DEVELOPMENT OF HYBRIDS WITH BACTERIAL WILT RESISTANCE IN TOMATO (*Solanum lycopersicum* L.)

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT OF HYBRIDS WITH BACTERIAL WILT RESISTANCE IN TOMATO (*Solanum lycopersicum* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society

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CERTIFICATE

Certified that this thesis, entitled **"DEVELOPMENT OF HYBRIDS WITH BACTERIAL WILT RESISTANCE IN TOMATO (*Solanum lycopersicum* L)"** is a record of research work done by independently by Ms Shalini, K R (2014-12-132) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her

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Shalini K R

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LIST OF ABBREVIATIONS

%	-	per cent
&	-	and
σ^2A		Additive variance
σ^2D	-	Dominance variance
ANOVA	-	Analysis of variance
AVRDC	-	Asian Vegetable Research Development Center
a m	-	Anti meridian
BP	-	Better parent
CD (0 05)	-	Critical difference at 5 % level
cm	-	centimeter
d f	-	Degrees of freedom
et al	-	and co-workers/co-authors
F_1	-	First filial generation
g	-	gram
GCA	-	General combining ability
ha	-	hectare
HB	-	Heterobeltiosis
i e	-	that is
kg	-	kilogram
KAU	-	Kerala Agricultural University
LE	-	*Lycopersicon esculentum*
MP	-	Mid parent
NBPGR	-	National Bureau of Plant Genetic Resources
RH	-	Relative heterosis
RBD	-	Randomized Block Design
SCA	-	Specific combining ability
SH	-	Standard heterosis
sp	-	Species
TSWV	-	Tomato spotted wilt virus
viz	-	namely

Introduction

1 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely cultivated vegetable crop in the world. It belongs to family *Solanaceae* with chromosome number of 2n = 24. The South American centre consisting of Peru, Eucador Bolivian region is believed to be the primary center of origin (Rick, 1969) and it is presumed to have been brought to India during the second half of the 16th century. Primitive relatives of the edible tomato occupy diverse environments based on latitude and represent an almost inexhaustible gene pool for improvement of the species (Alcazer, 1981).

Tomato is referred as poor man's orange because of its high nutritional security and attractive appearance (Singh *et al.*, 2004). It is a rich source of vitamin A (320 IU/ 100g), vitamin C (31 mg/ 100g) and minerals (680 mg/ 100g) (Anand and Sankari, 2015). It is an annual, day neutral and short-lived herbaceous plant. It is a self pollinated crop, with certain percentage of cross pollination. It is a warm season crop reasonably tolerant to heat, drought and grows in a varied range of soil and climatic conditions.

In India, tomato occupies 3rd position in area, 2nd in production and 3rd in productivity among the vegetables grown in India. It is being cultivated in an area of 8.82 lakh ha with a production of 18.74 lakh tons and productivity of 21.2 t ha^{-1} (NHB, 2015).

The great efforts made by several vegetable breeders from different sectors have resulted in tremendous crop improvement with respect to yield and yield contributing characters. As a result of this, many new cultivars have been developed to meet the varied consumer requirements and climatic conditions under which tomato is cultivated.

In the era of increasing population with dwindling land area, there exists a constant pressure in realizing nutritional security. There is an immediate need for crop improvement programmes which helps in developing superior stable and resistant varieties with better yield and quality

Heterosis is one of the methods to improve the yield and quality It is the superiority of F_1 s over their parents and its manifestation in tomato is extensively utilized in the form of high vigour, good crop growth and development, earliness in flowering and maturity, increased fruit yield and its characters, good level of resistance to pests and diseases (Yordanov, 1983)

The general and specific combining ability pertaining to yield and other characters greatly influences the selection efficiency and cultivar improvement programmes Hence, the assessment of combining ability is of greater importance in crop breeding programmes intended to exploit heterosis or for combining the desirable genes

In the tropics and subtropics, the productivity of tomato is comparatively low due to attack of various diseases caused by bacteria, fungi, virus and nematodes Among them the soil borne pathogen *Ralstonia solanacearum* (Smith), causing bacterial wilt is one of the serious limiting factors in tomato cultivation The area under tomato is very meagre in Kerala since it is the hot spot for bacterial wilt disease Control of this disease is difficult because of the acidic soil condition, broad host range, widespread distribution, and vast genetic variability of the pathogen (Hayward, 1991)

R solanacearum is known to infect more than 450 plant species in 54 families (Mondal *et al*, 2014) The bacterium is soil borne and can indefinitely persist in infested fields even in the absence of any host (Chellemi *et al*, 1994) It is found upto 45 cm depth, concentrated near the rhizosphere, with the advancement of the disease Bacterial wilt is mainly prevalent in the states like Kerala, Karnataka, Maharashtra, Orissa and West Bengal The yield loss due to this disease is up to 90 62 per cent (Dharmatti *et al*, 2009) Often the damage can extend upto 100% crop loss (Rao *et al*, 1975)

Symptoms of the disease include rapid and complete wilting of grown up plants Pathogen is mostly confined to vascular regions Upon infection, bacterial polysaccharides mechanically block the vascular system, which checks the translocation of water and other food material resulting in complete wilting of plants The disease can be confirmed by doing ooze test (Alvarez *et al* , 2010)

The disease mainly spreads through infected soil, unhealthy plant materials, irrigation water, farm implements etc Therefore, it is found difficult for the complete eradication of the disease and the only way to overcome this problem is to concentrate on the development of varieties/ hybrids resistant to the disease

Keeping in view of aforesaid requirements in tomato, the present investigation was taken up with the following objectives

1 To assess the magnitude of heterosis in crosses for yield and its components

2 To estimate the general combining ability of parents and specific combining ability of hybrids and gene actions for yield and its related characters

3 To identify bacterial wilt resistant and high yielding crosses

Review of Literature

2. REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L), is the second most important vegetable in terms of total production and has worldwide commercial distribution It is the most popular solanaceous vegetable crop grown under both open and protected conditions because of its wider adaptability, high yield potential and suitability for the preparation of a variety of processed products The main objective of any breeding programme is to improve both qualitative as well as quantitative parameters of a crop The information on genetics of various quantitative traits particularly of yield would be the most useful in planning the breeding programmes so as to make effective selections

The literature pertaining to the various features of present investigation is reviewed and presented below under different captions

2 1 Mean performance

2 2 Heterosis

2 3 Combining ability

2 4 Bacterial wilt disease

2 1 MEAN PERFORMANCE

Kurian and Peter (2001) recorded that the cross Sakthi x TH 318 performed better for yield plant^{-1} (1280 34 g), Sakthi x Fresh Market 9 for fruit weight (70 97 g), LE 206 x Ohio 8129 for lycopene content (11 66 mg/ 100 g)

According to Bhatt *et al* (2004), the cross Mechin x EC 386023 exhibited higher *per se* performance under open condition for yield plant^{-1} (2 48 kg), Hawaii-7998 x EC 386037 for fruits plant^{-1} (134 67), EC 386032 x BL-342 for fruit weight (62 33 g), DARL-64 x Hawaii-7998 for days to maturity (83 00), EC 386037 x Sel-7 for plant height (76 33 cm), Hawaii-7998 x Sel-7 for ascorbic acid content (35 56 mg/ 100 g), EC 386037 x BL-342 for lycopene content (7 70 mg/ 100 g) and EC 386032 x BL-342 for TSS (6 33^{0} brix)

Rao *et al* (2007a) reported that the crosses Feb-2 x Pusa Sheetal and Feb-2 x Pusa Gaurav were found to be the best in terms of yield potential (2 88 and 2 80 kg/ plant, respectively) and also exhibited moderate resistance to early blight with a disease intensity of 32 51 and 36 29%, respectively

Gul *et al* (2010) observed highly significant differences among tomato genotypes for number of flowers cluster^{1}, number of fruits cluster^{1}, fruit length, fruit width, fruit weight and yield plant^{1} Among the parents, the mean value for fruit weight ranged from 24 g (P_{38}) to 55 g (P_{54}), while in the crosses it ranged from 30 g ($P_{28}\times P_{38}$) to 59 g (E-02$\times P_{30}$) For yield plant^{1}, the mean value ranged from 391 3 g (P_{38}) to 924 g (P_{45}) in the parents whereas, it ranged between 394 3 g ($P_{38}\times P_{59}$) to 953 g (E-02$\times P_{28}$) in the crosses

According to Dhahwal and Cheema (2011), the highest yield plant^{1} was exhibited by the cross 56-14-6 x 56-12-7-1 (3 76 kg/ plant) while, 54-26-1-1 x 57-9-6-1 exhibited high *per se* performance for fruit weight (138 50 g)

In a line x tester analysis done by Kumari and Sharma (2011), the cross EC-13736 x Solan Vajr was found to be the earliest for flowering (32 00), EC-521041 x FT-5 had the highest plant height (198 25 cm), Sioux x FT-5 recorded maximum fruits cluster^{1} (4 47), Sioux x FT-5 had maximum fruits plant^{1} (28 50), S- 1001 x Solan Vajr exhibited maximum fruit weight (90 61g), Sioux x FT-5 recorded the highest yield plant^{1} (2100 00 g), EC-521051 x Solan Vajr had high TSS (4 6 ^{0}brix) and EC-13736 x Solan Vajr recorded high ascorbic acid content (39 36 mg/ 100 g)

According to Chattopadhyay and Paul (2012), fruit length ranged from 3 10 cm (P_8) to 7 cm (P_2), fruit width ranged from 3 30 cm (P_2) to 6 90 cm (P_4), pericarp thickness ranged from 0 40 cm (P_3 and P_{10}) to 0 80 cm (P_4), locules fruit^{-1} ranged from 2 (P_2) to 6 (P_4 and P_8), TSS (^{0} brix) ranged from 5 7 (P_6 and P_{12}) to 7 67 (P_8), vit C (mg/ 100 g) ranged from 23 (P_2) to 40 (P_3 and P_9)

Farzane *et al* (2012) reported that the cross Mb3× V1j P... for fruit number plant^{-1} (76 22), Mb3× Sps for fruit weight (82 66 g), Pte12 × Ptk for yield plant^{-1} (3 64 kg) and Sps × Prg for locule number (6 59)

According to Shankar *et al* (2014), the mean performance of F_1 hybrids for plant height ranged from 58 3 to 153 63 cm, number of primary branches per plant from 6 73 to 10 37, days to 50% flowering from 28 to 35, number of flowers per cluster from 4 57 to 6 37, number of fruits per cluster from 1 97 to 3 6, fruit weight from 41 43 to 105 5 g, yield per plant from 1 6 to 3 9 kg, TSS from 3.17 to 5^0 brix, ascorbic acid content from 14 67 to 40 mg/ 100 g, lycopene content from 2 53 to 8 73 mg/ 100 g

Highly significant differences among tomato gnotypes was observed by Baban *et al* (2015) and reported that the parent P_2 xhibited the highest fruit weight of 53 99 g, P_4 recorded maximum fruit polar iameter (4 18 cm), P_2 for equatorial diameter (5 31 cm), P_6 for number of locules(3 01), P_4 for fruit pericarp thickness (0 50 cm) and fruit firmness (3 05 kg/ cm)

Pandiarana *et al* (2015) crossed five inbred lines f tomato in a half diallel fashion and observed that among the parents, *BCT- 115* ecorded the maximum fruit weight (80 10 g), yield plant^{-1} (3 12 kg), TSS(4 8^0 bri) and lycopene content (4 5 mg/ 100 g) while, Ailsa Craig recorded the highest iscorbic acid content (33 56 mg/ 100 g)

2 2 HETEROSIS

Heterosis is defined as the superiority f the hybrids over their parents in vegetative, adaptiveness and productivity (ill, 1908, East, 1936, Gustafsson, 1946 and Hayes, 1952) Heterosis in toma as first observed by Hedrick and Booth (1968) and later by number of w s (Bhatt *et al*, 1999, 2001a) Choudhary *et al* (1965) reported the utiliz of heterosis for higher tomato production Being a self pollinated crop, oretical sense the degree of heterosis is less in tomato (Gallias *et al* , 198 phenomenon of exploitation of heterosis in tomato has become a reality be ... nificant increase in the important traits in F_1 hybrids over their parental values Heterosis helps in developing early, high yielding and disease resistant hybrids with increased fruit qualities

Baishya *et al* (2001) reported that the hybrid, ECA881 x EC-130204 (113 03%) exhibited superior heterosis over better parent for yield plant^{1} which was followed by the crosses, EC-429 x Pant T-1 (28 19%), EC-41025 x Pant T-1 (26 65%) and EC-32557 x Pant T-1 (22 75%)

Kurian and Peter (2001) observed significant heterosis for fruit weight over the mid parent in Sakthi x Fresh Market 9 and Sakthi x HW 208F (18 73 and 10 90% respectively) and relative heterosis for fruit yield in the crosses, Sakthi x TH 318 and Sakthi x Fresh Market 9 (9 20 and 13 24% respectively)

Superior heterobeltiosis for plant height was observed in hybrid, 97/640 x KT-15 (37 28%), FEB-2 x KT-15 for number of primary branches (48 93%), Sel-2 x KT15 for number of fruits plant^{1} (38 96%), Futestio x KT-15 (26 29%) and BT-207 x KT-15 (42 87%) for fruit weight High level of heterosis for fruit yield plant^{1} was observed in hybrids, Futestro x KT-15, KT-1 0 x KT-'15, 97/640 x KT-15 and BT-1 02-2-1 x KT-15 (Asati *et al*, 2007)

Singh *et al* (2008) estimated appreciable level of heterobeltiosis for plant height in the crosses, Sikkim Local x EC-521 080 (117 29%), Vaibhav x EC-521080 (116 83%) Arka Vikas x H-86 showed significant heterobeltiosis for number of primary branches (155 85%) Tura local x H-88-78-1 and H-24 x DVRT-2 showed negative heterosis with respect to days to flowering which ranged from 4 13 to -37 5 percent respectively The cross PKM-1 x EC521080 (165 43%) showed heterosis over better parent for number of fruits plant^{1} The highest heterosis for yield plant^{1} was seen in H-88-87 x H-88-78-2 (210 45%)

Significant heterosis over better parent and standard check for yield plant^{1} ranged from -43 67 to 30 91 per cent and -63 49 to 63 78 per cent, respectively of which four crosses *viz* S- 65xArkaAlok, S-05xDMT, S-05x Arka Alok and S-05xBFL exhibited significant positive heterosis Significant heterobeltiosis for fruit weight ranged from 37 76 to 30 50 per cent The hybrids, S-61 x Ark Alok, (44 45%) S-0 5 x DMT -1 (36 61%) and S-0 5x BFL (39.22%) showed positive heterosis over standard check for fruit number plant^{1} (Kumar *et al*, 2009)

Gul *et al* (2010) observed positive heterosis for flowers cluster^{1} in hybrid $P_{38} \times P_{54}$ (53 1%) and fruits cluster^{1} in the cross $P_{28} \times P_{30}$ (38 9%) Relative heterosis for fruit length and width was exhibited by E-02 × P_{38} (32 7%) and E-02 × P_{45} (10 6%) respectively The crosses, E-02 × P_{28} and E-02 × P_{30} exhibited superior heterotic effects of 45 0 and 24 4 percent respectively for fruit weight Relative heterosis for yield plant^{1} was recorded in E-02 × P_{51} (19 3%) and E-02 × P_{28} (34 9%)

Kumari *et al* (2010) studied heterotic expression for yield and its components in tomato and observed that the crosses, KS-16 x Azad T-3, Azad T-3 x KS-7, Angoorlata x KS-7 and KS-16 x Angoorlata showed high heterotic effects over their parents in terms of yield and its related characters, percent values ranging from 65 181 to 98 62

Ahmad *et al* (2011) studied the heterosis of 21 tomato cross combinations and found that the crosses $P_2 \times P_3$, $P_3 \times P_4$, and $P_3 \times P_5$ showed significant heterosis for early flowering while, the hybrids $P_1 \times P_7$ (16 67%) and $P_1 \times P_2$ (12 44%) showed desirable heterosis for fruit weight The study also revealed that the hybrids, $P_4 \times P_7$ (62 31%), $P_2 \times P_6$ (37 44%), $P_4 \times P_6$ (34 77%), $P_2 \times P_7$ (33 67%), $P_3 \times P_7$ (32 09%), and $P_3 \times P_4$ (29 82%) exhibited higher manifestation of heterobeltiosis for yield plant^{1}

Dhaliwal and Cheema (2011) evaluated 91 F_1 hybrids of tomato to identify the crosses which are performing better under leaf curl virus infested areas Appreciable amount of heterosis for yield and fruit size was exhibited by the crosses, 58-18-1-1 x 56-4-6-1, 56-14-6 x 56-12-7-1 and 54-26-1-1 x 57-9-6-1 and were recommended for cultivation under severe leaf curl virus infested areas Higher magnitude of heterobeltiosis for total yield was exhibited by 54-26-1-1 x

57-9-6-1 (58 75%) while, 56-14-6 x 56-12-7-1(49 20%) exhibited the standard heterosis for the same trait

In a line x tester analysis, Kumari and Sharma (2011) reported higher magnitude of heterobeltiosis for days to first flowering in negative direction in EC-538146 x Solan Vajr (-8 41%), Sioux x Solan Vajr for number of fruits cluster^{1} (51 17%), Sioux x FT-5 for number of fruits plant^{1} (66 08%), S-1001 x Solan Vajr for fruit weight (24 98%), Sioux x FT-5 for yield plant^{1} (71 14%) EC-521051 x Solan Vajr for TSS (28 49%) and EC-1914 x EC-15998 for ascorbic acid content (23 49%)

Chattopadhyay and Paul (2012) conducted studies on heterosis for different fruit quality parameters in tomato The study revealed the highest amount of relative heterosis and heterobeltiosis to be 38 26% and 36 28% respectively, exhibited by the hybrid P_5 x P_7 (Sel 12 x Pusa Ruby) for fruit length Maximum positive heterosis was recorded for fruit width in the hybrid P_8 x P_2 (EC 12217 x Roma) (17 66%) followed by P_{11} x P_{12} (17 63%) and P_{10} x P_6 (17 33%) Higher magnitude of relative heterosis for TSS was recorded in P_{10} x P_6 (27 03%) The crosses *viz* P_1 x P_2 (28 43%) and P_8 x P_6 (3 41%) showed significant relative heterosis for vit C content

An investigation was carried out by Islam *et al* (2012) in winter tomato hybrids and found that all the crosses actively exhibited heterosis P_3 x P_8 showed heterosis over better parent for earliness (-18 46%) and P_1 x P_6 exhibited percent heterosis of 8 57 for flowers cluster^{1} The cross P_2 x P_6 exhibited good heterosis for fruits cluster^{1} (21 73%), P_6 x P_7 for plant height (75 54%), P_5 x P_6 for fruits plant^{-1} (67 44%), P_9 x P_{10} for yield plant^{1} (54 82%), P_2 x P_8 for fruit weight (21 21 %), P_7 x P_8 for fruit length (3 09%), P_3 x P_8 for fruit diameter (14 11%) and P_1 x P_6 for brix content (13 11%)

Souza *et al* (2012) observed significant heterosis, in a diallel cross among fresh market tomato inbreeding lines, for fruit yield and fruit number plant^{1} with percent values of 49 72 and 47 19 respectively High level of positive heterosis was observed for fruit weight in the crosses IAC-3 x IAC-5 (15 79%) and IAC-2 x IAC- 5 (5 88%) while for TSS, the heterosis ranged between -21 82% and 36 71%

Heterosis among 6 generations of tomato by involving four parents was studied by Droka *et al* (2013) The study indicated good level of heterosis for all the traits over then respective better parents Pusa Sadabahar x Pusa Rohini recorded significant heterobeltiosis and relative heterosis for days to 50% flowering (5 and 8 5% respectively), number of fruits plant^{1} (12 33 and 8 92% respectively) and yield plant^{1} (29 04 and 30 92% respectively)

