**) and P5xP6 (-4.232**). Bhuiyan (1982) also found some hybrids showed significant positive SCA in tomato.

4.1.6 Individual fruit weight (g)

The analysis of variance for individual fruit weight indicated the importance of both additive and non-additive gene action as the variances due to GCA and SCA were significant (Table 1). But the higher GCA component compared to SCA component indicated the predominance of additive gene action. Similar result was also reported by Bhuiyan (1982). Additive gene action was also reported by Kumar *et al.* (1997) and Wang *et al.* (1998 a). Where Perera and Liyanaarachchi (1993) reported directional dominance and epistatic effects for fruit weight.

Among seven parent studies 4 parents P1, P2, P6 and P7 showed significant positive GCA value (12.667**, 11.889**, 6.4** and 3.056* respectively) for individual fruit weight. So parents P1, P2 and P6 were the best general combiners which could be used in crosses for the improvement of individual fruit weight as indicated by the significance and higher GCA effect. On the other hand 3 parents showed negative GCA value and the significant negative GCA value was found in parents P3 (-17.556**) and P4 (-15.956**). Bhuiyan (1982); Chadha *et al.* (1997) and Ahmed (2002) also reported some good general combiners for individual fruit weight.

Table 7. Estimates of GCA and SCA effects in tomato for individual fruit weight (g)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	15.319**	-9.236**	-10.336**	-6.292**	4.308	20.153**	12.667**
P2		-7.458*	-7.558*	-3.014	0.086	-1.569	11.889**
P3			4.386	-13.569**	7.031*	11.875**	-17.556**
P4				2.731	2.931	-2.725	-15.956**
P5					5.075	-13.681**	-0.500
P6						-5.581	6.400**
P7							3.056*
S.E.(Gi)							1.463
S.E.(Gi-Gj)							2.234
S.E.(Sij)						3.620	
S.E.(Sii-Sjj)						4.996	
5%						6.165	2.491
1%						8.952	3.618

* Significant at 5% level

* * Significant at 1% level

Among 21 cross combinations 10 crosses showed positive SCA effects for individual fruit weight out of which only 4 crosses showed significant positive SCA value. The highest significant positive SCA value was found in P1xP7 (20.153**) followed by P1xP2 (15.319**), P3xP7 (11.875**) and P3xP6 (7.031*). This indicated that this hybrid produced heavier fruit weight compared to the mean of their parents. The highest significant negative SCA effect was obtained by the cross P5xP7 (-13.681**) followed by P3xP5 (-13.569**) and P1xP4 (-10.336**). So the cross P1xP7 was the best specific combiner for individual fruit weight. Chadha *et al.* (1997) selected some hybrids for individual fruit weight.

4.1.7 Yield per Plant (kg)

The mean squires for GCA and SCA were significant for yield per plant indicating that both additive and non-additive gene effects are important in contributing for this trait (Table 1). Chandrasekhar and Rao (1989) and Bhatt *et al.* (2001 a) also found similar result. The lower GCA components than SCA component suggest the predominance of non-additive gene action for this trait. Khalfullah (1970), Bhutani and Kalloo (1988) Bhuiyan (1982), and Dharmatti *et al.* (1999), Dhaliwal *et al.* (2000), Bhatt *et al.* (2001 a) and Bhatt *et al.* (2001 b) also reported the predominance of non-additive genetic variance in tomato for yield per plant. Sahrigy *et al.* (1970) reported dominance effect in the inheritance of yield. On the other hand Singh *et al.* (1999) and Ahmed (2002) reported predominance of additive genetic variance.

Among the seven parents three parents showed positive GCA effects and two showed highly significant positive effects (Table 8). The highest significant GCA effects was obtained in the parents P7 (0.36**) followed by P2 (0.296**). Thus these parents were good general combiner for yield per plant. Again the highest significant negative GCA value was found in P1 (-0.359**) followed by P3 (-0.248**). Bhatt *et al.* (2001b) found highly significant desirable GCA effects for yield per plant in tomato. Similarly Chandrasekhar and Rao (1989), Sharma *et al.* (1999), Dhaliwal *et al.* (2000) and Bhatt *et al.* (2001 b) reported some good general combiners for this character.

Table 8. Estimates of GCA and SCA effects in tomato for yield per plant (kg)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	-0.165	0.023	-0.502**	-0.185	0.058	0.531**	-0.359**
P2		-0.122	-0.202	0.055	0.878**	0.466**	0.296**
P3			0.116	-0.007	0.257*	0.639**	-0.248**
P4				0.143	0.496**	1.268**	-0.067
P5					-0.232	-0.734**	-0.039
P6						-0.511**	0.057
P7							0.360**
S.E.(Gi)							0.058
S.E.(Gi-Gj)							0.088
S.E.(Sij)						0.143	
S.E.(Sii-Sjj)						0.198	
5%						0.244	0.099
1%						0.354	0.143

* Significant at 5% level

* * Significant at 1% level

Among 21 cross combinations 12 crosses showed positive SCA effects for yield per plant and 7 crosses showed significant positive SCA value. The highest significant positive SCA was obtained by the cross P4xP7 (1.268**) followed by P2x P6 (0.878**), P3xP7 (0.639**), P1xP7 (0.531**), P4xP6 (0.496**), P2xP7 (0.466**) and P3xP6 (0.257*). Thus the cross combinations P4xP7, P2xP6, P3xP7, P1xP7, P4xP7 and P2xP7 were best general combiner for increasing fruit yield per plant. On the other hand 3 crosses showed significant negative SCA effects. They were P5xP7 (-0.734**), P6xP7 (-0.511**) and P1xP4 (-0.502**). Several workers like Dharmatti *et al.* (1999), Sharma *et al.* (1999), Dhaliwal *et al.* (2000). Bhatt *et al.* (2001 a) and Bhatt *et al.* (2001 b) reported some hybrids superior for these character.

4.1.8 Fruit Length (cm)

The combining ability variances for fruit length are presented in the table 1. The significant value for GCA suggests the presence of additive gene action for this character. The lower GCA components than SCA component indicated the predominance of non-additive gene action. Similar result was also reported by Srivastava *et al.* (1998).