Heterosis and its manifestation for fruit yield, quality and shelf-life was studied in tomato hybrids by incorporating *rin*, *nor* or *alc* alleles The magnitude of standard heterosis varied from -48 74 (L_1 x T_3) to 165 88% (L_4 x T_1) for total yield, -58 59 (L_1 x T_3) to 174 60% (L_5 x T_1) for marketable yield, -66 15 (L_1 x T_3) to 102 28% (L_4 x T_1) for numbei of fruits and -21 63 (L_{12} x T_2) to 101 77% (L_3 x T_3) for average fruit weight (Garg *et al*,2013)

An investigation was conducted to identify the superior parents for yield and quality characters in a LxT crossing method The cross *rin* x Sankranti recorded the significant heterotic effects over better parent for plant height (10 53%), *alc* x Pusa Ruby recorded significant heterobeltiosis for number of branches (28 89%), TSS (72 13%) and lycopene content (84 20%) while, *alc* x Vaibhav exhibited heterosis over better parent for keeping quality (7 95%) (Narasimhamurthy and Gowda, 2013)

The nature of gene action, heterosis and inbreeding depression was observed for yield and its related traits in tomato by Shalaby (2013) Significant relative heterosis was observed for plant height, number of branches plant^{1}, early yield, total yield, average fruit weight and fruit firmness with values of 30 1%, 52%, 58 2%, 69 5%, 15 8% and 46 7%, respectively The study also indicated the significant positive heterobeltiosis for numbei of branches plant^{1}, early yield, total yield and fruit firmness with values of 35 7%, 43 1%, 32 4% and 38 9%, respectively

Solieman *et al* (2013) conducted an investigation using five commercial tomato cultivars and their ten F_1 hybrids with a view to study heterosis The percent heterosis over mid parent ranged from −16 04 to 29 75 for plant height, −5 74 to 20 95 for number of primary branches plant^{1}, −11 46 to 25 50 for total soluble solids, −1 26 to 15 66 for ascorbic acid content, −9 39 to 22 48 for number of flowers cluster^{1}, 4 37 to 104 69 for number of fruits plant^{1}, −32 78 to 11 29 for average fruit weight and 22 29 to 64 33 for total yield plant^{-1}

Genetic study of heterosis for yield and quality components in tomato was carried out by Yadav *et al* (2013) using line × tester analysis The hybrid LCT-6 × Arka Vikas recorded maximum standard heterosis for plant height (50 50%), LCT-6 × NDT-5 for number of primary branches plant^{1} (36 81%), Azad-T-5 × VR-20 for fruits plant^{1} (58 50%), KS-229 × Arka Vikas for fruit length (40 77%), KS-229 × NDT-5 for fruit diameter (41 67%), KS229 ×A Vikas for fruit weight (29 58%), CO-3 ×A Vikas for yield plant^{1} (29 57%) and LCT-6 ×NDT-5 for TSS (37 50%)

Agarwal *et al* (2014) crossed eight parental lines of diverse origin of tomato in a 8 × 8 diallel mating design excluding reciprocals High level of heterobeltiosis (74 69%) and standard heterosis (117 27%) was observed for fruit weight which was followed by TSS for heterobeltiosis The percent heterosis was in the range of 6 63 to 35 90 over the better parent for fruit yield The hybrid, CLN 5915-206 × CLN 1314G registered the significant heterosis over better parent (35 90%) and standard parent (56 32%) for the same character

An experiment was carried out by Shankar *et al* (2014) and observed heterosis for yield and quality in tomato in a line × tester analysis Higher magnitude of standard heterosis was recorded in LE-53 × Arka Alok for number of flowers cluster^{-1} (25 66%), EC-164838 × Arka Alok for fruits cluster^{1} (92 86%), LE-64 × Arka Alok for fruit length (13 70%) and fruit weight

(29 22%), LE-64 × Arka Vikas for yield plant[1] (56%) and LE-56 × Arka Meghali for TSS (79 41%)

Pandiarana *et al* (2015) studied heterobeltiosis and genetic control of processing quality and disease severity traits in tomato Significant heterobeltiosis was observed in the cross CLN 2777E × Ailsa Craig for fruit yield plant[1] (32 31%), CLN2777F × Ailsa Craig fulgens for TSS (11 70%) and lycopene content (15 94%) and CLN2777E × Ailsa Craig fulgens for vit C content (13 10%)

Marbhal *et al* (2016) studied the heterosis in cherry tomato for quantitative traits Significant positive heterosis was recorded for height of plant by the hybrid 4x6 (24 74 %), length of cluster by 2x6 (23 13 %), average weight of cluster by 2x5 (32 59 %), number of fruits per cluster by 3x6 (25 00 %), fruit yield by 2x6 (46 52 %) and 1x3 (38 25 %) over better parent and number of clusters plant[1] by 3x6 (24 91 %, 22 82 %, 101 10 %) over better, top parent and commercial hybrid respectively

2 3 COMBINING ABILITY

The selection of better parent is inevitable for the success of any hybridization programme Parents are selected mainly based on their genotypic performance as well as performance of cross combinations as heterosis is not solely dependent on phenotypic expression So, for developing F_1 progeny, it is essential to analyse the combining ability Analysing *gca* will help to improve breeding works as it will provide information on gene actions Line x tester and diallel designs are mostly used in the studies undertaking combining ability

Spargue and Tatum (1942) were the first to propose the idea of combining ability in corn General combining ability (*gca*) is the comparative ability of line to combine with other lines It shows how much the mean performance of a variety is altered from all other varieties in crosses where that particular variety is involved Specific combining ability (*sca*) is deviation in the performance of specific crosses from the performance expected on the basis of general combing ability effect of parents involved in the crosses A parent, if producing progenies with above average performance, it is exhibiting a positive *gca* and vice versa If the crosses are specific, it points to *sca*

Genetically, general combining ability is associated with genes which are additive in their effects, while specific combining ability is attributed to deviation from the additive scheme caused by dominance and epistasis Combining ability involves both additive effects as well as additive x additive, additive x dominance and dominance x dominance types of interactions The general combining ability (GCA) coming from the two parents and the specific combining ability (SCA) arising from the interaction between the genotypes of the two parents, determines the performance of progeny developed by crossing each parents The popular line x tester analysis, developed from the concept of North Carolina designs, is helpful in determining the *gca* and *sca* effects

Bhatt *et al* (2001) reported the predominance of non additive gene action for yield and yield attributes in fourteen varieties of tomato crossed in a half diallel fashion The parent Punjab Chhuhara was the good general combiner for number of flowers truss^{1}, fruits truss^{1}, fruits plant^{1} and yield plant^{1} Sweet-72 was found to be the best parent for early maturity by exhibiting significant *gca* in negative direction The cross Arka Saurabh x NDT 5 was considered as the valuable combiner for earliness by exhibiting high *sca* effects in negative direction, while, Punjab Chhuhara x Azad Kranti showed high preferable *sca* effect for yield plant^{1}

Twelve divergent lines of tomato and their 66 F_1 hybrids were studied by Bhatt *et al* (2004) Analysis of variances for combining ability revealed that the crosses EC 386032 x BL-342 and Azad T-2 x Hawaii-7998 were found superior for yield plant^{1}, Hawaii-7998 x EC 386037 for fruits plant^{1} and BL-342 x Mani Thoiba and DARL-64 x Hawaii-7998 for early maturity The crosses DARL-64 x EC 386037, EC 386023 x Mani Thoiba and DARL-64 x BL-342 showed higher plant height The crosses Hawaii-7998 x Sel-7, EC 386032 x EC 386037 and BL-342 x 386023 exhibited high *sca* for ascorbic acid content and DARL-64 x EC

386019 for lycopene content EC 386032 x BL-342 and BL-342 x Sel-7 had the highest *sca* effects for total soluble solids

Premalakshme *et al* (2005), in a diallel crossing programme, observed that the parents P_1, P_2 and P_3 exibited the highest significant negative *gca* effects for days to flowering while, significant *sca* in negative direction was observed in the hybrids P_1 x P_3, P_1 x P_4, P_1 x P_5, P_1 x P_6, P_2 x P_3, P_2 x P_5 and P_4 x P_6 The parents P_1, P_2 and P_3 showed high *gca* effects for number of laterals plant^{1} The hybrids P_2 x P_3 followed by P_1 x P_4 and P_5 x P_6 showed highly significant positive *sca* effects for the same trait Among the hybrids, P_6 x P_3 (63 35) and P_6 x P_5 (62 10) recorded high *sca* effects for fruit weight

According to Singh *et al* (2005), significant additive gene effects for plant height, earliness in maturity, fruit weight (average), fruit length and yield was exhibited by the parent CH -171 Prominent non additive gene effects were exhibited by the hybrids, Arka Abha x CH-189-1 and CH-48 x CH-171 for plant height, CH-159 x CH-180 for TSS, Arka Abha x CH- 171, Arka Abha x CH-180 and CHRT-4 x CH-159 for average fruit weight, length and girth

Joshi and Kohli (2006) studied the gene effects for processing quality attributes in tomato in a half-diallel mating design Among the parents, CLN-1351E and FT-5 exhibited high *gca* for TSS The crosses UHF-II x EC-401927 and CLN5915-206D4-2-2-0 x FT-5 exhibited significant *sca* effects for TSS and number of locules respectively High *sca* was shown by the cross CLN1462A x FT-5 for ascorbic content

Asati *et al* (2007) conducted line x tester analysis by using thirteen lines and three testers and reported that the crosses Futestro x BT-117-5-3-1, BT116-8-1 x BT-II 7-5-3-1 and Sel-2 x KT-15 exhibited high positive *sca* effects for number of fruits plant^{1} while, BT-1 02-2-1 x KT-15, BT-116-8-1 x FloraDade and Type-1 x KT-15 showed high *sca* effects for fruit weight

Hannan *et al* (2007) carried out an investigation involving ten parents of tomato in a diallel fashion The variance due to *gca* and *sca* were found to be highly significant for fruits plant^{-1}, flowers cluster^{-1}, and fruit weight plant^{-1} The crosses Deshy x Ratan, Deshy x Epoch, Dynasagar x Ratan, Bari- 4 x Pusharubi and Dynamo x Namdhari exhibited high *sca* effects for yield

An experiment was conducted by Rao *et al* (2007b) by crossing five parents of tomato in a diallel fashion, excluding reciprocals Higher magnitudes of *sca* effects in desirable direction for yield and its related character was observed Feb-2 x Pusa Sheetal and Feb-2 x Pusa Gaurav were good combiners for yield and also exhibited moderate resistance to early blight in tomato

In a line x tester crossing programme of tomato, Singh *et al* (2008) used thirteen lines and five testers to develop 65 F_1 hybrids High pronounced *sca* effects for yield and quality components was exhibited by the hybrids, Meghalaya local x H-88-78-2(1 44), Punjab Chuhara x DVRT-2 (1 41), H-88-87x H-88-78-2 (1 05), H-24xEC-521080 (1 03) and H-24 xH-86 (1 01) Among the parents, FLA-742t recorded good *gca* for plant height, TLBR-3 for number of primary branches, H-88-87 for days to first flowering, H-88-78-2 for days to first harvest, Meghalaya Local for fruits plant^{-1}, H-88-78-2 for yield plant^{-1}, Vaibhav for pericarp thickness, TLBR-5 for less number of locules fruit^{-1}, H-88-78-2 for high dry matter content and Arka Vikas for TSS

A line x tester crossing programme involving seven lines and four testers was done by Rattan *et al* (2008) Among the lines, high *gca* was shown by BT-18, BL-342 and CLN- 212 (total fruits plant^{-1}), Rodade and BL-333 (average fruit weight) Among the testers *viz*, EC-392698 and Hawaii- 7998 (fruits plant^{-1}), EC-191536 (average fruit weight) were found to be good general combiners High *sca* was shown by CLN-2026 x PTOM-9802 (gross yield plant^{-1}), CLN-2026 x PTOM-9802 (total fruits plant^{-1}), BL-333 x EC-191536 (average fruit weight)

Saidi *et al* (2008) conducted a line x tester study and revealed the significance of both *gca* and *sca* effects in controlling the expression of number of fruits plant^{-1}, fruit weight (average) and days to 50 percent flowering The hybrid, M-3-1 x 18-1-1 exhibited high *sca* for yield ha^{-1}, yield plant^{-1} and number of fruits plant^{-1}

Sirohi and Gaurav (2008) developed 36 hybrids of tomato using diallel cross method The study revealed the predominance of both *gca* and *sca* variances for different parameters except total soluble solids Among the parents, EC534-1-2-1 and PS-6-1-1 showed good *gca* for most of the characters For fruit setting %, days from fruit setting to turning stage, fruit weight, harvesting period, total fruits and marketable yield plant^{-1}, the cross 1-7- 1-1 × UC82B exhibited superior *sca* variances

An experiment was conducted in a line x tester mating design by Mondal *et al* (2009) and reported the involvement of both *gca* and *sca* effects for the control of fruits plant^{-1}, fruit weight, locules fruit^{-1} and equatorial diameter of fruit Non additive gene effects played a prominent role in inheriting fruit quality characters like TSS and lycopene contents Two promising cross combinations, H-24 × NF-31 and H-24 × Hissar Arun exhibited high significant *sca* effects for different characters

Rattan and Chadha (2009) estimated the combining ability and gene action for yield and its attributing characters in tomato by involving 28 crosses derived from seven lines and four testers in line x tester method The study revealed the greater variance of *sca* influencing most of the characters like gross yield plant^{-1}, total fruits plant^{-1}, marketable yield plant^{-1}, marketable fruits plant^{-1} and average fruit weight which showed the predominance of non- additive gene action

Saleem *et al* (2009) developed 30 F_1 hybrids of tomato and evaluated their performance using L x T mating design Analysis of variances for combining ability indicated the significance of *sca* effects controlling all the characters The line 88572, UC-134 and Nagina (tester) exhibited good *gca* for yield and other components Three prominent cross combinations namely, 88572 × Riogrande, Pidenneto × Riogrande and H- 24 × Riogrande were the valuable specific combiners for yield

Sekhar *et al* (2010) raised a 10 x 10 half-diallel set by crossing the single cross hybrids and 45 double cross hybrids were developed Characters like number of fruits plant^{-1}, plant height and number of branches plant^{-1} in tomato were under the control of non-additive gene effects Among the single cross hybrids, JK-Desi showed significant high *gca* for yield plant^{-1}, number of fruits plant^{-1} and plant height in desirable direction Two prominent hybrids namely, JK-Desi x Sasya and JK-Desi x Shivaji exhibited significant *sca* effects for yield plant^{-1}

According to Chattopadhyay *et al* (2011), there exists a significant role of additive gene action in inheriting the characters like days to 50 percent flowering and percent disease incidence The study also recorded the importance of both additive (*gca*) and non additive (*sca*) gene actions in controlling polar diameter, thickness of pericarp and acidity of fruit Non additive gene action played a prominent role in regulating the expressions of fruit weight, fruit number plant^{-1}, locules fruit^{-1}, total soluble solids and fruit yield plant^{-1} The crosses CLN2777G x BCT–59 and CLN2777A x BCT-82P were good specific combiners for yield and quality with low PDI for ToLCV

Gene action and combining ability studies in tomato using line x tester analysis was conducted by Kansouh and Zakher (2011) The ratio of *gca* by *sca* was less than one which indicated the significance of non-additive variance in controlling almost all of the characters The parent G 16 was the good combiner for plant height, main stem length, early and total yield, fruit firmness, TSS and vit C content The cross combinations, S 60 x G 19, S 125 x G 19, G 30 x SSB and G 30 x Peto 86 were considered the best specific combiners, since they showed significant *sca* values for five traits

Angadi *et al* (2012) reported greater magnitude of *sca* variance than *gca* variance for all parameters in a L x T analysis which clearly suggested greater influence of dominance (*sca*) effect The lines DMT-1 and DMT-2 (tester) were good general combiners for yield Among 45 hybrids studied, DMT-1 x Arka

Alok, DMT-1 x DMT-2, DM-3 x DMT-2 and DM-5 x Arka Alok were found to have high *sca* effects for yield

Amin *et al* (2012) studied the nature of gene action and inheritance pattern of tomato for different characters like days to fruit setting, days to first harvest, plant height, number of primary branches plant^{1}, fruit shape (size), flesh thickness, number of fruits plant^{1}, fruit weight (average) and yield plant^{1} None of the parents had the desirable combining ability effects for all the characters individually as well as under pooled environmental conditions However, based on the performance of genotypes for most of the traits, significant *gca* was observed in the parents Arka Vikas, KS-227, Roma, DVRT-I and DARL-63

An investigation was conducted by Farzane *et al* (2012) in a 10×10 diallel cross set of tomato, including reciprocal crosses and reported that both *gca* and *sca* variances played a significant role and relative magnitude of these variances revealed greater influence of additive gene effects for all characters For yield and number of fruits plant^{1}, the parent Mb3 was found to be the good combiner Among the hybrids, Mb3×Prg showed high *sca* for fruits plant^{1}, Mb3×Sps for average fruit weight, Supl44×Sps for locule number and Prg×Supl44 for yield plant^{1}

Line x tester analysis was carried out by Kumari and Sharma (2012) to study the combining ability effects in tomato Additive gene effects showed its significance in governing the traits like fruit shape index, thickness of pericarp, number of seeds fruit^{1}and ascorbic content of fruit while the remaining characters were under the supremacy of non additive gene effects The hybrids, Sioux x FT-5 (269 07), EC 521041 x FT-5 (148 91) and S-1001 x Solan Vajr (143 59) were found to be good specific combiners for yield

A L x T mating experiment involving three lines and three testers was conducted by Shende *et al* (2012) and reported that TSS was under the great influence of both *gca* and *sca* effects while, other characters were controlled by non additive gene effects The parents, 'CLN2498-D', 'CLN2762-A' and 'BCT-

110' exhibited greater *gca* effects for yield and processing qualities The two promising cross combinations namely, CLN2498-D x DVRT-2 and CLN2777-C x BCT-53 were regarded as the best specific combiners for yield

Souza *et al* (2012) evaluated 15 genotypes of tomato and observed pronounced *sca* variance than *gca* variance for all the parameters suggesting the significance of non additive gene effects The parent, IAC-2 was treated as the best for fruit yield since the *gca* effect was prominent which was followed by the lines IAC-4 and IAC-1 For yield, the crosses IAC-1 x IAC-2, IAC-1 x IAC-4 and IAC-2 x IAC-4 were found to be the best specific combiners

In a line x tester crossing study conducted by Raju *et al* (2012), the parent, EC 145057 was the good combiner for fruit weight, fruit length, fruit diameter and ascorbic acid content since it recorded high *gca* effects The cross combinations, EC257489 x Arka Saurabh, EC338735 x Marutham and EC163663 x Pusa Ruby were found to be good specific combiners for yield plant^{-1} since *sca* effects were high

Farzane *et al* (2013) carried out complete diallel analysis using nine parents to study the combining ability of tomato All the characters were in association with the pronounced results of both *gca* and *sca* effects except plant height The cross Sps×Supl44 recorded good *sca* for plant height The hybrids Vfj×Pte12, Prg ×Supc and Sps×Mb3 showed earliness among the different crosses involved in the study

Tomato genotypes which are having resistance to bacterial wilt were examined for combining ability and gene action over different environmental conditions by Kapur *et al* (2013) They observed that *sca* effects regulated the characters like days to 50 % flowering, thickness of pericarp, plant height (cm), harvesting period, marketable yield plant^{-1} and total soluble solids under different environments However, additive gene effects influenced days to first harvest, number of fruits plant^{-1}, fruit weight and locule number fruit^{-1} The crosses, BWR-

5 x 16-B, 17-2 x CLN1314G and 7-2 x Palam Pride were recorded as the best combiners under both the environments

Kumar *et al* (2013) developed thirty F_1 hybrids of tomato derived from line x tester analysis by using ten diverse lines and three testers For earliness and average fruit weight, the parent Punjab Upma exhibited high *gca* effects Pant T-3 exhibited significant *gca* effects for yield Among the hybrids developed, CO-3 x AzadT-5 had high *sca* effects for all desirable characters

Saleem *et al* (2013) conducted diallel analysis in tomato for yield and its contributing traits and reported that characters like days to fruit maturity, plant height, fruit number plant^{1}, fruit length and yield plant^{1} were under the great influence of *sca* effects as the *gca* by *sca* ratio was less than one For fruit weight it was observed to be more than one, which pointed the pronounced *gca* effect B26 and B27 were the parents which concede the importance of *gca* for yield and its attributing characters and among the cross combinations, B23 x B27, B25 x B26 and B24 x B27 showed the vital importance of non additive components for yield

Shankar *et al* (2013) reported the preponderance of *sca* effects in the characters fruit number cluster^{1} and yield plant^{1}, on evaluating 24 F_1 hybrids along with their parents, by using line x tester method Among the parents LE-53, LE-64 (lines) and Arka Alok (tester) were considered as better combiners for almost all the characters Significant *sca* effects were exhibited by the hybrids, EC-157568 x Arka Vikas, EC-163611 x Arka Alok, LE- 62 x Arka Alok and LE-64 x Arka Vikas for yield plant^{1}

Thirty F_1 hybrids of tomato derived from a cross between ten lines and three testers in a line x tester method by Yadav *et al* (2013) Most of the characters in the study were regulated by *sca* variances Based on the combining ability for *gca*, the parents Pant t-7, potato leaf and NDTVR-60 were treated as the best ones for ten characters The hybrids, RCMT-2 × VR-20, LCT-6 × VR-20 and Azad T-5 × VR-20 showed superior performance for all the traits, hence were regarded as good specific combiners

Gabry *et al* (2014), in a diallel cross system without reciprocals, observed that most of the characters were influenced by non additive gene effects The parent Super Strain (P_1) exhibited good *gca* for fruit firmness and fruit yield per plant The F_1 hybrid CastelRock × Peto-86 ($P_3 \times P_4$) showed high *sca* for fruit shape index, fruit weight and fruit yield plant ^{1}

In a half diallel set involving seven parents, Muttappanavar *et al* (2014) developed twenty one crosses of tomato Additive gene effects played a significant role in inheriting all the parameters which showed the presence of higher *gca* variances Based on the performance of genotypes for combining ability, the parent IIHR-2754 was the best general combiner for yield plant ^{1} The crosses, IIHR-2754× IIHR-2860 exhibited greater magnitude of *sca* for yield plant ^{1} which was followed by IIHR-2858×IIHR-2866

Rajan (2014) carried out a study involving six tomato lines of diverse nature and three testers having resistance to fruit borer Most of the characters were under the predominance of non additive genetic variances For yield and other traits, the parents EC461070, EC461018 and MTM Local were observed to be the best combiners and among the crosses, EC 461070 x MTM Local was the good specific combiner

Baban *et al* (2015) crossed eight tomato lines in a diallel method excluding reciprocals and reported that the characters *viz* fruit-polar and equatorial diameter and number of locules fruit ^{1} were influenced by both *gca* and *sca* effects which showed the prominent role of both additive and non additive genetic variances However, the characters fruit weight, thickness of pericarp and firmness of fruit were controlled by the additive gene effects due to high *gca* variance The hybrids, GT 1 x Ec 177371 and H 24 x Ec 490130 were the valuable combiners for fruit firmness

A line x tester analysis was undertaken by Basavaraj *et al* (2015) involving fifteen lines and three testers The lines *viz*, T-26, T-36, Swarna Naveen, Vaibhav, DMT-1, DMT-5, S-22 and HUB-18 and the testers Arka Abha and DMT-2 were identified as good combiners for all characters Similarly the crosses *viz*, S-22× Arka Abha, DMT-5× Arka Alok, DMT-5× Arka Abha and T-26× DMT-2 were identified as the good specific combiners for yield plant^{-1} and Swarna Naveen × Arka Alok and T-36× Arka Alok were found to be superior for processing qualities

Chaudhari *et al* (2015) evaluated 28 F_1 hybrids of tomato in a half diallel analysis and reported the significance of both *gca* and *sca* effects in the inheritance of all characters which indicated the vital role of both additive as well as non-additive gene effects Among the parents, AT-3, GT-2 Vybhav and Flordade were treated as the valuable combiners for yield by exhibiting high *gca* effects The hybrids, DVRT-2 x IIHR 2195, AT-3 x JT-3 and JT-3 x DVRT-2 were found to be good specific combiners by disclosing high *sca* effects for fruit yield plant^{-1}

A half diallel analysis in tomato was conducted by Pandiarana *et al* (2015) and observed that fruit weight was under the control of additive variance while all other traits were influenced by non-additive gene effects The parents CLN 2777E, BCT-115 and CLN 2777F showed high *gca* for yield plant^{-1}and other important horticultural traits The prominent *sca* effects for yield plant^{-1} and other desirable horticultural traits was seen in the hybrids, CLN2777F × Ailsa Craig fulgens, CLN 2777E × Ailsa Craigogc, CLN 2777E × Ailsa Craig fulgens and CLN2777F × CLN2777E

Zengin *et al* (2015) used fifteen lines as female and two testers as male parents in order to develop thirty cross combinations of tomato by using LxT method The variance due to *sca* was greater than *gca* showing the superiority of non additive gene effects in controlling almost eight characters The parent, BH-135 showed high *gca* for yield plant^{-1} and days to first flowering, BH-93 for days to first fruit ripening, BH-28 for early harvest and yield plant^{1} and G-8 for plant height and fruit weight

A diallel analysis of tomato was carried out by Figueiredo *et al* (2016) and reported that characters like total fruits plant^{1}, marketable yield, pulp yield and total soluble solids were under the pronounced *sca* effects while, average fruit mass was controlled by additive (*gca*) effects The crosses, RVT-08 x RVT-09, RVT-07 x RVT-10 and RVT-08 x RVT-10 were noted as the valuable combiners for all the traits examined under the study

A study was conducted in a 6 × 6 full diallel cross set of tomato by Aisyah *et al* (2016) and observed that the variances for *gca* and *sca* were highly significant indicating the prominence of both additive as well as non-additive gene effects except the fruit thickness The tomato genotype IPB 78 is parental with the best *gca* for yield plant^{1}, fruit weight (average), fruit length and thickness The hybrid IPB T73 x IPB T3 was pointed as the best combiner for yield and number of fruits plant^{1}

2 4 BACTERIAL WILT DISEASE

Of the major diseases of tomato and other solanaceous crops, bacterial wilt is considered as the most serious (Milling *et al* 2011) Bacterial wilt of tomato caused by *Ralstonia solanacearum* (Smith) has provided many enigmas for scientists working on tomato and other crop species Although it is difficult to estimate total economic losses caused directly or indirectly by bacterial wilt, it ranks one of the most important plant diseases in the entire world (Gnanamanickam, 2006)

The disease is endemic in tropics, subtropics and warm humid regions of the world It is especially devastating during the warm wet months in the tropics and subtropics and causes incalculable losses to many hosts The yield loss due to this disease is up to 90 62 per cent (Dharmatti *et al* 2009)

Generally, the losses due to bacterial wilt depends on several factors which mainly includes the local climate, types of soil, different cropping practices, choice of crop and plant cultivar and the virulent characteristics of the *R solanacearum* local strain (Alvarez *et al*, 2010)

2.4.1 Germplasm evaluation

An experiment was conducted by Narayanankutty (1985) with a view to develop new source of resistance to bacterial wilt Four non- segregating and two segregating populations were evaluated for bacterial wilt resistance Among the segregating population, Saturn x LE 79 was found to have resistance to bacterial wilt in F_2 generation Among the non- segregating ones, LE 79 showed moderate resistance, while Saturn was in moderately susceptible to susceptible range

A study was conducted to evaluate tomato lines for bacterial wilt resistance by Sadhankumar (1995) It revealed consistent resistance of Sakthi and Mukthi and also identified four additional sources *viz* LE 214, CAV-5, LE 415 and LE 382-1 for bacterial wilt resistance The study suggested the importance of recessive genes in governing resistance to bacterial wilt in these lines

Two lines of tomato (LE 36 and LE 26) with better fruit size were crossed with six wilt resistant lines (LE 1, LE 12, LE 21 LE 23, LE 27 and LE 66) having low fruit size and F_1 seeds were collected under field trials at ARS, Mannuthy Twenty one lines were found resistant to bacterial wilt (Gopalakrishnan, 2004)

Twenty-four varieties and lines of tomato were evaluated for yield, quality and bacterial wilt resistance for two consecutive years Of the 24 varieties studied, LE-3704 gave the highest average fruit yield of 30815 kg ha^{-1} followed by BT-1 (30478 kg ha^{-1}) These varieties also produced the largest number of fruits per plant Hundred percent resistance to bacterial wilt was recorded in BT-118-4-1-1, BT-116-8-1-1, and Tomato-415 during both years (Swaroop and Suryanarayana, 2005)

Evaluation of tomato against bacterial wilt in Jharkhand was done by Sharma *et al* (2006) Eight tomato parental lines and 28 F_1 crosses were tested in bacteria (*R solanacearum*) sick plot Five most promising parental lines and four F_1 crosses were tested during rainy season to evaluate the yield and resistance

Data revealed that three parental lines *viz* CHDT-4 (EC 339074 released as Swarna Lalima), CH-180 (BT-17) and CHDT-5 (EC-369060-A released as Swarna Naveen), and three F_1 crosses CHDT-4 × CHDT-1 × CHDT-1 × CH-180 and CH-195 × CH-180 showed resistant reaction to bacterial wilt Among the F_1 crosses, CHDT-4 × CHDT-1 (EC-339074 × EC-386021 recently released as Swarna Sampada), CHDT-1 × CH-180 (EC-386021 × BT-17) and CH-195 × CH-180 (Sonali × BT-17) showed resistant reaction The F_1 cross EC-339074 × EC-386021 (Swarna Sampada) was found superior to the others in terms of resistance and yield in a sick plot

Three screening methods were used by Wang *et al* (2007) to identify the resistance of nine tomato lines The lines 85198 and 203 were found susceptible to bacterial wilt whereas, 47254, 51255, 7585 and 85254 showed resistance to bacterial wilt

Techawongstien and Thummabenjapone (2009) conducted screening of tomato varieties for bacterial wilt resistance in Thailand. Three tomato lines A4-7-1-1-5, THBW104, and THBW109 carried high levels of bacterial wilt resistance (20% of wilt incidence) and good fruit yield performances (>1200 g/plant) A4-7-1-1 5 line showed the best stability, followed by X12207B-5, X12207B-4-2, and A2-10-3-1 for bacterial wilt resistance and good yield performances

Screening tomato cultivars for high β-carotene and bacterial wilt resistance was done by Sangrit *et al* (2011) under open field and plastic net house Thirty two cultivars during dry season and 12 cultivars during rainy season were evaluated for bacterial wilt resistance and yield The cultivars 222, 223, 225 and 226 gave the highest fruit yield and resistance to bacterial wilt during dry season No resistant cultivars were detected during rainy season

Dutta and Rahman (2012) conducted varietal screening of tomato against bacterial wilt disease using vascular bundle discoloration index (VBDI) and observed that four tomato varieties *viz* Swarakhsha, Rakshak, Trishul and Arka Alok were moderately resistant (>10 – 20% mortality), varieties Yash F_1 Hybrid, TO 1458, Hybrid 7610 and F_1 Amulya 1744 moderately susceptible (>30 – 70% mortality) and Loknath and Arka Vikas highly susceptible (>70 – 100% mortality)

Screening of tomato genotypes against bacterial wilt under field condition was conducted by Tiwari *et al* (2012) Twenty genotypes were screened along with two checks Cherry Jaspur had high resistant reaction (HR); three genotypes *viz*, ATL- 01-19, Pant T-10 and CO-3 recorded moderate resistance in field condition against bacterial wilt

2.4.2 Heterosis and combining ability

A line x tester analysis was carried out among bacterial wilt resistant accessions and processing varieties by Kurian *et al* (2001) and identified superior hybrids for the characters like fruit weight (average), number of locules, thickness of pericarp and yield plant^{-1}

Sadhankumar *et al* (2007) studied heterosis in bacterial wilt resistant tomatoes The crosses, LE 415 x Mukthi, LE 415 x Sakthi, LE 415 x BWR-1 and Sakthi x Mukthi were found to have good level of resistance to the disease with survival percentage of 97 5%, 95%, 90% and 82 5% respectively The hybrids LE 415 x LE 421, Sakthi x LE 421, Sakthi x BWR-1, Mukthi x LE 421, Mukthi x BWR-1 and LE 421 x BWR-1 were categorized as moderate resistant ones for bacterial wilt

The female parent 'T9175', having high level of resistance to bacterial wilt was crossed with male parent 'T9185' and 'Zheza 204' hybrid was developed This was an excellent hybrid having multiple disease resistance to bacterial wilt, fusarium wilt, leaf mould and tomato mosaic virus (Qing *et al*, 2007)

A study was conducted to estimate the heterosis for bacterial wilt resistance in tomato by Virupannavar *et al* (2010) using line x tester method Among the 40 hybrids studied, DMT-6 x DMT- D, DMT-2 x IMP-B and DMT-5 x DMT-D were found to be superior over commercial check Ruchi for bacterial wilt resistance and significantly superior for higher fruit yield plant^{1}, fruit weight (average) and number of fruits plant^{1}

Thirty nine hybrids of tomato derived from 13 lines and 3 testers were produced by Singh and Asati (2011) to examine their combining ability and heterosis for different traits like plant height, number of primary branches plant^{1}, fruit weight, yield plant^{1} and bacterial wilt incidence Higher magnitude of heterobeltiosis for yield plant^{1} and plant height under bacterial wilt condition was shown by the hybrid Type-1 × KT-15

Heterosis for yield in tomato was studied by Singh *et al* (2012) using 7x7 diallel cross (excluding reciprocals) between bacterial wilt resistant genotypes and high yielding varieties For number of fruits per plant, three crosses *viz* , BRH-2 x LO-5973 (38 88%), Arka Ahuti x TWC-4 (36 30%) and Arka Vikas x TWC-4 (27 12%), for fruit weight CLN- 2026-D x LO-5973 (62 70%), Arka Ahuti x LO-5973 (62 51%) and Arka Ahuti x CAU-TS-9 (24 12%) and for yield per plant Arka Ahuti x LO-5973 (45 89%) and Arka Ahuti x CAU-TS-9 (21 63%) showed significant heterosis over BP

2.4.3 Inheritance pattern

The inheritance pattern of bacterial wilt resistance is complex and contradictory, conflicting conclusion about the genetic control on resistance could be attributed to strong genotypes x environment, involving polygenic systems in both host and pathogen and pathogen variability

Table 1 Genetics of bacterial wilt resistance

Material	**Gene action**	**Reference**
Sakthi	Single recessive gene	Kurian and Peter, 1991
---	Oligogenes	Danesh *et al* , 1994
Hawaii - 7996	Monogenic dominant	Grimault *et al* , 1995
Hawaii 7996 x *L pimpinellifolium*	Polygenic	Thoquet *et al* , 1996
LA 1421	Duplicate form of epistasis	Mohamed, 1997
L 285 and C 285	Dominant gene	Patil, 1998

---	Additive-dominance	Osiru *et al*, 2001
---	Non-additive gene & presence of epistasis	Venkataramana, 2001
---	Additive - dominance	Feng *et al*, 2003
---	Polygenic	Wang, 2004
---	Single dominant gene	Zhu, 2004
---	Single recessive gene	Thakur *et al*, 2004
Hawaii-7998 × Solan Gola, Hawaii-7998 × Roma, BT-18 × Solan Gola and TBL-4 × Solan Gola	Additive, dominance & AxD interaction	Sharma and Verma, 2004
Hawaii - 7996	Single major genes and several minor genes	Scott *et al*, 2005
Hawaii-7998 × Solan Gola, Hawaii-7998 × Roma, BT-18 × Solan Gola and TBL-4 × Solan Gola	Additive - dominant	Sharma *et al*, 2005
BL-312 × Roma	Complementary or duplicate recessive gene interactions	Sharma *et al*, 2006a
Hawaii 7998 × Roma	Dominant and recessive or inhibitory type of gene action	Sharma *et al*, 2006b
Hawaii -7998 x Solan Gola, Hawaii-7998 x Roma, BT-18 x Solan Gola and TBL-4 x Solan Gola	More than one interacting genes	Sharma and Sharma, 2015

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Development of hybrids with bacterial wilt resistance in tomato (*Solanum lycopersicum* L)" was conducted in the Department of Olericulture, College of Agriculture, Vellayani, during 2015- 16 The objective of the experiment was to develop F_1 hybrids of tomato with high yield, quality and resistance to bacterial wilt

The experimental site is located at 8 5^0 North latitude and 76 9^0 East longitude, at an altitude of 29 00 m above mean sea level Predominant soil type of the experimental site is red loam to Vellayani series, texturally classified as sandy clay loam The area enjoys a warm humid tropical climate

The experiment comprised of two parts

Part 1 Production of F_1 hybrids

Part 2 Evaluation of F_1 hybrids

3 1 PRODUCTION OF F_1 HYBRIDS

3.1.1 Experimental materials

The experiment was done in a line x tester fashion using seven lines and three testers Seven high yielding genotypes identified and maintained in the Department of Olericulture, College of Agriculture, Vellayani were selected as lines The testers were the bacterial wilt resistant varieties released from the Kerala Agricultural University *viz* , Anagha, Manulekshmi and Vellayani Vijai

The ten parents were planted in a crossing block for hybridization during January - May 2015 and were crossed in a line x tester fashion involving seven lines and three testers to produce 21 F_1 hybrids The detailed description of parents and crosses are given in Tables 2, 3 and 4 (Plate 1, 2, 3 and 4)

Table 2 Details of parental lines used for hybridization

Sl No	Code number	Accession Number	EC No / Accession Name	Source
1	L_1	LE 3	EC-775047	AVRDC, Taiwan
2	L_2	LE 12	EC-570017	NBPGR, New Delhi
3	L_3	LE 13	EC-570021	NBPGR, New Delhi
4	L_4	LE 16	EC-608244	NBPGR, New Delhi
5	L_5	LE 19	EC-608363	NBPGR, New Delhi
6	L_6	LE 20	EC-608365	NBPGR, New Delhi
7	L_7	LE 26	EC-685176	NBPGR, New Delhi

Table 3 Details of testers (bacterial wilt resistant) used for hybridization

Sl No	Code number	Accession Name	Source
1	T_1	Anagha	KAU, Vellanikkara
2	T_2	Manulekshmi	KAU, Vellanikkara
3	T_3	Vellayani Vijai	KAU, Vellayani

Table 4 Details of hybrid combinations

Sl No	Parents	Cross combinations
1	$L_1 \times T_1$	LE 3 x Anagha
2	$L_1 \times T_2$	LE 3 x Manulekshmi
3	$L_1 \times T_3$	LE 3 x Vellayani Vijai
4	$L_2 \times T_1$	LE 12 x Anagha
5	$L_2 \times T_2$	LE 12 x Manulekshmi
6	$L_2 \times T_3$	LE 12 x Vellayani Vijai
7	$L_3 \times T_1$	LE 13 x Anagha
8	$L_3 \times T_2$	LE 13x Manulekshmi
9	$L_3 \times T_3$	LE 13 x Vellayani Vijai
10	$L_4 \times T_1$	LE 16 x Anagha
11	$L_4 \times T_2$	LE 16 x Manulekshmi
12	$L_4 \times T_3$	LE 16 x Vellayani Vijai
13	$L_5 \times T_1$	LE 19 x Anagha
14	$L_5 \times T_2$	LE 19 x Manulekshmi
15	$L_5 \times T_3$	LE 19 x Vellayani Vijai
16	$L_6 \times T_1$	LE 20 x Anagha