Table 9. Estimates of GCA and SCA effects in tomato for fruit length (cm)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	0.295	0.104	-0.241	0.012	-0.241	0.041	0.060
P2		-0.196	-0.341*	0.142	-0.131	-0.259	0.250**
P3			-0.212	0.071	0.178	-0.271	-0.599**
P4				-0.014	0.094	-0.115	0.126
P5					0.016	-0.103	-0.127
P6						0.135	0.206**
P7							0.084
S.E.(Gi)							0.079
S.E.(Gi-Gj)							0.121
S.E.(Sij)						0.196	
S.E.(Sii-Sjj)						0.270	
5%						0.334	0.135
1%						0.485	0.195

* Significant at 5% level

* * Significant at 1% level

However Wang *et al.* (1998 a) and Ahmed (2002) also0 observed highly significant GCA and SCA, but predominance of additive gene effects for fruit length in tomato.

Among the 7 parents only 2 parents showed significant positive GCA effects. The highest signioficant positive GCA value was observed in P2 (0.25**) followed by P6 (0.206**). Therefore, the parent P2 and P6 wre good general combiner for fruit length. Only one parent P3 (-0.599**) showed significant negative GCA effects. Susic (1998) and Ahmed (2002) also reported some good general combiners for fruit length.

Among the 21 cross combinations no cross showed significant positive SCA effects but 10 crosses showed positive effects. Again only the cross P2xP4 (-0.341*) showed significant negative SCA effects. But Susic (1998) reported a good specific combiners for fruit lengthy in tomato. Superior hybrids for fruit length were also reported by Ahmad (2002).

4.1.9 Fruit breadth (cm)

The analysis of variance for fruit breadth indicated the importance of both additive and non-additive gene actions as the variances due to GCA and SCA were significant. The significant value for GCA suggests the presence of additive gene action for this character (Table 1). However considerably greater GCA variances compare to SCA variances suggested that the additive portion of genetic variance was substantial which agreed with the findings of Wang *et al.* (1998 a). Contrary Srivastava *et al.* (1998) reported non-additive effects of genetic variance for fruit breadth in tomato.

Table 10 represented the combining ability effects (GCA and SCA) for fruit breadth. Among the 7 parents the highest GCA effects for fruit breadth was exhibited by the parent P1(0.354**) followed by P2(0.260**) and P5 (0.141*). So the parent P1 and P2 were the good general combiners for fruit breadth. The highest significant negative GCA effects was obtained from P4 (-0.472**) followed P3 (-0.34**). Susic (1998) and Ahmad (2002) also reported some good general combiners for this trait in tomato.

Table 10. Estimates of GCA and SCA effects in tomato for fruit breadth (cm)

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	0.597**	-0.163	0.009	-0.194	0.140	0.366*	0.354**
P2		-0.119	-0.126	-0.120	0.175	0.010	0.260**
P3			0.244	-0.390*	0.255	0.090	-0.340**
P4				0.163	-0.003	-0.197	-0.472**
P5					0.374*	-0.171	0.141*
P6						0.044	-0.013
P7							0.071
S.E.(Gi)							0.083
S.E.(Gi-Gj)							0.126
S.E.(SIj)						0.205	
S.E.(Sii-Sjj)						0.282	
5%						0.349	0.141
1%						0.507	0.205

* Significant at 5% level

* * Significant at 1% level

Among the 21 cross combinations 12 crosses showed positive SCA effects for fruit breadth out of which 3 crosses showed significant positive SCA effects. The highest significant positive SCA was obtained in the cross combination P1xP2 (0.597**) followed by P5xP6 (0.374*) and P1xP7 (0.366*). So P1xP2 was the best specific combiners for this trait. Rest of the cross combinations only P3xP5 (-0.39*) showed significant negative SCA effects. Susic (1998) and Ahmad (2002) also reported about some superior hybrids for fruit breadth.

4.1.10 Brix%

The combining ability variances for brix% in fruit are presented in Table 11. The significant GCA and SCA variances indicated the importance of both additive and non-additive gene effects. Bhatt *et al.*(2001 a) also found similar result. The higher magnitude of SCA variance compare to GCA variance indicates the predominance of non-additive (dominance and epistasis) gene action for this trait. Non-additive genetic variance for brix% in tomato was also reported by Kumar *et al.* (1997), Wang *et al.* (1998 a) and Dhaliwal *et al.* (2002).

Table 11. Estimates of GCA and SCA effects in tomato for brix%

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	0.645*	-0.824**	-0.234	0.541*	0.283	0.804**	0.481**
P2		-0.032	-0.842**	0.073	0.005	0.676**	-0.171
P3			0.079	0.364	0.696**	-1.143**	-0.712**
P4				-0.026	0.676**	0.387	-0.372**
P5					0.661**	0.632*	-0.247*
P6						-0.246	0.621**
P7							0.400**
S.E.(Gi)							0.108
S.E.(Gi-Gj)							0.164
S.E.(Sij)						0.266	
S.E.(Sii-Sjj)						0.368	
5%						0.453	0.184
1%						0.658	0.267

* Significant at 5% level

* * Significant at 1% level

Where as additive gene action for TSS % in tomato was reported by Dod *et al.* (1995) and Shrivastava (1998 a).

Table 11 represented the combining ability effects of GCA and SCA for brix%. The highest significant positive GCA for brix% was recorded in the parent P6 (0.621**) followed by P1 (0.481**) and P7 (0.40**). Thus the parent P6, P1 and P7 were the good general combiner for brix%. The highest significant negative GCA value was obtained by the parent P3 (-0.712**) followed by P4 (-0.372**) and P5 (-0.247*). Dod *et al.* (1995) also reported some parents as good general combiners for TSS%.

It is revealed from Table 11 that among 21 cross combinations 14 crosses showed positive SCA effects for brix%, out of which 8 cross combinations exhibited significant positive effects. The highest positive SCA effects was observed in the cross P1xP7 (0.804**) followed by P3xP6 (0.696**), P4xP6 (0.676**), P2xP7 (0.676**), P5xP6 (0.661**). Thus these cross combinations were good specific combiner for brix%. Only 3 cross combinations showed significant negative SCA effect. The highest negative SCA was observed in the cross P3xP7 (-1.143**) followed by P2xP4 (-0.842**) and P1xP3 (-0.824**). Shrivastava (1998 a) and Bhatt *et al.* (2001 a) also reported some best hybrids for TSS%.

4.1.11 Locules per fruit

The analysis of variance for locules per fruit indicated the importance of both additive and non-additive gene actions as the variances due to GCA and SCA were significant (Table 12). But here lower magnitude of GCA variance than SCA variance indicated predominance of non-additive genetic variance. Non-additive genetic variance for luculs per fruit in tomato was also reported by srivastava *et al.* (1998). Where as, additive genetic variance was reported by Dod e al. (1995) and Dhaliwal *et al.* (2000).