Plate 1 Fruits of parents used in the hybridisation

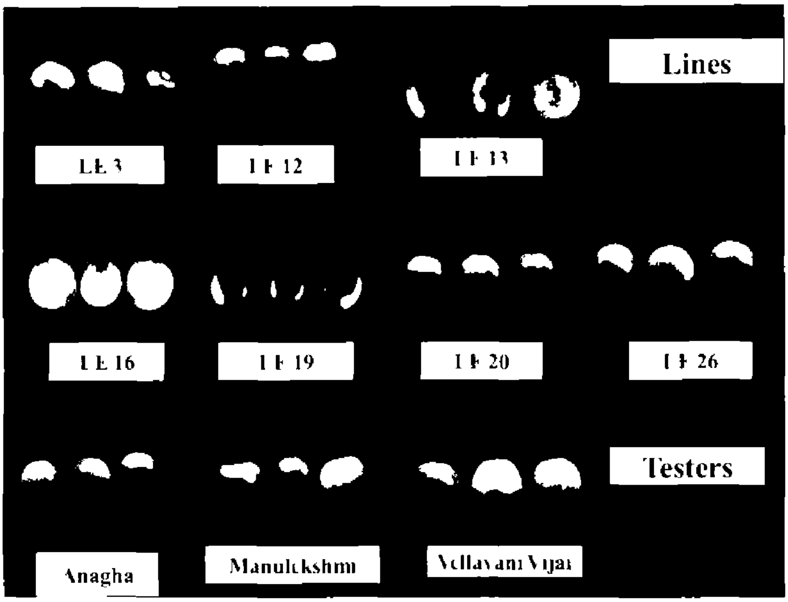
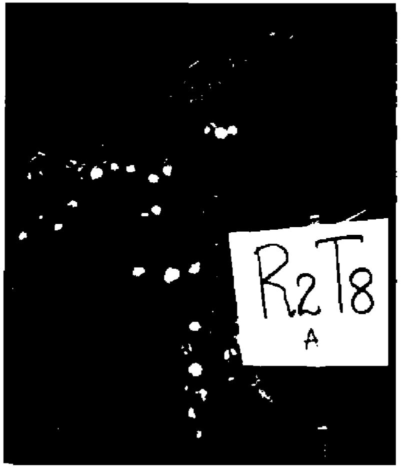


Plate 2 Parental lines used as experimental material

Plate 3 Testers (bacterial wilt resistant) used in hybridization

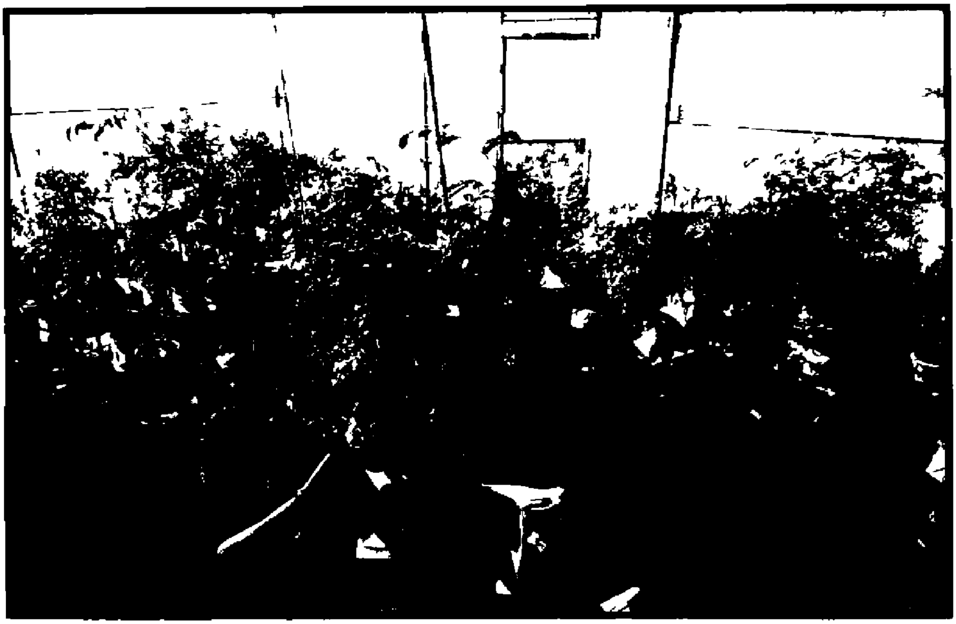


Anagha (T_1)

Manulekshmi (T_2)

Vellayani Vijai (T_3)

Plate 4 Development of F_1 hybrids in a crossing block



17	$L_6 \times T_2$	LE 20 x Manulekshmi
18	$L_6 \times T_3$	LE 20 x Vellayani Vijai
19	$L_7 \times T_1$	LE 26 x Anagha
20	$L_7 \times T_2$	LE 26 x Manulekshmi
21	$L_7 \times T_3$	LE 26 x Vellayani Vijai

3.1.2 Selfing and crossing technique

In tomato, anthesis occurs between 7 and 8 a m The well developed flower buds which are expected to open the next day morning were emasculated by the removal of anthers using forceps during evening hours and bagged using butter paper covers On the next day morning (between 7 and 8 a m) emasculated flower buds were pollinated by the pollen from the male parents (testers) The pollinated buds were again bagged with paper bags and labeled The mature crossed fruits were harvested and the seeds were collected separately from each cross For maintenance of parental lines, flower buds of the ten parents were selfed by bagging the individual buds and properly tagged and later the seeds were collected from the mature fruits

3 2 EVALUATION OF F_1 HYBRIDS

3.2.1 Materials

The 21 F_1 hybrids derived from the line x tester mating and their 10 parents and two hybrid checks *viz* Indam 9802 (Indo - American Hybrid Seeds Pvt Ltd) and Lekshmi (Nunhems seed Pvt Ltd) were evaluated in the field to study the heterosis, combining ability and gene action

3.2.2 Methods

3.2.2 1 Design and Layout

The experiment was laid out as fallows

Design	RBD (Randomized Block Design)
Replication	Three
Treatments	33 (21 F_1 hybrids + 10 parents + Indam 9802 and Lekshmi as check)
Spacing	60 cm x 60 cm
Plants/ plot	20
Plot size	7 2 m^2
Season	September 2015 – January 2016

One month old protray seedlings at 3-4 leaf stage were transplanted into the main field at a spacing of 60 x 60 cm The crop received timely management practices as per package of practices recommendations of Kerala Agricultural University (KAU, 2011)

3.2.2.2 **Main Items of Observations**

Five plants were randomly selected in each treatment per replication to record the observations and the average was worked out for statistical analysis To record the observations on fruit characters, five fruits randomly selected from each treatment in each replication were used Observations on the following characters were recorded in this experiment

3.2.2.3 Vegetative Characters

3.2.2.3.1 Plant height (cm)

Plant height was recorded from the ground level to the top-most bud leaf of the plants at the time of final harvest and presented in centimeters

3.2.2.3 2 Height at flowering (cm)

Height of the observational plants from ground level to the first flower bud at the time of first flowering was recorded

3.2.2.3.3 Node to first inflorescence

Number of the node at which emergence of first inflorescence of the observational plants from ground level was recorded

3.2.2.3.4 Primary branches plant^{-1}

The total number of primary branches of each observational plant at harvest was recorded

3.2.2.3.5 Leaf length (cm)

The length of leaf was measured as the distance from the base of the petiole to the tip of the leaf and expressed in centimeters

3.2.2.3.6 Leaf width (cm)

The width of the same leaf used for recording leaf length was taken at the region of maximum width

3 2.2.4 Flowering Characters

3.2.2.4.1 Days to first flowering

Number of days from the date of transplanting to first flowering of observational plants was recorded and the average obtained

3.2.2.4.2 Days to fruit set

Number of days taken from anthesis to the emergence of young fruits from the calyx was recorded and the average obtained

3.2.2.4.3 Flowers cluster

Number of flowers per cluster was recorded from the same cluster which was tagged for taking observation on days to fruitset and the mean obtained

3.2.2.4 4 Inflorescence plant^{-1}

Total number of inflorescences per plant was recorded and the mean obtained

3.2.2.4.5 Fruit set (%)

Number of flowers per cluster of the same inflorescences tagged for recording days to fruit set was counted Number of fruits present per cluster after two weeks of flowering was recorded and percentage fruitset was calculated using the formula

$$\text{Percentage fruitset} = \frac{\text{Number of fruits / inflorescence}}{\text{Number of flowers / inflorescence}} \times 100$$

3 2.2.4.6 Pollen viability (%)

Pollen viability of the flowers of the observational plants were analysed using acetocarmine dye method and expressed in percentage

3.2.2.5 Fruit and Yield Characters

3.2.2.5.1 Fruits cluster^{-1}

Number of fruits per cluster of the observational plants were recorded and the mean obtained

3.2.2.5.2 Fruits plant^{-1}

Total number of the fruits harvested per observational plant till last harvest was recorded and the mean obtained

3.2.2.5.2 Fruit length (cm)

Fruit length was measured as the distance from pedicel attachment of the fruit to the apex using vernier calipers Average was taken and expressed in centimeters

3.2.2.5.3 Fruit girth (cm)

Fruit girth was taken as diameter at the maximum width of the fruit using vernier calipers Mean was taken and expressed in centimeters

3 2.2.5.4 Fruit weight (g)

Weight of fruits used for recording fruit length and girth was measured and average was found out and expressed in grams

3.2.2.5.5 Yield plant^{-1} (g)

Weight of all fruits harvested from each observational plant was recorded and expressed in grams

3.2 2.5 6 Yield plot^{-1} (kg)

The total weight of fruits from each plot (7 2 m^2) after every harvest was recorded and expressed in kilograms per plot

3 2 2.6 Quality characters

3.2 2.6.1 Total soluble solids (%)

The juice was extracted by crushing the fruits in a muslin cloth and the total soluble solids was measured using Abbe hand refractometer

3.2 2.6.2 Lycopene (mg/100g)

Lycopene content of the fruits was estimated at full ripe stage by following the method of Srivastava and Kumar (1949)

Reagents

Acetone, petroleum ether (40-60 degree celcius), anhydrous sodium sulphate and 5% sodium sulphate

Procedure

The fruits were harvested at red ripe stage and crushed with the help of pestle and mortar and pulped well to a smooth consistency in a blender Five gram of this pulp was weighed and the pulp was extracted repeatedly with acetone using pestle and mortar until the residue is colourless The acetone extracts were pooled and transferred to a separating funnel containing about 20 ml petroleum ether and gently mixed About 20 ml of five per cent sodium sulphate solution was washed and shaken in a separating funnel gently Since the volume of petroleum ether might be reduced during the process because of its evaporation, 20 ml more of petroleum ether was added to the separating funnel for the clear separation of two layers The colour was prominent in the upper petroleum ether layer The two phases were separated and the lower aqueous phase was re-extracted with additional 20 ml of petroleum ether until the aqueous phase was colourless The petroleum ether extracts were pooled and washed with a little distilled water The washed petroleum ether extract containing carotenoids was poured into a brown bottle containing about 10 g anhydrous sodium sulphate and kept aside for 30 minutes The petroleum ether extract was decanted into a 100 ml volumetric flask through a funnel containing cotton wool Sodium sulphate slurry was washed with petroleum ether until it was colourless and washings were transferred to the volumetric flask The volume was made up and absorbance was measured in a spectrophotometer at 503 nm using petroleum ether as blank

3.2.2.6.3 Ascorbic acid (mg/ 100 g)

Ascorbic acid content of tomato fruits was estimated using 2, 6-dichlorophenol indophenole dye method (Sadasivam and Manickam, 1996)

Reagents

1 Oxalic acid (4%)
2 Ascorbic acid (standard)

Stock solution was prepared by dissolving 100 mg of ascorbic acid in 100 ml of 4 % oxalic acid Ten ml of this stock solution was diluted to 100 ml with 4% oxalic acid to get working standard solution

3 2, 6 dichlorophenol indophenole dye

Sodium bicarbonate (42 mg) was dissolved in a small volume of distilled water 52 mg of 2, 6-dichlorophenol indophenole was added into this and made upto 200 ml with distilled water

4 Working standaid

Ten ml of stock solution was diluted to 100 ml with 4 % oxalic acid The concentration of working standard is 100 mg per ml

Procedure

Five ml of the working standard solution was pippeted out into a 100 ml conical flask and 10 ml of 4% oxalic acid was added This was titrated against the dye (V_1) End point is the appearance of pink colour which persisted for at least 5 seconds

Five grams of fresh fruit was extracted in four per cent oxalic acid medium, the extract was filtered and volume was made upto 100 ml using oxalic acid From this five ml of aliquot was taken, 10 ml of 4% oxalic acid was added and titrated as above against the dye and the endpoint (V_2) was determined

Ascorbic acid content of the sample was calculated using the formula

$$\text{Amount of ascorbic acid in mg / 100 g sample} = \frac{0\,5 \times V_2 \times 100}{V_1 \times 5 \times \text{Weight of sample}} \times 100$$

3.2.2.7 Incidence of bacterial wilt

The hybrids and parents were evaluated for the incidence of bacterial wilt under field conditions Daily observation of plants was done for the incidence of bacterial wilt and the disease was confirmed by doing ooze test The number of plants wilted per plot was recorded

Table 5 Scoring procedure for bacterial wilt disease (Winsted and Kelmen, 1952)

Scale	Incidence (%)	Category
0	Plants did not show any wilt symptom	Highly iesistant (HR)
1	1 20% plants wilted	Resistant (R)
2	21-40% plants wilted	Moderately resistant (MR)
3	41-60% plants wilted	Moderately susceptible (MS)
4	61-80% plants wilted	Susceptible (S)
5	More than 80% plants wilted	Highly susceptible (HS)

3.2.2.8 Incidence of othei pests and diseases

3.2.2.8.1 Fusarium wilt

Fusarium wilt in tomato is caused by *Fusarium oxysporum f lycopersici* (Bruschi) Both the parents and hybrids were closely monitored for the incidence of fusarium wilt

3.2.2.8.2 Spotted wilt (TSWV)

A scoring procedure with 0 to 5 scale was adopted for the incidence of spotted wilt based on the extent of damage to plants

Table 6 Disease scale for scoring TSWV

Score	Symptoms
0	No symptom
1	Spots develop
2	25 % of leaf area infected
3	25 to 50 % of leaf area infected
4	50 to 75 % of leaf area infected
5	> 75 % of leaf area infected and bud necrosis

3.2.2.8.3 Fruit borer (Spodoptera litura)

Number of fruits infested per plant was counted The percentage infestation was worked out using the formula

$$\text{Percentage of infestation} = \frac{\text{Number of infested fruits per plant}}{\text{Total number of fruits per plant}} \times 100$$

Table 7 Scoring procedure for fruit borer

Score	Symptoms
0	zero % infestation
1	upto 15 % infestation
2	15 to 25 % infestation
3	25 to 50 % infestation
4	50 to 75 % infestation
5	> 75 % infestation

3.2.2.9 Statistical analysis

3.2.2.9.1 Analysis of Variance

The statistical analysis used in the present study is presented under the following sub heading

1 Analysis of variance for line x tester design

2 Estimation of heterosis

3 Estimation of combining ability and gene action

3.2.2.9.2 Analysis of variance for the line x tester design

In order to find differences among parents, hybrids and parent vs hybrids, the data obtained for each character were analysed by Randomized Block Design (RBD) which was based on the following mathematical model

$Y_{ik} = \mu + g_i + r_k + e_{ik}$

Where,

Y_{ik} is the phenotype of the i^{th} genotype grown in the k^{th} replication

μ is the general mean

g_i is the effect of i^{th} genotype

r_k is the effect of k^{th} block

e_{ik} is the error component associated with the i^{th} genotype and k^{th} replication

The effects in the above model were assumed to be fixed and unknown parameters except e^{ijk} was assumed to be normally and independently distributed with mean zero and common variance (σ^2) The analysis of variance based upon this model is given below

Table 8 Analysis of variance for L x T design

Source of variance	d.f.	Sum of square
Replication	r-1	$\sum_{k=1}^{r} \frac{Y^2k}{g} - \frac{(Yk)^2}{g\,r}$ ---------- ----------(1)
Genotype	g-1	$\sum_{i=1}^{g} \frac{G^2i}{g} - \frac{(Gi)^2}{g\,r}$ ---------------------(2)
Parents	p-1	$\sum_{i=1}^{p} \frac{P^2i}{r} - \frac{(Pi)^2}{p\,r}$ --------------------(3)
Female (lines)	f-1	$\sum_{r=1}^{F} \frac{F^2i}{r} - \frac{(Fi)^2}{f\,r}$ -------------------(4)
Male (tester)	m-1	$\sum_{r=1}^{m} \frac{M^2i}{i} - \frac{(Mi)^2}{m\,r}$ ------------------(5)
Line Vs Tester	1	(3) - (4) - (6) ------------------ (6)
Hybrids	mf-1	$\sum_{r=1}^{M} \frac{fC^2i}{r} - \frac{(Ci)^2}{m\,f\,r}$ --------------------(7)
Parents Vs Hybrids	1	(2) – (3) – (6) ---------------------(8)
Error	(r-1) (g-1)	Total SS – (1) – (2) -------------------(9)

Where,

r - Number of replications

g - Total number of genotypes (hybrids+ lines+ testers)

p - Number of parents (lines + testers)

f - Number of female parents

m - Number of male parents

Yk - total of k^{th} replication over genotypes

G_i - total of i^{th} genotype over replication

P_i - total of i^{th} parents over replication

F_i - total of i^{th} female parents over replication

M_i - total of i^{th} male parents over replication

C_i - total of i^{th} hybrid over replication

The mean sum of squares were calculated by dividing the sum of squares by their respective degree of freedom and were tested against the error variance by F-test at five per cent and one percent level of significance

The standard error of difference (SE_d) between the genotypic means and critical difference (CD) were calculated by using the following formula

$SE_d = \pm (2\ MSE/r)^{0.5}$

Where,

MSE = error mean square

r = number of replications

$C\,D = t_{(g-1)(r-1)} \times S\,E_d$

Where, $t_{(g-1)(r-1)}$ is the t value at (g-1) (r-1) degrees of freedom

If the differences among the hybrids were found significant, only then combining ability analysis was done

3.2.2.9.3 Estimation of heterosis

The mean of all the replications for each parents, hybrids and check for all characters was computed and used in estimation of heterosis Heterosis was calculated as the percentage increase or decrease of mean F_1 performance over the means of mid parent (MP), better parent (BP) and the standard check (SC)

$$\text{Mid parent value (MP)} = \frac{P_1 + P_2}{2}$$

a) Heterosis over mid parent (MP) $= \frac{F_1 - \overline{MP}}{\overline{MP}} \times 100$ **(Relative heterosis)**

Where,

MP = Mean performance of parent P_1 and P_2

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

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

Where,

$\overline{BP}$ = Mean performance of better parent

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

c) Heterosis over standard check (SC) $= \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$ (**Standard heterosis**)

Where,

$\overline{SC}$ = Mean performance of standard check

3.2.2.9.3.1 Test of Significance

Test of significance was done by comparing the mean deviation with values of critical difference (CD) obtained separately for $\overline{MP}$, $\overline{BP}$ and $\overline{SC}$ by using the following formula

Mean deviation for heterosis over MP $= \sqrt{\frac{3 \times mse}{2r}} \times$ 't' value

Mean deviation for heterosis over BP & SC $= \sqrt{\frac{2 \times mse}{r}} \times$ 't' value

Where,

r = Number of replications

t = Table value of 't' at error degree of freedom at 0 01 and 0 05 levels of probability

m s e = Error mean sum of squares

3 2.2 9.4 Analysis of variance for combining ability

The combining ability analysis for different characters was done as per the model suggested by Kempthorne (1957)

Mathematical model

$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$

Where,

Y_{ijk} is the performance of $(i \times j)^{th}$ hybrid in k^{th} replication

μ is the general population mean

g_i is the general combining ability (GCA) effect of i^{th} line

g_j is the general combining ability (GCA) effect of j^{th} tester

s_{ij} is specific combining ability (SCA) effect of the $(i \times j)^{th}$

r_k is the effect of k^{th} replication

e_{ijk} is experimental error associated with ijk^{th} observation

The effects in the above model were assumed to be fixed unknown parameters except e_{ijk} which is assumed to be normally and independently distributed with mean zero and common variance (σ^2) The analysis of variance based upon this model is given below

Table 9 Analysis of variance for combining ability

Source of variation	d.f.	M.S.S.	Expectations of mean square
Testers in hybrids	(m-1)	mhMS	σ^2 + r[Cov (FS)-2Cov (HS)] + [fr Cov (HS)]
Lines in hybrids	(f-1)	fhM	σ^2+r [Cov (FS)] - 2Cov (HS)] + [mr Cov (HS)]
(Line × Tester) in hybrids	(m 1)(f-1)	fmhMS	σ^2+r[Cov (FS)-2Cov (HS)]
Error	(r-1)(mf-1)	eMS	σ^2
Total	Mfr-1		

The different sum of squares were calculated using the following formula

C F = $(Y\ \ )^2$/mfr

TSS = $\sum_i \sum_j \sum_k (Y_{ijk})^2$ - C F

fhSS = $[\sum_i (Y_i\ )^2$ /mr] - C F

mhSS = $[\sum_i (Y_j\ )^2$/fr] - C F

fmhSS = $[\sum_i \sum_j (Y_{ij})^2$ /r] – C F – fhSS - mhSS

eSS = TSS $[\sum_k (Y\ _k)^2$ /fm –C F]- $[\sum_i \sum_j (Y_{ij})^2$ / r – C F]

Where,

Y = total of all hybrids over all replication

Y_i = i^{th} female total

Y_j = j^{th} male total

Y_{ij} = $(i \times j)^{th}$ hybrid total

Y_k = k^{th} replication total

Cov (HS) = (mhMS + fhMS - 2fmhMS) / r (m+f)

Cov (FS) = [mhMS + fhMS + fmhMS - 3eMS + 6r Cov (HS) - r(m + f) Cov(HS)] / 3r

The different sum of squares were divided by their respective d f to obtain mean sum of squares First of all, fmhMS was tested against eMS If it was significant the both fhMS and mhMS were tested against fmhMS On the contrary, if fmhMS was non-significant, then both fhMS and mhMS were tested against eMS

The variance due to the combining ability (σ^2_{gca}) and specific combining ability (σ^2_{sca}) were calculated as under

σ^2_{gca} = Cov (HS)

σ^2_{sca} = Cov (FS) – 2 Cov (HS)

Additive variance (σ^2_A), dominance variance (σ^2_D) at F = 1 (tomato being a self pollinated crop) and degrees of dominance were calculated as below

$\sigma^2_A = \sigma^2_{gca} / [(1 + F)/4] = 2\sigma^2_{gca}$

$\sigma^2_D = \sigma^2_{sca} / [(1 + F)/2] = \sigma^2_{sca}$

Degree of dominance = $(2\sigma^2_D / \sigma^2_A)^{0.5}$

The proportional contribution of lines, tester and their interaction to hybrids variance (Sharma 1998) was calculated as

Line contribution (%) = [fhSS / cSS] x 100

Tester contribution (%) = [mhSS / cSS] x 100

(Line x tester) contribution (%) = [fmhSS / cSS] x 100

Where,

cSS = sum of square due to hybrids

3.2.2.9.5 Estimation of combining ability effects

The model adopted to estimate gca and sca effects of ijk observations was as follows

$$X_{ijk} = m + g_i + g_j + S_{ij} + e_{ijk}$$

Where, μ = population mean

g_i = gca effects of ith line

g_j = gca effects of jth tester

S_{ij} = sca effects of i x j cross

e_{ijk} = error associated with observation ijk

The gca effects of parents and sca effects of crosses (hybrids) were estimated as indicated below

General combining ability effects

$$(a)\text{Line} \cdot \; g_i = \frac{x_{i..}}{t \times r} - \frac{x_{...}}{l \times t \times r}$$

$$(b)Testers \quad g_j = \frac{x_{.j.}}{l \times r} - \frac{x_{...}}{l \times t \times r}$$

Specific combining ability effects

$$S_{ij} = \frac{x_{ij}}{r} - \frac{x_{i..}}{t \times r} - \frac{x_{j..}}{l \times r} - \frac{x_{...}}{l \times t \times r}$$

Where, l = number of lines

t = number of testers

r = number of replications

g_i = gca of ith line

x_i = total of ith line over all the testers

x = total of all the crosses

g_j = gca of jth testers

x_j = total of jth testers over all lines and replications

S_{ij} = sca effects of i x j crosss

x_{ij} = total of cross i x j over all replications

Standard errors of gca and sca effects

SE (GCA) for lines = $\sqrt{\frac{\text{Error variance}}{t \times r}}$

SF (GCA) for testers = $\sqrt{\frac{\text{Error variance}}{l \times r}}$

SE (SCA) = $\sqrt{\frac{Error\ variance}{r}}$

SE for (BP and Check) = $\sqrt{\frac{2\ Error\ variance}{r}}$

Critical differences (CD) were calculate by multiplying the SE with table 't' value at 5 per cent and 1 per cent of probabilities for error degrees of freedom

Results

4. RESULTS

The results obtained from the present study entitled "Development of hybrids with bacterial wilt resistance in tomato (*Solanum lycopersicum* L)" are presented under the following headings Field view of this experiment was given in Plate 5

1 Analysis of variance for experimental design
2 Mean performance of parents and hybrids
3 Estimation of heterosis
   a) Relative heterosis (RH)
   b) Heterobeltiosis (BH)
   c) Standard heterosis (SH)
4 Combining ability analysis
   a) Analysis of variance for combining ability
   b) Estimates of combining ability (*gca* and *sca*) effects
5 Components of genetic variance
6 Proportional contribution
7 Incidence of pests and diseases other than bacterial wilt

4 1 ANALYSIS OF VARIANCE FOR EXPERIMENTAL DESIGN

The abstract of ANOVA for all the characters are presented in Table 10 Analysis of variance revealed that the lines were significantly different for plant height, height at flowering primary branches plant^{1}, days to fruit set, flowers cluster^{1}, inflorescence plant^{1} fruits plant^{1}, fruit length, fruit girth, fruit weight, yield plant^{1} and yield plot^{1} while the testers were significantly different for height at flowering, leaf width, days to first flowering, flowers cluster^{1}, fruits cluster^{1}, fruit length, fruit girth, fruit weight, TSS, lycopene and bacterial wilt incidence (%) Line x Tester interaction was significant for all the characters except flowers cluster^{1}

Analysis of variance revealed significant difference among the parents and crosses for all the traits Among the parents Vs crosses, significant difference was

Table 10 Line x Tester ANOVA summary

Traits / Sources	Degree of freedom	Plant height (cm)	Height at flowering (cm)	Node to first inflorescence	Primary branches plant [1]	Leaf length (cm)	Leaf width (cm)	Days to first flowering	Days to fruit set
Replication	2 00	12 85	9 29	0 16	0 41	1 49	0 68	1 20	0 00
Lines	6 00	795 78**	157 01**	0 16	20 79*	29 80	10 05	28 25	3 29**
Testers	2 00	549 82	114 37*	0 16	20 40	27 23	17 09*	69 79**	0 90
L x T	12 00	143 72**	21 52**	0 16**	6 65**	14 31**	4 17*	9 50**	0 48**
Parents	9	175 36**	42 34**	3 25**	4 99**	38 91**	6 23**	24 21**	3 48**
Crosses	20 00	379 95**	71 45**	0 16**	12 27**	20 25**	7 23**	21 16**	1 36**
Parents Vs crosses	1	5552 99**	829 20**	0 64	138 95**	778 26**	321 64**	144 41**	23 73**
Error	40 00	21 39	3 79	0 16	0 88	3 26	1 70	0 58	0 14

*Significant at 5 percent level

**Significant at 1 percent level

Table 10 Continued

Traits / Sources	Degree of freedom	Flowers cluster ^{1}	Inflorescence plant ^{1}	Fruit set %	Pollen viability %	Fruits cluster ^{1}	Fruits plant ^{1}	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield plant ^{1} (g)
Replication	2 00	0 79	0 30	0 62	2 19	0 03	4 01	0 00	0 53	0 07	14366 71
Lines	6 00	1 95*	63 11**	198 80	315 15	1 55	3282 84**	1 42*	4 98*	368 43*	1781710 00**
Testers	2 00	10 75**	14 65	307 21	193 99	7 12*	1016 48	3 92**	9 59**	542 97*	53559 43
L x T	12 00	0 58	9 35**	128 25**	149 36**	1 05**	523 49**	0 42**	1 27**	83 97**	195795 13**
Parents	9	6 93**	12 33**	152 42**	195 74**	0 94**	219 44**	0 59**	0 71**	17 81**	66201 93**
Crosses	20 00	2 00**	26 01**	167 31**	203 56**	1 81**	1400 60**	1 07**	3 22**	215 21**	657346 00**
Parents Vs crosses	1	1 55*	140 00**	1705 60**	2393 56**	22 37**	7897 11**	5 75**	14 38**	1249 66**	6829870 50**
Error	40 00	0 37	0 41	16 01	4 45	0 05	16 46	0 02	0 24	6 67	12226 89

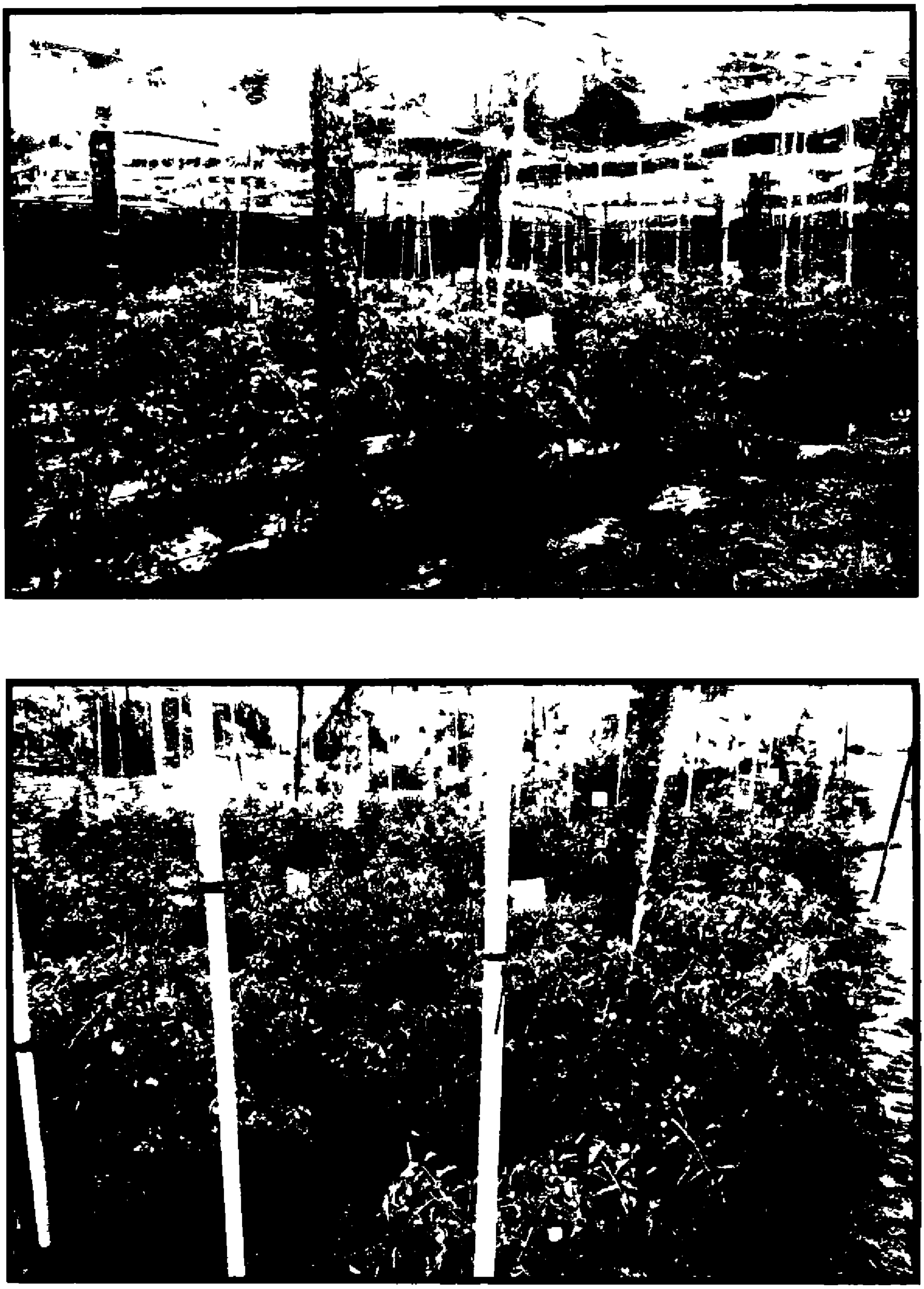
*Significant at 5 percent level **Significant at 1 percent level

Table 10 Continued

Traits / Sources	Degree of freedom	Yield plot^{-1} (kg)	TSS(%)	Lycopene (mg/ 100g)	Ascorbic acid (mg/ 100g)	Bacterial wilt incidence (%)
Replication	2 00	5 72	0 04	0 12	1 00	20 63
Lines	6 00	560 92**	0 96	9 99	94 39	868 92
Testers	2 00	152 39	3 58*	42 31*	14 31	1826 59*
L x T	12 00	71 52**	0 62**	6 63**	39 83**	429 83**
Parents	9	38 92**	0 43**	7 08**	8 54**	1483 79**
Crosses	20 00	226 43**	1 02**	11 21**	53 65**	701 23**
Parents Vs crosses	1	1377 22**	0 56**	0 12	705 03**	253 48*
Error	40 00	5 49	0 02	0 09	2 29	48 97

*Significant at 5 percent level **Significant at 1 percent level

Plate 5 Field view of the experiment



noticed for all the parameters except for node to first inflorescence and lycopene content

4 2 MEAN PERFORMANCE OF PARENTS AND HYBRIDS

The performance of parents and hybrids for different quantitative and qualitative characters are presented in Tables 11 to 14 The performance of hybrids has been compared with checks (Indam 9802 and Lekshmi) for different characters The salient features for each character are described in ensuing paragraphs

4.2 1 Vegetative Characters

The performance of parents and hybrids for vegetative characters are presented in Table 11

4.2.1.1 Plant Height (cm)

Among the lines, LE 16 recorded the highest mean value for plant height (83 77 cm) and the lowest was recorded in LE 26 (54 44 cm) The testers were not significantly different for plant height Among crosses, LE 13 x Manulekshmi (110 44 cm) was the tallest which was on par with LE 20 x Manulekshmi (103 67 cm) and the shortest was LE 19 x Anagha (71 33 cm)

4.2.1 2 Height at Flowering (cm)

Lower height at flowering is the desirable character in tomato which was observed in LE 13 (25 10 cm) and the highest value was observed in LE 12 (36 16 cm) among the lines Among the testers, the lowest height at flowering was recorded in Manulekshmi (26 36 cm) and the highest in Vellayani Vijai (32 11 cm) Among the hybrids, the lowest height at flowering was recorded in LE 19 x Anagha (27 94 cm) and the highest in LE 20 x Manulekshmi (46 99 cm)

Table 11 Performance of parents, hybrids and checks for vegetative characters of tomato

Parents and crosses	Plant height (cm)	Height at flowering (cm)	Node to first inflorescence	Primary branches plant⁻¹	Leaf length (cm)	Leaf width (cm)
Lines						
LE 3	70 11	32 15	8 89	4 78	19 47	13 56
LE 12	70 10	36 16	9 44	5 44	28 10	15 83
LE 13	65 11	25 10	9 22	5 66	19 68	14 64
LE 16	83 77	33 10	10 55	7 55	23 68	16 03
LE 19	61 89	32 82	9 77	4 66	19 49	13 74
LE 20	68 77	34 02	11 77	4 44	20 93	14 29
LE 26	54 44	34 49	8 33	4 22	24 63	14 14
Testers						
Anagha	64 66	27 29	8 67	4 77	18 57	13 22
Manulekshmi	71 89	26 36	9 44	8 00	24 97	14 05
Vellayani Vijai	71 55	32 11	8 55	5 55	27 98	17 92
Hybrids						
LE 3 x Anagha	86 94	39 22	9 77	7 77	28 94	17 22
LE 3x Manulekshmi	88 89	38 11	9 22	8 00	26 31	17 81
LE 3x V Vijai	79 00	35 55	8 44	7 77	27 51	17 58
LE 12x Anagha	74 55	43 00	9 00	6 44	32 16	19 31
LE 12x Manulekshmi	82 37	45 83	9 33	5 77	32 66	20 99
LE 12x V Vijai	79 47	45 00	9 66	6 00	32 22	20 83
LE 13x Anagha	82 89	33 52	9 22	8 00	25 17	17 96
LE 13x Manulekshmi	110 44	42 33	9 66	9 78	33 01	20 80
LE 13x V Vijai	102 00	34 18	8 67	8 00	29 72	20 00
LE 16x Anagha	97 66	36 50	9 33	10 44	29 51	19 04
LE 16x Manulekshmi	94 78	39 00	9 55	12 22	26 77	17 58
LE 16x V Vijai	88 44	37 77	11 11	10 22	29 86	20 89
LE 19x Anagha	71 33	27 94	8 77	8 44	26 19	17 02
LE 19x Manulekshmi	81 22	37 33	9 89	8 11	31 67	18 16
LE 19x V Vijai	71 44	32 10	8 66	4 77	28 99	18 14
LE 20x Anagha	82 55	39 94	10 77	5 44	26 28	16 41
LE 20x Manulekshmi	103 67	46 99	11 11	12 55	32 34	21 60
LE 20x V Vijai	79 77	37 02	10 22	7 55	29 03	18 17
LE 26x Anagha	73 22	35 11	9 44	7 33	25 51	16 86
LE 26x Manulekshmi	73 11	33 50	10 00	8 33	26 53	18 59
LE 26x V Vijai	76 22	32 75	10 66	7 66	27 34	18 19
Indam 9802 (check)	88 78	42 70	10 89	8 66	29 38	20 74
Lekshmi (check)	84 22	34 26	9 66	9 33	25 37	16 79
Mean	79 85	35 85	9 62	7 38	26 97	17.52
CD (0 05)	7 41	3 08	0 78	1 37	2 45	1 88

4.2.1.3 Node to First Inflorescence

For node to first inflorescence, the lowest value is preferred which was observed in LE 26 (8 33) and the highest was recorded in LE 20 (11 77) among the lines while, among the testers lowest value for the trait was recorded in Vellayani Vijai (8 55) and the highest was observed in Manulekshmi (9 44) Among hybrids, the lowest node to first inflorescence was exhibited by LE 3 x Vellayani Vijai (8 44) which was on par with LE 19 x Vellayani Vijai (8 66), LE 13 x Vellayani Vijai (8 67), LE 19 x Anagha (8 77), LE 12 x Anagha (9 00), LE 3 x Manulekshmi (9 22) and LE 13 x Anagha (9 22) Highest value was shown by LE 16 x Vellayani Vijai and LE 20 x Manulekshmi (11 11)

4.2.1.4 Primary Branches Plant^{-1}

Among the lines, LE 16 (7 55) produced maximum number of primary branches plant^{-1} and minimum was recorded in LE 26 (4 22) Among the testers, Manulekshmi (8 00) recorded maximum primary branches plant^{-1} while, the minimum was observed in Anagha (4 77) Among the hybrids, LE 20 x Manulekshmi (12 55) produced the maximum number of primary branches plant^{-1} which was on par with LE 16 x Manulekshmi (12 22) while, the minimum was observed in LE 19 x Vellayani Vijai (4 77)