Among the seven parents 4 parents showed positive GCA effects out of which 3 parents showed significant positive GCA effects for this trait. The highest significant positive GCA value was obtained by the parent P2 (0.406**) followed by P1 (0.306**) and P5 (0.173*). The parent P2 and P1 were good general combiner for locules per fruit. Only one parent P4 (-0.716**) showed significant negative GCA value. Dod *et al.* (1995) reported that Punjab Chhuhara and Pusa Ruby as good general combiners for locules per fruit.

Table 12. Estimates of GCA and SCA effects in tomato for locules per fruit

Parent	SCA						GCA
	P2	P3	P4	P5	P6	P7	
P1	0.819**	-0.403*	-0.058	-0.147	0.486*	0.264	0.306**
P2		-0.603**	-0.158	0.153	0.186	0.364	0.406**
P3			0.319	-0.369	0.564*	0.542*	0.029
P4				-0.025	-0.192	-0.414*	-0.716**
P5					0.619**	0.197	0.173*
P6						-0.369	-0.160
P7							-0.038
S.E.(Gi)							0.095
S.E.(Gi-Gj)							0.145
S.E.(Sij)						0.235	
S.E.(Sii-Sjj)						0.324	
5%						0.400	0.162
1%						0.581	0.235

* Significant at 5% level

* * Significant at 1% level

Among the 21 cross combinations 11 crosses showed positive SCA effects, out of which only 5 cross combinations showed significant positive SCA effects for locules per fruit. The highest significant positive SCA effects was obtained by the cross combinartion P1xP2 (0.819**), followed by P5xP6 (0.619**), P3xP6 (0.564*), P3xP7 (0.542*) and P1xP6 (0.486*). Thus P 1xP2 and P5xP6 was good specific combiner for this trait. The highest significant negative SCA effect was obtained in the cross P2xP3 (-0.603**) followed by P4xP7 (-0.414*) and P1xP3 (-0.403*).

From the above results and discussion it is observed that the parent P7 showed significant positive GCA effects for plant height at 50% flowering, fruits per cluster, fruits per plant, individual fruit weight, yield per plant and brix%.

The parent P1 showed significant positive GCA effects for plant height at 50% flowering, plant height at last harvest, individual fruit weight, fruit breath, brix% and locules per plant.

The parent P2 showed significant positive GCA effects for individual fruit weight, yield per plant, fruit length, fruit breath and locules per plant.

The parent P3 showed significant positive GCA effects for early flowering, fruits per cluster and fruits per plant.

The parent P6 showed significant positive GCA effects for individual fruit weight, fruit length and brix% whereas, P5 showed significant positive GCA effects for fruit breath and locules per plant and the parent P4 for early flowering.

Yield of tomato depends on various parameters *viz.* earliness, no of fruits per plant, fruit diameter, fruit weight, locules per plant and its quality is largely related with brix%.

The maximum SCA effects was observed in the cross combinations P3xP6, P1xP3 and P3xP7 for earliness, P3xP6, P4xP6 , P1xP4, P1xP3, P2xP6, P3xP5, P1xP5, P3xP7 for plant height at 50% flowering, P1xP3, P1xP2, P1xP4 and P1xP5 for plant height at last harvest, P2xP6, P4xP7 and P6xP7 for fruits per cluster, P4xP7, P2xP7, P2xP6 and P3xP5 for fruits per plant, P1xP7, P1xP2, P3xP7 and P3xP6 for individual fruit weight, P4x P7, P2xP6, P3xP7, P1xP7, P4xP6 and P2xP7 for yield per plant, P1xP2 for fruit breadth, P1xP7, P3xP6, P4xP6, P2xP7 and P5xP6 for brix% and P1xP2 and P5xP6 for locules per fruit.

It is discovered that a combination of the two best general combiners involving poor and poor general combiners and a high SCA effects may not be the best combinations and that of poor x 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). Crosses between good x poor combinations may give transgressive segregants in the subsequent generation (Longhum, 1961).

4.2 Heterosis

The analysis of variance for genotypes i.e., parents and crosses showed significant difference for all the characters studied (Appendix 2). The estimates of percent heterosis observed in F1 high generation over better parents are presented through Table 13 to 15. The percent heterosis over mid parent value were also estimated and presented in Appendix 3. The mean performance of parents and F1's are presented in Appendix 4.

4.2.1 Days to 50% flowering

Among the 21 cross combinations only three crosses showed negative heterobeltosis for days to 50% flowering, but no cross showed significant negative heterosis that is earliness than their respective better parent (Table 13). Heterosis for this character ranged from -2.00 to 20%. The highest negative heterosis was observed in P2xP3 (-2.00), P3xP4 (-2.00) and P3xP5 (-2.00). The highest positive heterosis effect was observed in the cross P5xP6 (20%) and P5xP7 (20%). Singh and singh (1993), Kumar *et al.* (1995 a), E-Metwally *et al.* (1996) and Vidyasagar *et al.* (1997) also reported negative heterosis for days to 50% flowering.

4.2.2 Plant height at 50% flowering

Out of 21 cross combinations 20 crosses showed positive heterosis over better parent out of which 19 crosses showed significant positive heterosis (Table 13). The estimate of heterosis ranges from -3.06 to 41.68%. The highest significant positive heterosis was observed in the cross P3xP6 (41.68%). The highest significant negative heterosis was observed in the cross P6xP7 (-3.6%).

4.2.3 Plant height at last harvest

In case of plant height at last harvest out of 21 cross combinations 17 crosses showed positive heterosis over better parent, out of which 16 crosses showed significant positive heterosis. The heterobeltotic effects ranges from -11.14 to 70.16%. The highest significant positive heterosis was observed in the cross P1xP2 (70.16%) followed by P1xP4 (65.05%) and P1xP7 (60.08%). The highest significant negative heterosis was observed in the cross P4xP5 (-11.14%) for plant height at last harvest.