4.2.1.5 Leaf Length (cm)

Among the lines LE 12 (28 10 cm) recorded the highest mean value for leaf length and the lowest was recorded in LE 3 (19 47 cm) while, among the testers Vellayani Vijai (27 98 cm) had the highest leaf length and the lowest was recorded in Anagha (18 57 cm) Among crosses, LE 13 x Manulekshmi (33 01 cm) exhibited the highest leaf length which was on par with LE 12 x Manulekshmi (32 66 cm), LE 20 x Manulekshmi (32 34 cm), LE 12 x Vellayani

Vijai (32 22 cm), LE 12 x Anagha (32 16 cm) and LE 19 x Manulekshmi (31 67 cm) whereas, LE 13 x Anagha (25 17 cm) recorded the lowest

4.2.1.6 Leaf Width (cm)

The highest leaf width among the lines was recorded in LE 16 (16 03 cm) which was on par with LE 12 (15 83 cm), LE 13 (14 64 cm) and LE 20 (14 29 cm) and the lowest value was observed in LE 3 (13 56 cm) Among the testers, the highest leaf width was recorded in Vellayani Vijai (17 92 cm) and the lowest in Anagha (13 22 cm) The hybrid, LE 20 x Manulekshmi (21 60 cm) recorded the highest leaf width, which was on par with LE 12 x Manulekshmi (20 99 cm), LE 16 x Vellayani Vijai (20 89 cm), LE 12 x Vellayani Vijai (20 83 cm), LE 13 x Manulekshmi (20 80 cm) and LE 13 x Vellayani Vijai (20 00 cm) The lowest was observed in LE 20 x Anagha (16 41 cm)

4.2.2 Flowering Characters

The performance of parents and hybrids for flowering characters are presented in Table 12

4.2 2 1 Days to First Flowering

Among the lines, LE 12 (29 66 days) was the earliest and LE 19 and LE 26 were late flowering (35 44 days) Among the testers, Vellayani Vijai (27 44 days) flowered early while, Manulekshmi (33 11 days) was late Among the crosses, LE 16 x Anagha (24 33 days) exhibited early flowering whereas, LE 19 x Vellayani Vijai (35 55 days) recorded late flowering

4.2.2.2 Days to Fruit set

Among the female parents, LE 16 (6 67 days) took minimum number of days to fruit set and LE 20 (7 78 days) the maximum Among the testers, Vellayani Vijai (4 44 days) took minimum number of days to fruit set while, Manulekshmi (6 22 days) the maximum Among the hybrids, LE 20 x Vellayani

Table 12 Performance of parents, hybrids and checks for flowering characters of tomato

Parents and crosses	Days to first flowering	Days to fruit set	Flowers cluster^{-1}	Inflorescence plant^{-1}	Fruit set%	Pollen viability %
Lines						
LE 3	33 78	7 55	4 55	15 78	66 03	59 01
LE 12	29 66	7 22	7 11	16 22	65 52	59 22
LE 13	35 00	6 78	6 11	17 89	74 39	67 81
LE 16	34 66	6 67	5 66	18 55	66 70	62 17
LE 19	35 44	7 66	5 78	17 77	68 94	60 43
LE 20	34 33	7 78	5 44	17 22	50 11	55 31
LE 26	35 44	7 11	6 22	15 11	58 16	52 51
Testers						
Anagha	29 88	5 33	5 89	21 11	70 75	72 29
Manulekshmi	33 11	6 22	4 89	20 11	65 55	54 45
Vellayani Vijai	27 44	4 44	10 00	20 33	72 41	77 39
Hybrids						
LE 3 x Anagha	26 22	5 11	6 33	18 77	83 33	79 63
LE 3x Manulekshmi	33 44	5 66	5 33	17 33	64 44	63 97
LE 3x V Vijai	31 66	6 11	5 55	17 44	65 55	62 72
LE 12x Anagha	27 22	6 00	6 44	18 99	67 18	62 00
LF 12x Manulekshmi	28 66	7 22	5 67	15 77	70 54	70 13
LE 12x V Vijai	27 33	6 00	7 33	19 44	68 27	65 72
LE 13x Anagha	29 55	5 89	6 89	23 55	77 35	73 71
LE 13x Manulekshmi	31 77	6 33	5 00	23 33	65 37	65 17
LE 13x V Vijai	31 89	6 22	6 77	21 44	79 92	73 30
LE 16x Anagha	24 33	5 11	7 22	26 11	78 65	82 20
LE 16x Manulekshmi	27 89	5 22	5 33	23 00	85 73	85 24
LE 16x V Vijai	30 89	4 55	7 11	24 89	82 61	82 51
LE 19x Anagha	28 00	5 66	6 55	22 66	84 67	86 01
LE 19x Manulekshmi	32 55	5 78	5 22	22 22	73 80	72 31
LE 19x V Vijai	35 55	5 89	6 55	18 11	73 42	69 26
LE 20x Anagha	30 89	4 77	7 22	20 44	82 16	77 18
LE 20x Manulekshmi	31 55	4 89	6 22	24 89	73 14	71 73
LE 20x V Vijai	32 22	4 44	7 78	20 00	80 56	79 84
LE 26x Anagha	30 66	5 11	7 55	19 44	73 60	68 18
LE 26x Manulekshmi	31 11	5 44	6 55	18 44	62 22	58 59
LE 26x V Vijai	31 00	6 11	6 66	17 00	82 85	81 74
Indam 9802 (check)	31 22	5 44	6 33	30 11	74 44	79 66
Lekshmi (check)	30 77	4 78	6 78	31 77	78 026	81 03
mean	31 06	5 89	6 36	20 46	72 31	70 07
CD (0 05)	1 25	0 54	0 99	1 18	7 68	3 41

Vijai (4 44 days) recorded minimum days to fruit set which was on par with LE 16 x Vellayani Vijai (4 55 days), LE 20 x Anagha (4 77 days) and LE 20 x Manulekshmi (4 89 days) whereas, LE 12 x Manulekshmi (7 22 days) took maximum number of days to fruit set

4.2.2.3 Flowers Cluster ^{1}

The line LE 12 (7 11) recorded the highest number of flowers cluster ^{1} which was on par with LE 26 (6 22) while, LE 3 (4 55) recorded the least for the trait among the lines The tester Vellayani Vijai (10 00) recorded the highest number of flowers cluster ^{1} and the lowest was observed in Manulekshmi (4 89) The cross, LE 20 x Vellayani Vijai (7 78) recorded maximum number of flowers cluster ^{1} which was on par with LE 26 x Anagha (7 55), LE 12 x Vellayani Vijai (7 33), LE 16 x Anagha (7 22), LE 20 x Anagha (7 22), LE 16 x Vellayani Vijai (7 11) and LE 13 x Anagha (6 89) while, minimum was recorded in LE 13 x Manulekshmi (5 00)

4.2.2.4 Inflorescence Plant ^{1}

The highest number of inflorescence plant ^{1} among the lines was recorded in LE 16 (18 55) which was on par with LE 13 (17 89) and LE 19 (17 77) and the lowest was observed in LE 26 (15 11) There was no significant difference among the testers for this trait Among the cross combinations, LE 16 x Anagha (26 11) recorded the highest number of inflorescence plant ^{1} and the lowest was recorded in LE 12 x Manulekshmi (15 77)

4.2 2.5 Fruit set (%)

Among the lines, the highest fruit set per cent was observed in LE 13 (74 39%) which was on par with LE 19 (68 94%) while, LE 20 (50 11%) recorded the lowest for the trait The testers were not significantly different Fruit set was maximum in the hybrid, LE 16 x Manulekshmi (85 73%) which was on par with LE 19 x Anagha (84 67%), LE 3 x Anagha (83 33%), LE 26 x Vellayani Vijai

(82 85%), LE 16 x Vellayani Vijai (82 61%), LE 20 x Anagha (82 16%), LE 20 x Vellayani Vijai (80 56%), LE 13 x Vellayani Vijai (79 92%) and LE 16 x Anagha (78 65%) whereas, LE 26 x Manulekshmi (62 22%) recorded minimum fruit set

4.2.2.6 Pollen Viability (%)

Pollen viability (%) was highest for LE 13 (67 81%) and the lowest for LE 26 (52 51%) among the lines while, it was the highest for Vellayani Vijai (77 39%) and the lowest for Manulekshmi (54 45%) among the testers Among the crosses, LE 19 x Anagha (86 01%) recorded the highest mean value for pollen viability which was on par with LE 16 x Manulekshmi (85 24%) and the lowest was observed in LE 26 x Manulekshmi (58 59%)

4.2.3 Fruit Characters and Yield

The performance of parents and hybrids for fruit characters and yield are presented in Table 13 and fruits of different hybrid combinations are given in Plate 6

4.2.3.1 Fruits Cluster⁻¹

Among the lines, the highest fruits cluster⁻¹ was recorded in LE 13 (4 11) which was on par with LE 12 (4 00) and LE 20 (3 78) and the lowest was observed in LE 26 (2 77) Among the testers, the highest fruits cluster⁻¹ was recorded in Vellayani Vijai (4 66) and the lowest in Manulekshmi (3 00) Among the hybrids, LE 26 x Anagha (6 33) recorded the highest fruits cluster⁻¹ which was on par with LE 20 x Vellayani Vijai (6 22) and LE 13 x Vellayani Vijai (6 11) and the lowest was noticed in LE 3 x Manulekshmi, LE 12 x Manulekshmi, LE 13 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Manulekshmi (4 00) (Fig 1)

4.2.3.2 Fruits Plant⁻¹

The line LE 16 (42 48) recorded maximum fruits plant⁻¹ which was on par with LE 13 (41 55) and the minimum was noticed in LE 12 (21 66) Among the

Table 13 Performance of parents hybrids and checks for fruit characters and yield of tomato

Parents and crosses	Fruits cluster[1]	Fruits plant[1]	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield plant[1] (g)	Yield plot[1] (kg)
Lines							
LE 3	3.55	24.00	3.52	12.32	31.66	588.11	4.30
LE 12	4.00	21.66	3.23	11.43	27.77	530.77	4.08
LE 13	4.11	41.55	3.66	12.83	32.00	846.79	6.20
LE 16	3.55	42.48	3.69	12.97	32.51	982.00	14.50
LE 19	3.67	34.93	4.01	12.33	31.66	763.55	6.13
LE 20	3.78	33.33	4.10	11.63	29.66	742.11	6.63
LE 26	2.77	22.44	4.07	12.04	32.77	625.15	4.58
Testers							
Anagha	4.22	40.22	3.40	11.93	28.88	740.55	12.08
Manulekshmi	3.00	22.22	3.75	12.42	35.00	498.44	8.47
Vellayam Vijai	4.66	26.22	4.79	12.47	35.33	646.89	10.95
Hybrids							
LE 3 x Anagha	4.33	30.66	4.13	12.16	31.77	975.80	9.44
LE 3x Manulekshmi	4.00	32.22	4.13	12.70	36.55	748.33	9.24
LE 3x V Vijai	4.11	33.78	4.41	12.78	33.99	766.66	7.41
LE 12x Anagha	4.22	33.16	3.32	11.11	30.11	998.36	11.66
LE 12x Manulekshmi	4.00	28.33	3.81	12.20	31.55	894.91	8.65
LE 12x V Vijai	4.78	29.64	4.00	11.76	33.87	1005.70	7.96
LE 13x Anagha	5.66	86.44	4.12	13.01	38.07	1993.66	25.94
LE 13x Manulekshmi	4.00	61.44	4.50	15.07	55.74	1770.00	31.42
LE 13x V Vijai	6.11	68.44	5.41	13.40	47.83	1908.55	25.43
LE 16x Anagha	5.33	110.66	3.46	11.73	31.09	2191.44	24.63
LE 16x Manulekshmi	4.00	50.89	4.43	14.94	48.36	1560.66	25.34
LE 16x V Vijai	5.22	73.11	4.35	13.43	41.23	1733.33	24.92
LE 19x Anagha	4.89	63.33	3.71	13.00	37.22	1376.66	19.19
LE 19x Manulekshmi	4.44	53.66	4.82	15.00	62.85	1715.11	25.72
LE 19x V Vijai	4.78	35.77	5.14	13.12	46.14	890.22	5.95
LE 20x Anagha	5.11	44.44	3.67	12.66	35.24	953.44	9.23
LE 20x Manulekshmi	4.00	62.22	4.30	13.21	38.88	1491.00	25.83
LE 20x V Vijai	6.22	55.77	5.06	13.31	42.40	1363.66	14.05
LE 26x Anagha	6.33	41.66	5.12	13.11	34.99	829.51	9.22
LE 26x Manulekshmi	4.33	33.44	4.34	13.13	34.77	675.66	6.09
LE 26x V Vijai	4.55	33.89	5.22	13.84	38.25	956.55	9.17
Indam 9802 (check)	4.00	26.33	5.15	17.10	95.55	1721.22	9.82
Lekshmi (check)	3.66	36.44	5.05	18.96	86.77	1906.99	13.96
mean	4.40	43.48	4.24	13.12	40.32	1133.08	13.28
CD (0.05)	0.41	6.02	0.25	0.7481	3.95	152.40	3.46

Plate 6 Fruits of different hybrid combinations

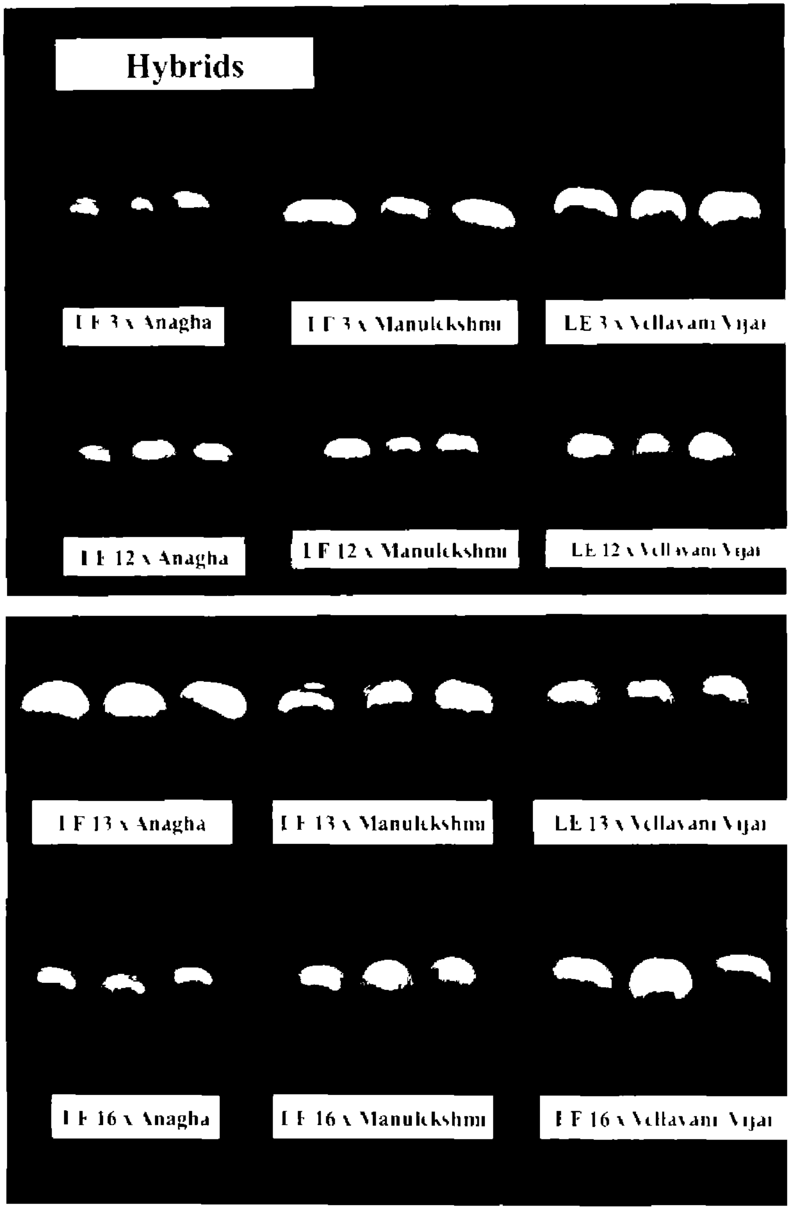
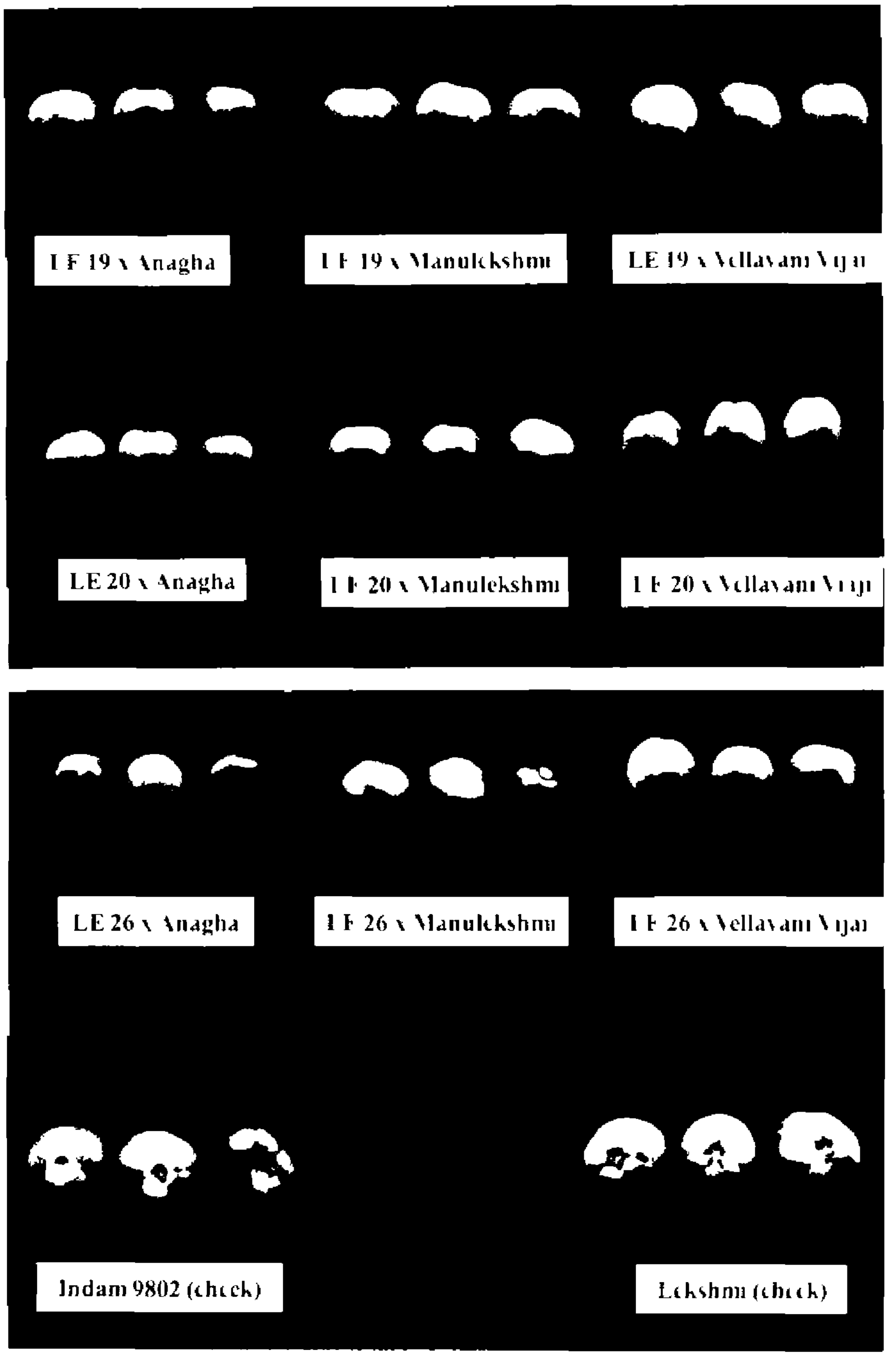


Plate 6 Continued



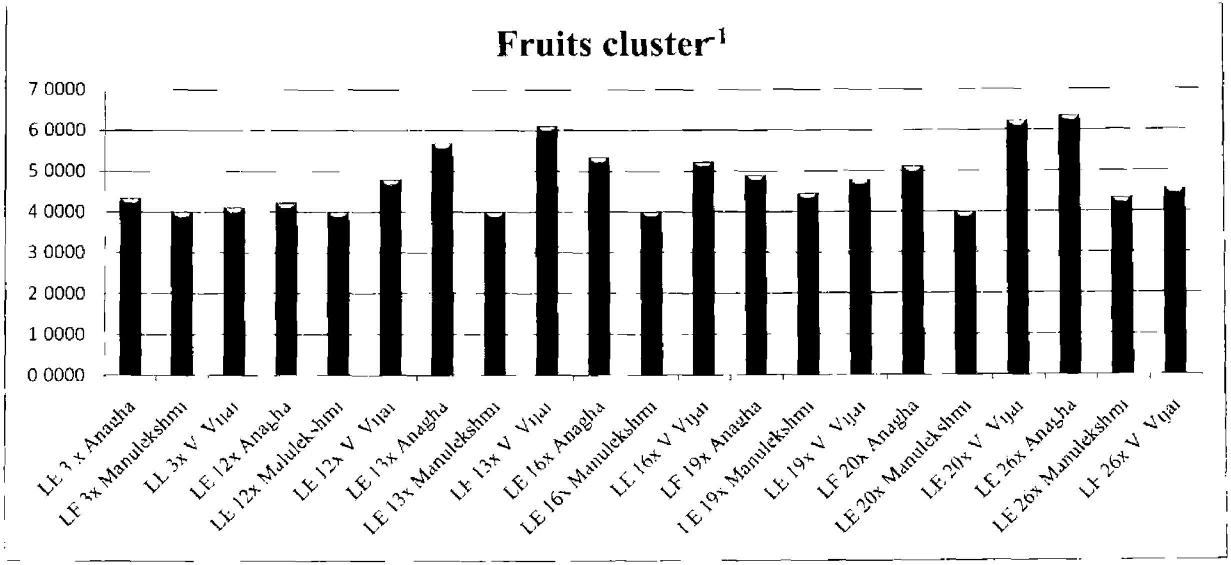


Fig. 1 Mean performance of hybrids for fruits cluster[1]

testers, Anagha (40.72) recorded the maximum fruits plant[-1] and the minimum was observed in Manulekshmi (22.22). Among the crosses, LE 16 x Anagha (110.66) recorded the maximum for the trait and the minimum was observed in LE 12 x Manulekshmi (28.33) (Fig. 2).

4.2.3.3 Fruit Length (cm)

Among the female parents, fruit length was highest for LE 20 (4.10 cm) which was on par with LE 26 (4.07 cm) and LE 19 (4.01 cm) and the lowest was observed in LE 12 (3.27 cm). Among the male parents, the highest fruit length was recorded in Vellayani Vijai (4.79 cm) and the lowest in Anagha (3.40 cm). Among the cross combinations, LE 13 x Vellayani Vijai (5.41 cm) recorded the highest fruit length which was on par with LE 26 x Vellayani Vijai (5.22 cm) and the lowest was observed in LE 12 x Anagha ([illegible] cm).

4.2.3.4 Fruit Girth (cm)

Among the lines, fruit girth was maximum for LE 16 (12.97 cm) which was on par with LE 15 (12.8[illegible] cm), LE 19 (12.[illegible]3 cm) and LE 3 (12.32 cm) while it was minimum for LE 12 (11.43 cm). The testers were not significantly different for the trait. Among the hybrids, LE 13 x Manulekshmi (15.07 cm) recorded the maximum fruit girth which was on par with LE 19 x Manulekshmi (15.00 cm) and LE 16 x Manulekshmi (14.94 cm) and the minimum was noticed in LE 12 x Anagha (11.11 cm).

4.2.3.5 Fruit Weight (g)

Maximum fruit weight among the lines was observed in LE 26 (32.77 g) which was on par with LE 16 (32.51 g), LE 13 (32.00 g), LE 3 (31.66 g), LE 19 (31.66 g) and LE 20 (29.66 g) and the minimum was recorded in LE 12 (27.77 g). Among the testers, fruit weight was maximum for Vellayani Vijai (35.33 g) which was on par with Manulekshmi (35.00 g). Anagha (28.88 g) recorded the lowest value for the trait. Among the crosses, maximum fruit weight was observed in LE

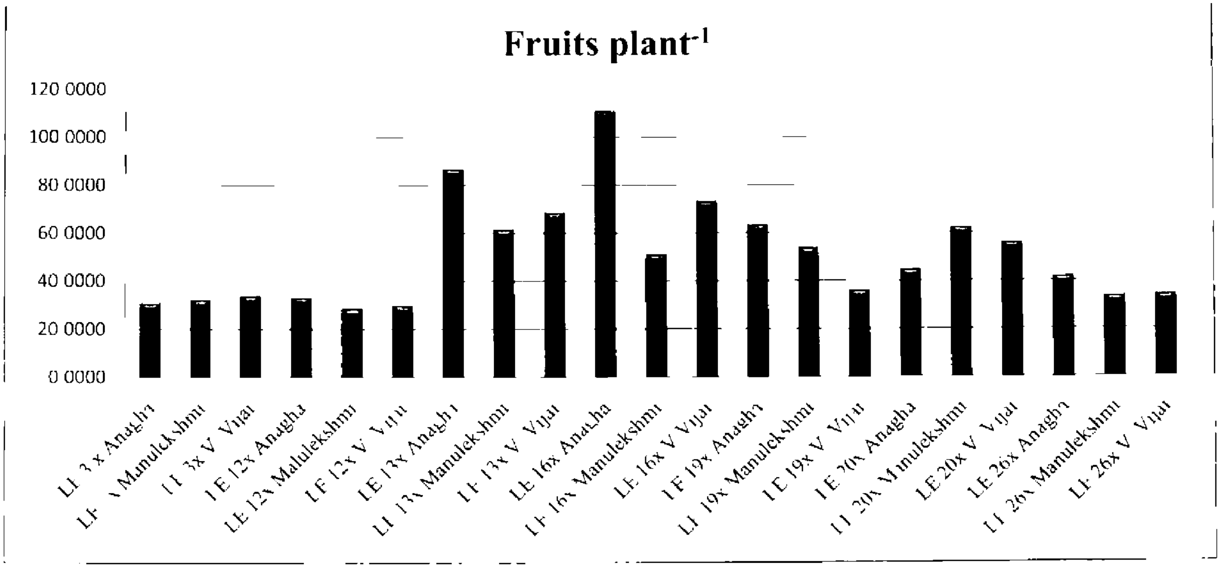


Fig 2 Mean performance of hybrids for fruits plant^{-1}

19 x Manulekshmi (62.85 [illegible]) and the lowest was recorded in LL 12 x Anagha ([illegible] 0.11 [illegible]) (Fig. [illegible])

4.2.3.6 Yield Plant[1] (g)

Among the lines LL 16 (982.00 g) recorded the highest yield plant[1] which was on par with LL 1 (846.79 g) and the lowest was observed in LL 12 (5[illegible]0.77 g). Among the testers, Anagha (740.55 g) recorded the highest yield plant[1] which was on par with Vellayani Vijai (646.89 g) and the lowest was observed in Manulekshmi (4[illegible]8.44 g). Among the cross combinations, the highest yield plant[1] was observed in LL 16 x Anagha (2[illegible]1.44 g) whereas LL 26 x Manulekshmi (675.66 g) recorded the lowest yield plant[1] (Fig. 4).

4.2.3.7 Yield Plot[1] (kg)

Among the lines, LL 16 (14.50 kg) recorded the highest yield plot[1] and the lowest was noticed in LL 12 (4.08 kg). Among the testers, Anagha (12.08 kg) exhibited the highest yield plot[1] which was on par with Vellayani Vijai (10.95 k[illegible]) and the lowest was recorded in Manulekshmi (8.47 kg). Among the hybrids, LL 1 x Manulekshmi ([illegible] 1.4[illegible] kg) recorded the highest yield plot[1] while the lowest was observed in LL 19 x Vellayani Vijai (5.[illegible]5 kg) (Fig. 5).

4.2.4 Quality Characters

The performance of parents and hybrids for quality characters are presented in Table 14.

4.2.4.1 TSS (° [illegible])

The line LL 20 ([illegible].75 [illegible]) recorded the highest TSS which was on par with LL [illegible] ([illegible].71 [illegible]), LL 1 ([illegible].61 [illegible]), LL 12 ([illegible] [illegible]) and LL 16 ([illegible] %) while the lowest was seen in LL 26 ([illegible].17 [illegible]). The tester Vellayani Vijai (4.40%) recorded the highest for the trait and the lowest was observed in Manulekshmi (4.02 [illegible]). Among the crosses, the highest TSS was recorded in LL 16 x Anagha (4.91 [illegible])

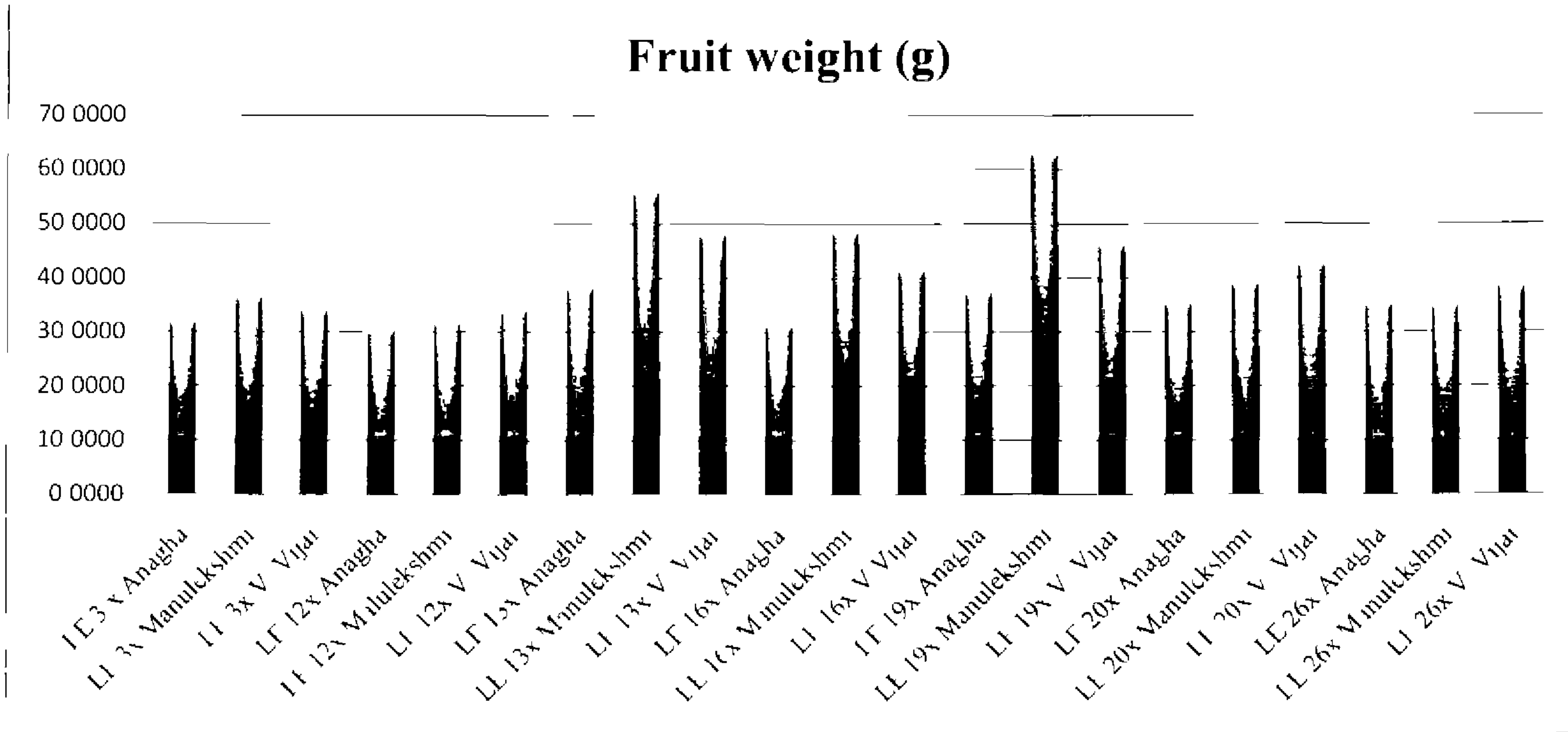


Fig 3 Mean performance of hybrids for fruit weight (g)

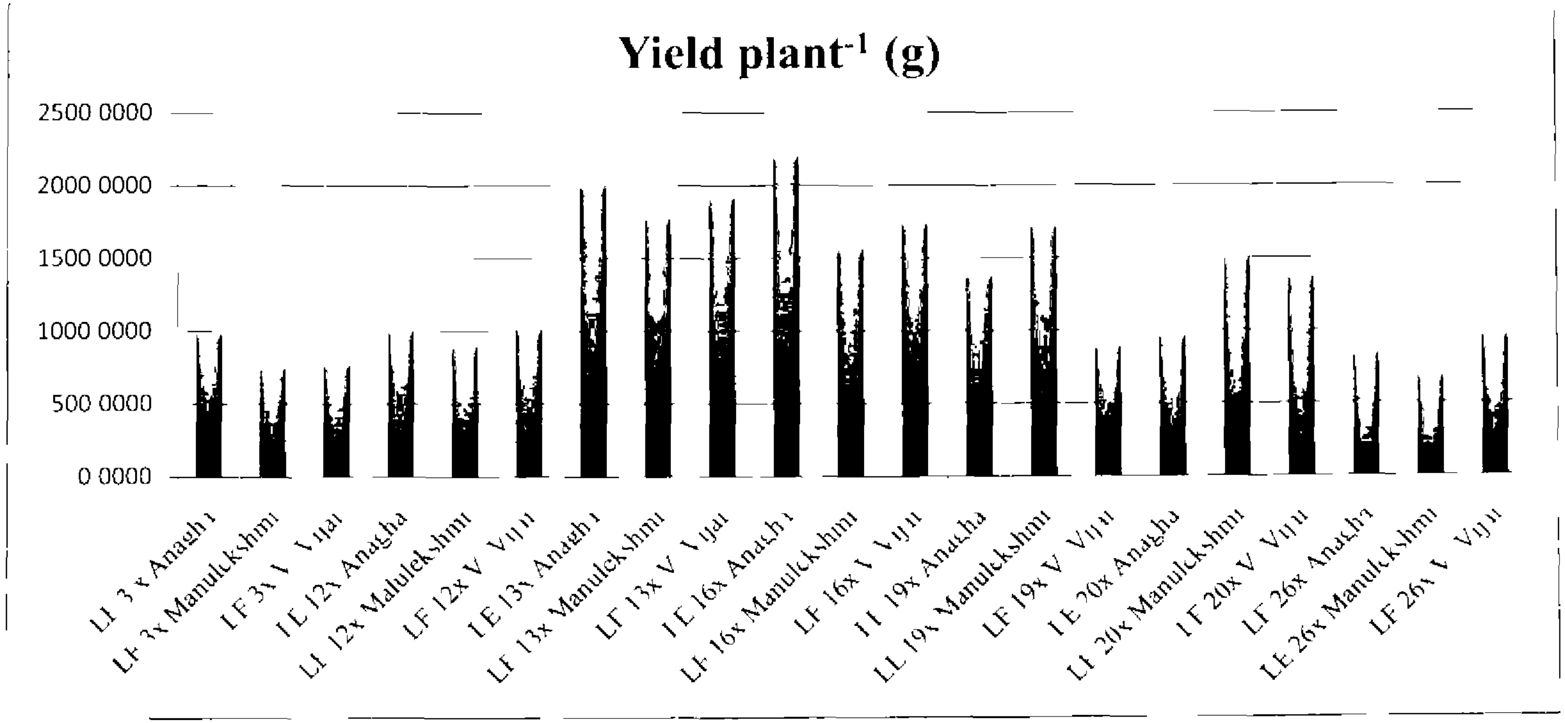


Fig 4 Mean performance of hybrids for yield plant^{-1} (g)

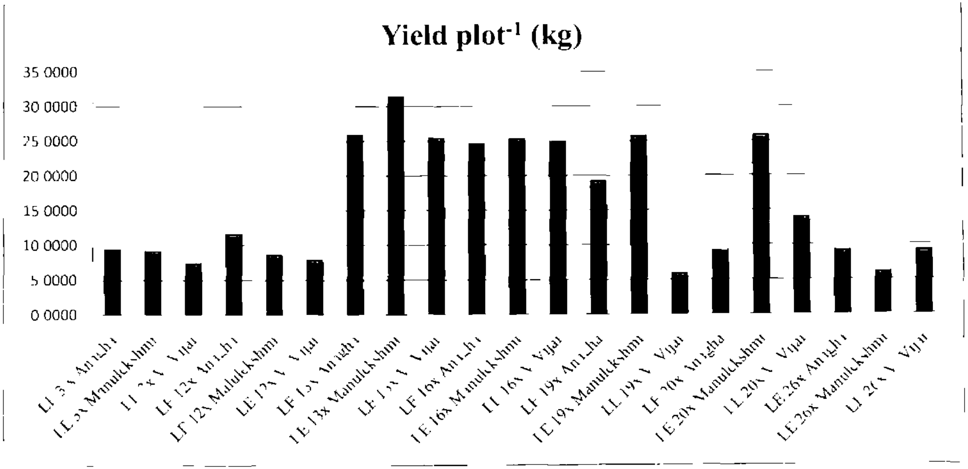


Fig. 5. Mean performance of hybrids for yield plot-1 (kg)

Table 14 Performance of parents, hybrids and checks for quality characters of tomato

[illegible]	TSS ([illegible])	Lycopene (mg 100 [illegible])	Ascorbic acid (mg 100 [illegible])
Lines			
LE [illegible]	[illegible]71	[illegible]14	17.[illegible]
LE 1[illegible]	[illegible]0	6.86	17.41
LE [illegible]	[illegible]61	7.8[illegible]	18.00
LE 16	[illegible]	[illegible]46	[illegible]1.0[illegible]
LE 1[illegible]	[illegible]	9.8	19.00
LE 20	[illegible]	8.9[illegible]	17.14
LE [illegible]6	[illegible]	[illegible]6[illegible]	[illegible]0.08
Testers			
Arka [illegible]	4.[illegible]	0.[illegible]4	18.16
Manu[illegible]	4.[illegible]	9.[illegible]	[illegible]0.88
Vellayani Vijai	4.4[illegible]	1[illegible].6[illegible]	[illegible]1.40
Hybrids			
LE [illegible] x Arka [illegible]	4.0[illegible]	[illegible].01	19.87
LE [illegible] x Manulekshmi	[illegible]	[illegible].0[illegible]	19.81
LE [illegible] x V. Vijai	4[illegible]	9.9	[illegible].76
LE 1[illegible] x Arka [illegible]	[illegible]0[illegible]	6.6	18.08
LE [illegible] x Manulekshmi	[illegible]	7.[illegible]4	[illegible]0.1[illegible]
LE [illegible] x V. Vijai	[illegible]	8.70	[illegible]1.66
LE [illegible] x Arka [illegible]	[illegible]	8.[illegible]8	[illegible].1[illegible]
LE [illegible] x Manulekshmi	[illegible]4	8.[illegible]	[illegible]2.20
LE [illegible] x V. Vijai	4.8[illegible]	1[illegible].8[illegible]	[illegible]7.1[illegible]
LE 16 x Arka [illegible]	4.[illegible]1	1[illegible].[illegible]0	[illegible]6.80
LE 16 x Manulekshmi	[illegible]	6.7[illegible]	[illegible]0.00
LE 16 x V. Vijai	4.04	10.46	[illegible]8.[illegible]7
LE 1[illegible] x Arka [illegible]	4.[illegible]	9.7	[illegible]4.[illegible]0
LE 19 x Manulekshmi	4.0[illegible]	[illegible]	[illegible]7.4[illegible]
LE [illegible]9 x V. Vijai	4.[illegible]	1[illegible].[illegible]0	[illegible].1[illegible]
LE 20 x Arka [illegible]	4.[illegible]0	8.4[illegible]	[illegible]6.10
LE [illegible]0 x Manulekshmi	[illegible]	7.[illegible]0	[illegible].[illegible]0
LE [illegible]0 x V. Vijai	4.84	8.[illegible]1	[illegible].[illegible]7
LE [illegible]6 x Arka [illegible]	[illegible]	[illegible].98	[illegible]7.48
LE [illegible]6 x Manulekshmi	[illegible]48	[illegible]46	[illegible]0.44
LE [illegible]6 x V. Vijai	4.0[illegible]	1[illegible].[illegible]7	[illegible]1.78
[illegible] 080 (check)	4.[illegible]0	1[illegible].74	[illegible]4.[illegible]
[illegible] (check)	[illegible]	[illegible]4	[illegible]7.6[illegible]
Mean	3.8[illegible]	9.[illegible]	23.20
CD (0.0[illegible])	0.[illegible]4	0.[illegible]1	[illegible]0

which was on par with LE 1 × Vellayani Vijay (4.89%) and LE 20 × Vellayani Vijay (4.84%) while the lowest TSS was recorded in LE 12 × Anagha (3.09%).