Table 13. Percent heterosis over better parent of 21 tomato hybrids for three Morphological characters

Crosses	Characters		
	Days to 50% flowering	Plant height at 50% flowering(cm)	Plant height at last harvest (cm)
P1 X P2	14.28**	11.66**	70.16**
P1 X P3	0.00	15.60**	59.10**
P1 X P4	3.74**	18.00**	65.05**
P1 X P5	16.0**	15.14**	53.10**
P1 X P6	3.45*	5.50**	33.72**
P1 X P7	0.00	8.94**	60.08**
P2 X P3	-2.00	5.07**	13.75**
P2 X P4	1.90	9.05**	11.14**
P2 X P5	12.0**	8.68**	16.83**
P2 X P6	10.48**	15.08**	47.01**
P2 X P7	6.67**	6.11**	33.11**
P3 X P4	-2.00	10.30**	-10.40**
P3 X P5	-2.00	13.49**	-7.84**
P3 X P6	0.00	41.68**	25.49**
P3 X P7	0.00	3.38	0.72
P4 X P5	7.00**	4.33*	-11.14**
P4 X P6	4.67**	32.14**	22.81**
P4 X P7	4.67**	3.60*	8.92**
P5 X P6	20.0**	5.82**	-6.22*
P5 X P7	20.0**	3.49*	28.16**
P6 X P7	3.45*	-3.60*	9.44**
Heterosis mean	5.82	11.12	24.90
SE	1.445	2.007	2.818
LSD(0.05)	2.461	3.417	4.799
LSD(0.01)	3.573	4.963	6.970

* Significant at 5% level

* * Significant at 1% level

Kumar *et al.* (1995 b) and Ahamed *et al.* (1988) also recorded appreciable heterosis plant height

4.2.4 Fruits per Cluster

Among the 21 cross combinations 8 crosses showed positive better parent heterosis and all of them showed significant positive heterosis over better parent. The heterosis over better parent ranges from -18.46 to 23.73% (Table 14). The highest significant positive heterosis was observed in the cross P4xP6 (23.73%) followed by P6xP7 (20.90%), P2xP6 (20.69%) and P4xP7 (19.4%). The highest significant negative heterosis was observed in the cross P2xP5 (-18.46%) followed by P1xP2 (-15.28%) and P2xP3 (-13.33%). Bhatt *et al.* (1999) also found appreciable heterosis for fruits per cluster in tomato.

4.2.5 Fruits per Plant

Out of 21 cross combinations 12 crosses showed positive heterosis over better parent out of which 11 crosses showed significant positive heterosis (Table 14). The estimate of heterosis ranges from -26.32 to 83.88%. The highest significant positive heterosis was observed in the cross P4xP7 (83.88%) followed by P2xP6 (45.28%), P3xP5 (38.05%) and P3xP4 (36.09%). The highest significant negative heterosis was observed in the cross P1xP5 (-26.32%) followed by P1xP4 (-22.89%) and P1xP2 (-22.61%). The heterosis for fruit per plant was also reported by several workers like Vidyasagar *et al.* (1997), Bhatt *et al.* (1999) and Sekar (2001).

4.2.6 Individual fruit weight (g)

Among the 21 cross combinations only 3 crosses showed positive better parent heterosis and out of them two crosses showed significant positive heterosis over better parent for individual fruit weight (g). The heterosis over better parent ranges from -45.0 to 16.67% (Table 14). The highest significant positive heterosis was observed in the cross P1xP7 (16.67%) followed by P1xP2 (12.44%). The highest significant negative heterosis was observed in the cross P3xP5 (-45.0%) followed by P2xP3 (-34.67%) and P1xP3 (-30.95%). Singh *et al.* (1995), Kumar *et al.* (1995 a), Kumar *et al.* (1995 b) and Vidyasagar *et al.* (1997) also reported heterosis from this trait.

4.2.7 Yield per Plant (kg)

Out of 21 cross combinations 11 crosses showed positive heterosis over better parent and all of them showed significant positive heterosis (Table 14). The estimate of heterosis ranges from -30.88 to 62.31%. The highest significant positive heterosis was observed in the cross P4xP7 (62.31%) followed by P2xP6 (37.44%), P4xP6 (34.77%) and P2xP7 (33.67%). The highest significant negative heterosis was observed in the cross P1xP5 (-30.88%) followed by P5xP7 (-25.55%) and P3xP5 (-21.79%). Singh *et al.* (1996), Bhatt *et al.* (1999) and Bhatt (2001 a) also reported heterobeltiosis for this trait.

4.2.8 Fruit Length (cm)

Among the 21 cross combinations no cross showed positive better parent heterosis. The heterosis over better parent ranges from -24.11 to -0.56% (Table 15). The highest significant negative heterosis was observed in the cross P3xP4 (-24.11%) followed by P3xP7 (-23.01) and P2xP3 (-22.71%). Singh *et al.* (1995), Susic (1998) and Wang *et al.* (1998 b) also reported heterosis for fruit length.

4.2.9 Fruit breadth (cm)

In case of fruit breathe out of 21 cross combinations 10 crosses showed positive heterosis over better parent and all of them showed significant positive heterosis. The heterobeltotic effects ranges from -17.93 to 15.49% (Table 15). The highest significant positive heterosis was observed in the cross P1xP2 (15.49%) followed by P3xP6 (8.7%) and P1xP7 (8.1%). The highest significant negative heterosis was observed in the cross P3xP5 (-17.93%). Haterosis for fruit breath was also reported by Chaudhury and Kanna (1972), Susic (1998) and Wang *et al.* (1998 b).

Table 14. Percent heterosis over better parent of 21 tomato hybrids for four yield component characters

Crosses	Characters			
	Fruits per cluster	Fruits per plant	Individual fruit weight (g)	Yield per plant (kg)
P1 X P2	-15.28**	-22.61**	12.44**	-12.48**
P1 X P3	0.00	-8.27**	-30.95**	0.68**
P1 X P4	-1.39**	-22.89**	-30.47**	-15.07**
P1 X P5	-9.72**	-26.32**	-11.43**	-30.88**
P1 X P6	-4.17**	-12.83**	4.76	4.73**
P1 X P7	1.39**	-10.56**	16.67**	23.88**
P2 X P3	-13.33**	10.98**	-34.67**	-7.18**
P2 X P4	-3.39**	12.80**	-33.33**	-3.76**
P2 X P5	-18.46**	0.31	-15.55**	-2.82**
P2 X P6	20.69**	45.28**	-6.67	37.44**
P2 X P7	2.99**	29.04**	-11.11**	33.67**
P3 X P4	-5.33**	36.09**	-4.17	29.82**
P3 X P5	-5.33**	38.05**	-45.0**	-21.79**
P3 X P6	-6.67**	3.76*	-10.81**	17.49**
P3 X P7	1.33**	26.92**	-5.08	32.09**
P4 X P5	-6.15**	17.32**	-27.1**	-11.44**
P4 X P6	23.73**	23.64**	-13.51**	34.77**
P4 X P7	19.40**	83.88**	-19.77**	62.31**
P5 X P6	-4.61**	-17.96**	-2.4	-19.28**
P5 X P7	11.94**	-2.63*	-24.5**	-25.55**
P6 X P7	20.90**	-1.65	-2.16	0.56**
Heterosis mean	0.41	9.64	-14.04	6.06
SE	0.495	1.542	4.105	0.162
LSD(0.05)	0.843	2.626	6.990	0.276
LSD(0.01)	1.225	3.813	10.151	0.401

* Significant at 5% level

* * Significant at 1% level

Table 15. Percent heterosis over better parent of 21 tomato hybrids for four fruit characters

Crosses	Characters			
	Fruit length (cm)	Fruit breadth (cm)	Brix %	Locules per fruit
P1 X P2	-2.46**	15.49**	14.39**	27.5**
P1 X P3	-11.24**	-8.45**	-33.81**	-5.41**
P1 X P4	-12.86**	-7.75**	-11.51**	-16.22**
P1 X P5	-3.75**	-2.59**	10.07**	5.41**
P1 X P6	-6.77**	2.64**	24.70**	13.51**
P1 X P7	-5.01**	8.10**	31.89**	10.81**
P2 X P3	-22.71**	-9.01**	-9.66**	-15.00**
P2 X P4	-12.50**	-11.48**	-24.30**	-22.50**
P2 X P5	-8.45**	-2.93**	8.10**	7.50**
P2 X P6	-7.39**	1.94**	6.22**	0.00
P2 X P7	-11.79**	0.53*	16.26**	7.50**
P3 X P4	-24.11**	1.49**	-7.87**	-11.11**
P3 X P5	-7.36**	-17.93**	14.18**	-8.11**
P3 X P6	-11.28**	8.70**	9.95**	11.11**
P3 X P7	-23.01**	-4.61**	-41.87**	13.89**
P4 X P5	-12.14**	-10.69**	3.93**	-18.92**
P4 X P6	-4.28**	0.62**	17.91**	-3.85**
P4 X P7	-10.18**	-12.36**	4.19**	-25.00**
P5 X P6	-5.45**	0.86**	20.65**	13.51**
P5 X P7	-11.13**	-7.09**	13.30**	5.41**
P6 X P7	-0.56**	0.55*	13.05**	-6.25**
Heterosis mean	-10.21	-2.57	3.80	-0.77
SE	0.222	0.232	0.302	0.266
LSD(0.05)	0.379	0.396	0.515	0.452
LSD(0.01)	0.550	0.575	0.748	0.657

* Significant at 5% level

* * Significant at 1% level

4.2.10 Brix%

Among the 21 cross combinations 15 crosses showed positive heterosis and all of them showed significant positive heterosis over better parent for brix%. The heterosis over better parent ranges from -41.87 to 31.89% (Table 15). The highest significant positive heterosis was observed in the cross P1xP7 (31.89%) followed by P1xP6 (24.7%). The highest significant negative heterosis was observed in the cross P3xP7 (-41.87%) followed by P1xP3 (-33.81%). Srivastava (1998 b), Bhatt (2001 a) and Kurian *et al.* (2001 a) also reported heterosis for this trait in tomato.

4.2.11 Locules per fruit

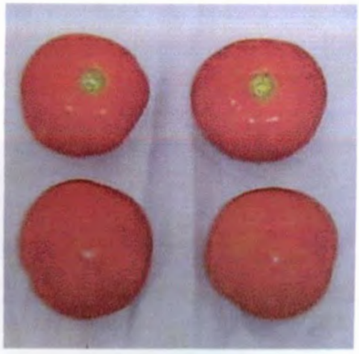
Out of 21 cross combinations, 10 crosses showed positive heterosis over better parent and all of them showed significant positive heterosis (Table 15). The estimate of heterosis ranges from -25.00 to 27.5%. The highest significant positive heterosis was observed in the cross PxP2 (27.5%) followed by P3xP7 (13.89%) and P1xP6 (13.51%). The highest significant negative heterosis was observed in the cross P4xP7 (-25.00%) followed by P2xP4 (-22.5%) and P1xP4 (-16.22%). Kurian *et al.* (2001 b) also identified heterotic hybrids for locule number.

From the result noticeable better parent heterosis was found for almost all the 11 characters (Table 13 to Table 15). It also shows the possibility of increasing yield by exploiting heterosis. From the present study it can be said that for high yielding and quality cultivars of tomato, hybrid can be used to smooth the progress of development. The photographs of the experimental field, fruit bearing hybrids and fruits are presented from plate 1 to plate 7.

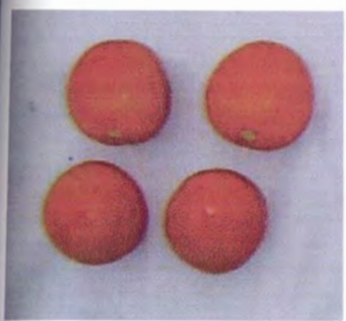
Plate 1. Field view of the experiment in winter 2005-2006

P1

P2



P3



P4

P5

P6

P7

Plate 2. Fruits of seven parental lines used in the experiment

Plate 3. Tomato plants of the cross combinations P2 x P7 of bearing stage

Plate 4. Tomato plants of the cross combinations P6 x P7 of bearing stage

Plate 5. Tomato plants of the cross combinations P2 x P6 of bearing stage

Plate 6. Tomato plants of the cross combinations P4 x P7 of bearing stage

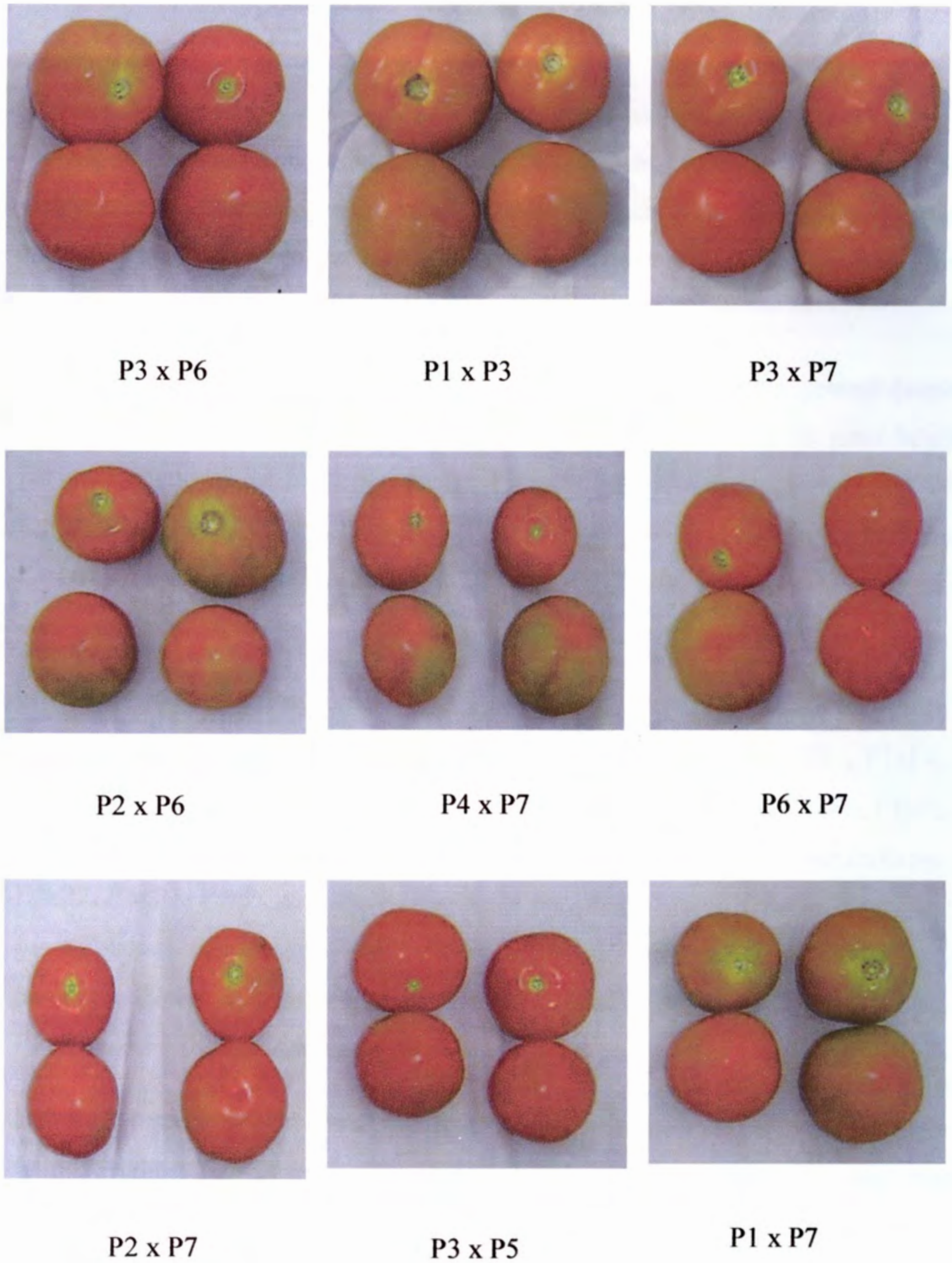


Plate 7. Fruits of some selected cross combinations.

CHAPTER V
SUMMERY

The combining ability and heterosis in tomato were studied during winter season of 2005-2006 at the experimental field of Olericulture division, Horticultural Research Center (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. The nature of combining ability and heterosis of seven parents and twenty-one cross combinations were evaluated for eleven parameters.

Among the seven parents P3 and P4 were considered as the best general combiner for early flowering, P1 and P7 for plant height at 50% flowering, P1 for plant height at last harvest, P7 and P3 for fruits per cluster, P3 and P7 for fruits per plant, P1, P2, P6 and P7 for individual fruit weight, P7 and P2 for yield per plant, P2 and P6 for fruit length, P1, P2 and P5 for fruit breath, P6, P1 and P7 for brix% and P2, P1 and P5 for locules per plant.

The cross combinations P3xP6, P1xP3 and P3xP7 showed significant SCA effects for earliness. Significant combinations were observed in P3xP6, P4xP6 , P1xP4, P1xP3, P2xP6, P3xP5, P1xP5, P3xP7 for plant height at 50% flowering, P1xP3, P1xP2, P1xP4 and P1xP5 for plant height at last harvest, P2xP6, P4xP7 and P6xP7 for fruits per cluster, P4xP7, P2xP7, P2xP6 and P3xP5 for fruits per plant, P1xP7, P1xP2, P3xP7 and P3xP6 for individual fruit weight, P4xP7, P2xP6, P3xP7, P1xP7, P4xP6 and P2xP7 for yield per plant, P1xP2 for fruit breadth, P1xP7, P3xP6, P4xP6, P2xP7 and P5xP6 for brix% and P1xP2 and P5xP6 for locules per fruit.

Heterotic responses over the better parent were calculated and significant heterosis was found. Highest significant positive heterobeltosis for fruits per cluster was observed in the cross P4xP6 followed by P6xP7, P2xP6 and P4xP7. The best heterotic cross for fruits per plant was P4xP7 followed by P2xP6, P3xP5 and P3xP4 and for individual fruit weight cross P1xP7 followed by P1xP2. For fruit yield per plant maximum heterosis was observed in the cross P4xP7 followed by P2xP6, P4xP6 and P2xP7 and for brix% highest heterosis was observed in the cross P1xP7 followed by P1xP6.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

Conclusion

Considering the results and discussions of the experiment, the following conclusion may be made:

- Combining ability analysis involving 7 x 7 half-diallel cross indicated that additive gene actions are important in governing the yield, its attributing components and quality indicating the possibility of improving the crop by direct selection of individual plant.

- The parent P7 was the best general combiner for plant height at 50% flowering, fruits per cluster, fruits per plant, individual fruit weight, yield per plant and brix%, P1 for plant height at 50% flowering, plant height at last harvest, individual fruit weight, fruit breath, brix% and locules per plant, P2 for individual fruit weight, yield per plant, fruit length, fruit breadth and locules per plant and P3 for early flowering, fruits per cluster and fruits per plant.

- The cross combinations P3xP6 was superior for earliness, P3xP6 for plant height at 50% flowering, P1xP3 for plant height at last harvest, P2xP6 for fruits per cluster, P4xP7 for fruits per plant, P1xP7 for individual fruit weight, P4x P7 for yield per plant, P1xP2 for fruit breadth, P1xP7 for brix% and P1xP2 for locules per fruit. Such SCA effects may be used for the improvement of the respective characters.

- Substantial heterosis over the better parent was found in a number of characters in many hybrids. Highest significant positive heterobeltosis for fruits per cluster was observed in the cross P4xP6, for fruits per plant cross P4xP7, for individual fruit weight cross P1xP7, for fruit yield per plant cross P4xP7 and for brix% highest heterosis was observed in the cross P1xP7.

- The genetic information generated in this study will be helpful to a plant breeder for developing an effective hybrid variety development programme of tomato in Bangladesh. These information might be helpful for a plant breeder of the similar tropical environment.

Recommendation

The promising crosses may be considered for further evaluation to release as hybrid variety.

CHAPTER VII

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CHAPTER VIII

APPENDICES

Appendix 1. Weather data of the experimental site during the period of October, 2005 to March, 2006.

Months	Air temperature (°C)		Relative humidity (%)		Rainfall (mm) (Average)
	Min.	Max.	Min.	Max.	
October	23.74	30.71	86.64	95.58	9.29
November	18.10	29.06	82.73	97.63	0.26
December	13.95	27.14	68.81	94.23	96
January	12.00	25.27	68.25	95.25	-
February	17.75	30.80	57.90	88.93	-
March	19.49	32.69	48.41	92.38	-

Source: Meteorological Department, BARI.

Appendix 2. Analysis of variance for genotypes (parents and crosses)

Source of variation	df	Mean sum of squares				
		Days to 50% flowering	Plant height at 50% flowering(cm)	Plant height at last harvest (cm)	Fruits per cluster	Fruits per plant
Block	2	2.16	0.37	62.69	1.86	501.00**
Genotypes	27	32.98**	173.57**	3582.63**	1.09	157.85**
Error	54	5.57	10.74	21.18	0.65	6.34

Appendix 2. Cont'd

Source of variation	df	Mean sum of squares					
		Individual fruit weight (g)	Yield per plant (kg)	Fruit length (cm)	Fruit breadth (cm)	Brix %	Locules per fruit
Block	2	27.18	2.61**	0.005	0.001	0.21	0.68
Genotypes	27	761.35**	0.78**	0.41**	0.49**	1.75**	0.87**
Error	54	44.93	0.07	0.13	0.14	0.24	1.89

* * Significant at 1% level

Appendix 3.1. Percent heterosis over mid parent of 21 tomato hybrids for three morphological characters

Crosses	Characters		
	Days to 50% flowering	Plant height at 50% flowering(cm)	Plant height at last harvest (cm)
P1 X P2	8.60**	14.52**	101.84**
P1 X P3	-7.41**	30.57**	104.28**
P1 X P4	-0.45	28.63**	76.58**
P1 X P5	7.41**	19.52**	70.80**
P1 X P6	1.69	16.83**	60.21**
P1 X P7	0.0	11.68**	77.13**
P2 X P3	-4.39*	16.06**	25.49**
P2 X P4	0.94	16.12**	24.25**
P2 X P5	9.29**	10.10**	25.11**
P2 X P6	3.11*	24.54**	48.83**
P2 X P7	1.36	11.45**	43.94**
P3 X P4	-5.31**	14.71**	9.18**
P3 X P5	-2.0	23.92**	8.08**
P3 X P6	-9.09**	44.87**	36.89**
P3 X P7	-7.41**	19.32**	19.14**
P4 X P5	3.38*	9.76**	-6.92**
P4 X P6	-1.32	34.45**	38.79**
P4 X P7	0.45	15.50**	12.94**
P5 X P6	9.09**	13.17**	1.59
P5 X P7	11.11**	10.03**	29.51**
P6 X P7	1.69	9.14**	19.69**
Heterosis mean	0.99	18.80	39.39
SE	1.67	2.32	3.25
LSD(0.05)	2.84	3.95	5.53
LSD(0.01)	4.13	5.74	8.04

* Significant at 5% level

* * Significant at 1% level

Appendix 3.2. Percent heterosis over mid parent of 21 tomato hybrids for four yield component characters

Crosses	Characters			
	Fruits per cluster	Fruits per plant	Individual fruit weight (g)	Yield per plant (kg)
P1 X P2	-3.94**	-14.04**	16.32**	0.0
P1 X P3	2.04**	12.65**	-9.37*	9.43**
P1 X P4	8.40**	-5.36**	-11.52*	-11.00**
P1 X P5	-5.11**	-10.53**	-9.27*	-18.03**
P1 X P6	6.15**	-2.53	11.39*	10.17**
P1 X P7	5.04**	5.86**	26.61**	36.06**
P2 X P3	0.0	24.35**	-12.24**	14.07**
P2 X P4	0.0	26.31**	-13.04**	14.43**
P2 X P5	-11.67**	10.96**	-10.59*	1.31**
P2 X P6	23.89**	46.39**	2.44	50.0**
P2 X P7	13.11**	38.65**	-0.49	39.64**
P3 X P4	5.97**	36.19**	0.0	34.89**
P3 X P5	1.43**	40.05**	-29.03**	-0.79**
P3 X P6	5.26**	15.48**	11.86**	33.72**
P3 X P7	7.04**	32.81**	17.07**	56.64**
P4 X P5	-1.61**	18.93**	-8.87*	9.07**
P4 X P6	24.79**	42.04**	4.92	48.19**
P4 X P7	26.98**	92.28**	-4.38	85.89**
P5 X P6	0.81	-9.86**	1.40	-8.36**
P5 X P7	13.64**	0.48	-19.89**	-19.08**
P6 X P7	29.60**	4.93**	0.0	5.27**
Heterosis mean	7.23	19.34	-1.75	18.64
SE	0.57	1.78	4.74	0.19
LSD(0.05)	0.97	3.03	8.07	0.32
LSD(0.01)	1.41	4.40	11.72	0.47

* Significant at 5% level   * * Significant at 1% level

Appendix 3.3. Percent heterosis over mid parent of 21 tomato hybrids for four fruit characters

Crosses	Characters			
	Fruit length (cm)	Fruit breadth (cm)	Brix %	Locules per fruit
P1 X P2	3.07**	15.70**	29.27**	32.47**
P1 X P3	0.0	0.19	-21.14**	-4.11**
P1 X P4	-8.61**	4.38**	2.22**	1.64**
P1 X P5	0.83**	-1.57**	44.34**	5.41**
P1 X P6	-4.62**	10.84**	27.14**	33.33**
P1 X P7	-2.10**	10.63**	33.82**	18.84**
P2 X P3	-8.35**	-0.58*	-3.81**	-10.53**
P2 X P4	-11.88**	0.0	-22.36**	-3.13**
P2 X P5	0.97**	-1.75**	28.52**	11.69**
P2 X P6	-4.36**	10.11**	18.61**	21.21**
P2 X P7	-9.48**	2.71**	29.67**	19.44**
P3 X P4	-10.53**	5.52**	-4.42**	6.67**
P3 X P5	0.47*	-9.51**	28.28**	-6.84**
P3 X P6	2.39**	10.06**	29.24**	29.03**
P3 X P7	-10.56**	2.17**	-31.39**	20.59**
P4 X P5	-3.72**	1.97**	21.92**	-1.64**
P4 X P6	-1.83**	5.88**	35.43**	0.0
P4 X P7	-8.46**	-2.86**	19.15**	-14.28**
P5 X P6	1.21**	10.17**	55.95**	33.33**
P5 X P7	-4.39**	-3.92**	46.96**	13.04**
P6 X P7	0.19	6.24**	13.61**	3.45**
Heterosis mean	-3.80	3.64	18.14	9.98
SE	0.26	0.27	0.35	0.31
LSD(0.05)	0.44	0.46	0.59	0.53
LSD(0.01)	0.64	0.67	0.87	0.77

* Significant at 5% level   * * Significant at 1% level

Appendix 4.1. Mean performance of three morphological characters of 7 parents And 21 cross combinations of tomato.

Genotypes	Morphological characters		
	Days to 50% flowering	Plant height at 50% flowering(cm)	Plant height at last harvest (cm)
P1	58	87.2	129.0
P2	52.5	82.9	88.5
P3	50	67.2	71.94
P4	53.5	72.8	112.16
P5	50	80.8	102.00
P6	60	70.3	86.33
P7	58	91.7	104.17
P1 X P2	60	97.4	219.5
P1 X P3	50	100.8	205.25
P1 X P4	55.50	102.9	212.92
P1 X P5	58	100.4	197.50
P1 X P6	60	92.0	172.50
P1 X P7	58	99.9	206.5
P2 X P3	49	87.1	100.67
P2 X P4	53.5	90.4	124.67
P2 X P5	56	90.1	119.16
P2 X P6	58	95.4	130.10
P2 X P7	56	97.3	138.67
P3 X P4	49	80.3	100.50
P3 X P5	49	91.7	94.0
P3 X P6	50	99.6	108.34
P3 X P7	50	94.8	104.92
P4 X P5	53.5	84.3	99.67
P4 X P6	56	96.2	137.75
P4 X P7	56	95.0	122.16
P5 X P6	60	85.5	95.66
P5 X P7	60	94.9	133.5
P6 X P7	60	88.4	114.0
CV%	7.38	10.37	32.62

Appendix 4.2. Mean performance of four yield component characters of 7 parents and 21 cross combinations of tomato.

Genotypes	Yield component characters			
	Fruits per cluster	Fruits per plant	Individual fruit weight (g)	Yield per plant (kg)
P1	7.2	20.9	105.0	2.19
P2	5.5	26.1	112.5	2.93
P3	7.5	33.25	55.0	1.84
P4	5.9	33.2	60.0	1.99
P5	6.5	32.3	100.0	3.19
P6	5.8	26.5	92.5	2.43
P7	6.7	30.3	88.5	2.68
P1 X P2	6.1	20.2	126.5	2.56
P1 X P3	7.5	30.5	72.5	2.21
P1 X P4	7.1	25.6	73.0	1.86
P1 X P5	6.5	23.8	93.0	2.21
P1 X P6	6.9	23.1	110.0	2.55
P1 X P7	7.3	27.1	122.5	3.32
P2 X P3	6.5	36.9	73.5	2.72
P2 X P4	5.7	37.45	75.0	2.82
P2 X P5	5.3	32.4	95.0	3.1
P2 X P6	7.0	38.5	105.0	4.02
P2 X P7	6.9	39.1	100.0	3.91
P3 X P4	7.1	45.25	57.5	2.59
P3 X P5	7.1	45.9	55.0	2.49
P3 X P6	7.0	34.5	82.5	2.86
P3 X P7	7.6	42.2	84.0	3.54
P4 X P5	6.1	38.95	72.9	2.83
P4 X P6	7.3	41.05	80.0	3.27
P4 X P7	8.0	61.05	71.0	4.35
P5 X P6	6.2	26.50	97.6	2.57
P5 X P7	7.5	31.45	75.5	2.37
P6 X P7	8.1	29.80	90.5	2.69
CV%	10.91	26.63	22.53	22.58

Appendix 4.3. Mean performance of four fruits characters of 7 parents and 21 cross combinations of tomato.

Genotypes	Fruit characters			
	Fruit length (cm)	Fruit breadth (cm)	Brix %	Locules per fruit
P1	5.07	5.68	4.17	3.7
P2	5.68	5.66	3.21	4.0
P3	3.9	4.71	2.82	3.6
P4	5.6	4.36	3.05	2.4
P5	4.62	5.8	2.2	3.7
P6	5.32	4.83	4.02	2.6
P7	5.39	5.42	4.06	3.2
P1 X P2	5.54	6.56	4.77	5.1
P1 X P3	4.5	5.2	2.76	3.5
P1 X P4	4.88	5.24	3.69	3.1
P1 X P5	4.88	5.65	4.59	3.9
P1 X P6	4.96	5.83	5.2	4.2
P1 X P7	5.12	6.14	5.5	4.1
P2 X P3	4.39	5.15	2.9	3.4
P2 X P4	4.97	5.01	2.43	3.1
P2 X P5	5.2	5.63	3.47	4.3
P2 X P6	5.26	5.77	4.27	4.0
P2 X P7	5.01	5.69	4.72	4.3
P3 X P4	4.25	4.78	2.81	3.2
P3 X P5	4.28	4.76	3.22	3.4
P3 X P6	4.72	5.25	4.42	4.0
P3 X P7	4.15	5.17	2.36	4.1
P4 X P5	4.92	5.18	3.17	3.0
P4 X P6	5.36	4.86	4.74	2.5
P4 X P7	5.03	4.75	4.23	2.4
P5 X P6	5.03	5.85	4.85	4.2
P5 X P7	4.97	5.39	4.6	3.9
P6 X P7	5.36	5.45	4.59	3.0
CV%	9.11	9.35	24.61	18.49