4.2.4.2 *Lycopene (mg/100 g)*

Among the lines, the highest lycopene content was observed in LE 19 (9.85 mg/100 g) which was on par with LE 26 (9.62 mg/100 g) and LE 16 (9.46 mg/100 g) while the lowest was recorded in LE 12 (6.86 mg/100 g). Among the testers, lycopene content was the highest for Vellayani Vijay (12.66 mg/100 g) and the lowest for Manulakshmi (9.25 mg/100 g). Among the hybrids, LE 16 × Anagha exhibited the highest lycopene content (13.05 mg/100 g) which was on par with LE 1 × Vellayani Vijay (12.85 mg/100 g) and LE 26 × Vellayani Vijay (12.57 mg/100 g) while LE 12 × Anagha (6.62 mg/100 g) recorded the lowest for the trait.

4.2.4.3 *Ascorbic acid (mg/100 g)*

The line LE 16 (21.09 mg/100 g) recorded the highest ascorbic acid content which was on par with LE [illegible] (20.08 mg/100 g) and LE 19 (19.00 mg/100 g) while the lowest was observed in LE 20 (17.14 mg/100 g). The tester Vellayani Vijay (21.40 mg/100 g) recorded the highest for the trait which was on par with Manulakshmi (20.88 mg/100 g) and lowest was seen in Anagha (18.16 mg/100 g). Among the crosses, ascorbic acid content was highest in LE 19 × Anagha (24.30 mg/100 g) while the lowest was recorded in LE 12 × Anagha (18.08 mg/100 g).

4.2.5 **Incidence of bacterial wilt**

The hybrids and parents were evaluated for the incidence of bacterial wilt under field conditions (Plate 8) based on the scoring procedure given by Winstead and Kelman (1952). The number of plants wilted per plot from the date of transplanting till the final harvest was recorded and disease incidence (%) was calculated for each treatment in all replications (Table 15) (Fig. 6).

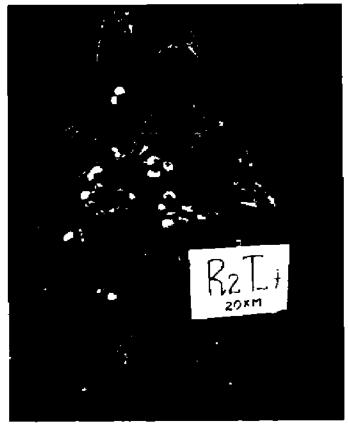
Table 15. Performance of parents, hybrids and checks for bacterial wilt incidence (%) under field conditions

Parents and crosses	Incidence (%)	Scale	Category
Lines			
LE 3	65.33	4	Susceptible
LE 12	61.67	4	Susceptible
LE 13	65	4	Susceptible
LE 16	26.67	2	**Moderately resistant**
LE 19	60		Moderately susceptible
LE 20	55	3	Moderately susceptible
LE 26	63.3	4	Susceptible
Testers			
Anagha	18.33	1	**Resistant**
Manulekshmi	15	1	**Resistant**
Vellayani Vijai	15	1	**Resistant**
Hybrids			
LE 3 x Anagha	51.67		Moderately susceptible
LE 3 x Manulekshmi	8.33	2	Moderately resistant
LE 3 x V. Vijai	5[illegible].67	3	Moderately susceptible
LE 12 x Anagha	41.67	3	Moderately susceptible
LE 12 x Manulekshmi	51.67		Moderately susceptible
LE 12 x V. Vijai	60	3	Moderately susceptible
LE 13 x Anagha	35	2	Moderately resistant
LE 13 x Manulekshmi	11.67	1	**Resistant**
LE 13 x V. Vijai	3[illegible]3	2	Moderately resistant
LE 16 x Anagha	43.[illegible]		Moderately susceptible
LE 16 x Manulekshmi	18.3	1	**Resistant**
LE 16 x V. Vijai	28.33	2	Moderately resistant
LE 19 x Anagha	30	2	Moderately resistant
LE 19 x Manulekshmi	25	2	Moderately resistant
LE 19 x V. Vijai	66.67	4	Susceptible
LE 20 x Anagha	51.67	3	Moderately susceptible
LE 20 x Manulekshmi	1[illegible]	1	**Resistant**
LE 20 x V. Vijai	48.3	3	Moderately susceptible
LE 26 x Anagha	45	3	Moderately susceptible
LE 26 x Manulekshmi	35	3	Moderately susceptible
LE 26 x V. Vijai	5[illegible]		Moderately susceptible
Indam 9802 (check)	71.67	4	Susceptible
Lakshmi (check)	63.[illegible]	4	Susceptible

Plate 7 Promising bacterial wilt resistant hybrids

I F 13 x Manulekshmi

I F 16 x Manulekshmi



I F 20 x Manulekshmi

Plate 8 Bacterial wilt disease noticed at different crop growth stages

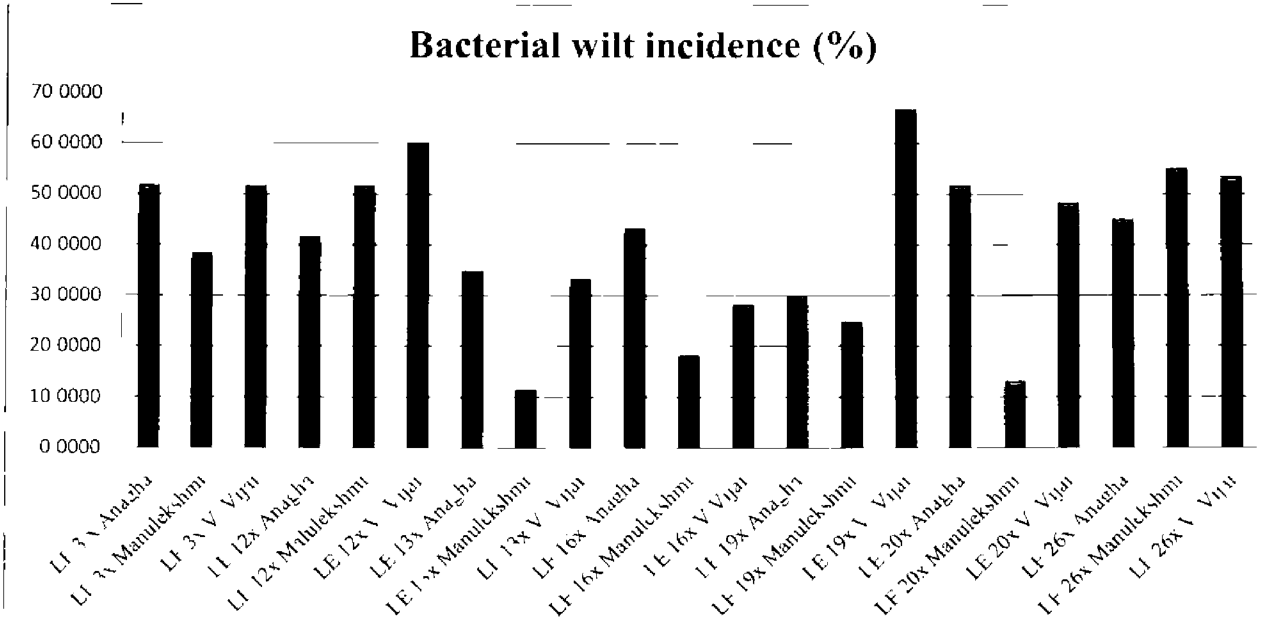


Fig 6 Performance of hybrids for bacterial wilt incidence (%)

Among the lines, LE 16 was found to be moderately resistant to bacterial wilt with a disease incidence of 26 67% while rest of the lines were in the range of moderately susceptible to susceptible All the testers were found to be resistant Among the hybrids, LE 13 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Manulekshmi were found resistant to bacterial wilt with a disease incidence of 11 67%, 18 33% and 13 33% respectively (Plate 7) The hybrids, LE 3 x Manulekshmi, LE 13 x Anagha, LE 13 x Vellayani Vijai, LE 16 x Vellayani Vijai, LE 19 x Anagha, LE 19 x Manulekshmi were categorised as moderately resistant to bacterial wilt with a disease incidence of 38 33%, 35%, 33 33%, 28 33%, 30% and 25% respectively The cross LE 19 x Vellayani Vijai was found to be susceptible with a disease incidence of 66 67% while, remaining hybrids were moderately susceptible The two standard checks Indam 9802 and Lekshmi were found susceptible with a disease incidence of 71 67% and 63 33% respectively

4 3 ESTIMATION OF HETEROSIS

The magnitude of heterosis, estimated as per cent increase or decrease of F_1 value over mid-parent (RH), better parent (HB) and standard checks (SH) for the 21 hybrids for various characters are presented in Tables 16 to 27 The character wise results are summarized in the following paragraphs

4.3.1 Plant Height (cm)

Twenty hybrids exhibited significant positive heterosis over mid parent with maximum heterosis of 61 24% (LE 13 x Manulekshmi) Fourteen hybrids recorded significant positive heterosis over better parent with maximum heterosis of 53 63% (LE 13 x Manulekshmi) Heterosis over standard check Indam 9802 ranged from -19 65% (LE 19 x Anagha) to 24 40% (LE 13 x Manulekshmi) with four hybrids showing significant desirable standard heterosis The magnitude of heterosis over standard check Lekshmi ranged from -15 30% (LE 19 x Anagha) to 31 14% (LE 13 x Manulekshmi)

Table 16 Heterosis (%) for plant height and height at flowering

Crosses	Plant height (cm)				Height at flowering (cm)			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	29 02**	24 01**	2 07	3 23	31 96**	21 98**	8 14*	14 48**
LE 3 x Manulekshmi	25 20**	23 65**	0 12	5 54	30 24**	18 51**	-10 75**	11 23*
LE 3x V Vijai	11 53*	10 40	11 02*	6 20	10 65*	10 57*	16 73**	3 77
LE 12x Anagha	10 65*	6 36	-16 02**	-11 48*	35 53**	18 89**	0 70	25 50**
LE 12x Manulekshmi	16 02**	14 58**	-7 22	-2 20	46 59**	26 73**	7 34	33 77**
LE 12x V Vijai	12 20*	11 06*	10 49*	5 64	31 82**	24 42**	5 39	31 34**
LE 13x Anagha	27 74**	27 31**	6 63	-1 58	27 98**	22 84**	-21 49**	2 16
LE 13x Manulekshmi	61 24**	53 63**	24 40**	31 14**	64 51**	60 56**	0 86	23 55**
LE 13x V Vijai	49 27**	42 54**	14 89**	21 11**	19 51**	6 47	19 94**	0 22
LE 16x Anagha	31 59**	16 58**	10 01*	15 96**	20 88**	10 27*	-14 52**	6 53
LE 16x Manulekshmi	21 77**	13 13**	6 76	12 53**	31 17**	17 82**	-8 67*	13 82**
LE 16x V Vijai	13 88**	5 57	-0 38	5 01	15 86**	14 13**	-11 53**	10 25*
LE 19x Anagha	12 73*	10 31	19 65**	15 30**	7 03	-14 86**	34 56**	18 45**
LE 19x Manulekshmi	21 42**	12 98*	8 52	3 57	26 15**	13 75**	12 57**	8 96
LE 19x V Vijai	7 07	-0 16	19 53**	15 17**	1 12	2 19	24 82**	6 31
LE 20x Anagha	23 73**	20 03**	7 01	1 98	30 29**	17 40**	6 46	16 58**
LE 20x Manulekshmi	47 40**	44 21**	16 77**	23 09**	55 64**	38 13**	10 06**	37 16**
LE 20x V Vijai	13 70**	11 49*	-10 14*	-5 28	11 97**	8 82	-13 29**	8 06
LE 26x Anagha	22 95**	13 23*	17 52**	13 06**	13 67**	1 81	17 77**	2 48
LE 26x Manulekshmi	15 74**	1 70	-17 65**	-13 20**	10 09*	-2 87	-21 55**	-2 23
LE 26x V Vijai	20 99**	6 52	-14 14**	-9 50*	-1 64	5 04	-23 29**	-4 41

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

4.3.2 Height at Flowering (cm)

Only three hybrids recorded negative heterosis over mid parent with a maximum of -7 03% (LE 19 x Anagha) Heterosis over better parent ranged from -14 86% (LE 19 x Anagha) to 60 56% (LE 13 x Manulekshmi). The magnitude of heterosis over standard check Indam 9802 ranged from -34 56% (LE 19 x Anagha) to 10 06% (LE 20 x Manulekshmi) Standard heterosis over Lekshmi ranged from -18 45% (LE 19 x Anagha) to 37 16% (LE 20 x Manulekshmi)

4.3.3 Node to First Inflorescence

Eight hybrids recorded negative heterosis over mid parent with maximum heterosis of -5 45% (LE 19 x Vellayani Vijai) The magnitude of heterobeltiosis ranged from -13 19% (LE 20 x Vellayani Vijai) to 24 66% (LE 26 x Vellayani Vijai) Sixteen hybrids recorded significant negative heterosis over standard check Indam 9802 with maximum of -22 47% (LE 3 x Vellayani Vijai) The estimates of standard heterosis over Lekshmi varied from -12 66% (LE 3 x Vellayani Vijai) to 14 93% (LE 16 x Vellayani Vijai and LE 20 x Manulekshmi)

4.3.4 Primary Branches Plant^{-1}

The estimates of relative heterosis revealed that 17 hybrids had significant positive heterosis with maximum heterosis of 101 77% (LE 20 x Manulekshmi) The per cent heterosis over better parent ranged from -27 79 (LE 12 x Manulekshmi) to 76 76 (LE 19 x Anagha) Heterosis over standard check Indam 9802 ranged from -44 88% (LE 19 x Vellayani Vijai) to 44 88% (LE 20 x Manulekshmi) of which four hybrids showed significant positive heterosis Only two hybrids registered the significant heterosis in positive direction over standard check Lekshmi The standard heterosis ranged from -48 82% (LE 19 x Vellayani Vijai) to 34 54% (LE 20 x Manulekshmi)

Table 17 Heterosis (%) for node to first inflorescence and primary branches plant [1]

Crosses	Node to first inflorescence				Primary branches plant [1]			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	11 35**	9 97*	-10 22**	1 14	62 75**	62 69**	-10 27	-16 68*
LE 3 x Manulekshmi	0 58	-2 36	15 34**	-4 62	25 20**	0 00	-7 69	-14 29*
LE 3x V Vijai	3 21	-5 02	-22 47**	-12 66**	50 47**	39 95**	-10 27	16 68*
LE 12x Anagha	-0 63	-4 69	17 36**	-6 90	26 05*	18 30	-25 65**	-30 96**
LE 12x Manulekshmi	-1 20	-1 20	-14 33**	3 48	-14 08	-27 79**	-33 35**	38 11**
LE 12x V Vijai	7 41*	2 36	-11 23**	0 00	9 06	7 98	30 77**	-35 71**
LE 13x Anagha	3 09	0 00	15 30**	-4 59	53 21**	41 18**	-7 69	-14 29*
LE 13x Manulekshmi	3 57	2 36	-11 23**	0 00	43 12**	22 25**	12 85	4 79
LE 13x V Vijai	2 47	6 00	-20 39**	-10 31*	42 56**	41 18**	-7 69	-14 29*
LE 16x Anagha	2 90	-11 56**	-14 29**	3 45	69 35**	38 20**	20 50**	11 89
LE 16x Manulekshmi	4 45	9 48*	-12 27**	-1 17	57 15**	52 79**	41 04**	30 96**
LE 16x V Vijai	16 27**	5 27	2 02	14 93**	55 87**	35 24**	17 92*	9 50
LE 19x Anagha	4 84	-10 23*	-19 41**	-9 21*	78 82**	76 76**	-2 58	-9 54
LE 19x Manulekshmi	2 91	1 16	9 18*	2 31	28 05**	1 37	-6 42	-13 11
LE 19x V Vijai	5 45	-11 35**	-20 42**	-10 34*	6 55	14 04	44 88**	-48 82**
LE 20x Anagha	5 41	8 49*	-1 04	11 48**	18 03	13 96	-37 19**	-41 68**
LE 20x Manulekshmi	4 71	-5 66	2 02	14 93**	101 77**	56 96**	44 88**	34 54**
LE 20x V Vijai	0 56	-13 19**	-6 12	5 76	51 08**	35 99**	-12 81	-19 04**
LE 26x Anagha	11 08**	8 92*	-13 28**	-2 31	63 02**	53 52**	-15 38*	-21 43**
LE 26x Manulekshmi	12 51**	5 89	8 17*	3 45	36 33**	4 12	-3 88	10 75
LE 26x V Vijai	26 31**	24 66**	-2 05	10 34*	56 84**	37 97**	-11 54	-17 86*

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

4.3.5 Leaf Length (cm)

Nineteen crosses showed significant positive relative heterosis The magnitude of heterosis ranged between 3 94% (LE 26 x Vellayani Vijai) and 52 12% (LE 3 x Anagha) over mid parent Eleven hybrids recorded significant positive heterobeltiosis with a maximum of 48 61% (LE 3 x Anagha) Heterosis over standard check Indam 9802 ranged from -14 33% (LE 13 x Anagha) to 12 34% (LE 13 x Manulekshmi) and over Lekshmi ranged from -0 79% (LE 13 x Anagha) to 30 09% (LE 13 x Manulekshmi) Significant positive standard heterosis was exhibited by five hybrids over Indam 9802 and 12 hybrids over Lekshmi

4.3.6 Leaf Width (cm)

All the 21 hybrids exhibited significant positive heterosis over mid parent which ranged from 11 65% (LE 3 x Vellayani Vijai) to 52 40% (LE 20 x Manulekshmi) Sixteen hybrids recorded significant and positive heterosis over better parent with maximum heterosis of 51 15% (LE 20 x Manulekshmi) Thirteen hybrids exhibited significant negative heterosis over standard check Indam 9802 with a maximum of -20 88 (LE 20 x Anagha) Eight hybrids showed significant positive heterosis over standard check Lekshmi with a maximum heterosis of 28 65% (LE 20 x Manulekshmi)

4.3.7 Days to First Flowering

Fifteen hybrids showed significant negative relative heterosis The hybrid LE 16 x Anagha (-24 61%) showed earliness in flowering over mid parent Twenty hybrids registered significant negative heterobeltiosis The hybrid LE 16 x Anagha (-29 81%) showed earliness in flowering over better parent Eight hybrids over Indam 9802 and seven hybrids over Lekshmi recorded significant negative heterosis The hybrid LE 16 x Anagha exhibited the highest standard heterosis in negative direction over both the checks with a value of -22 07% and -20 94% respectively

Table 18 Heteiosis (%) foi leaf length and leaf width

Crosses	Leaf length (cm)				Leaf width (cm)			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	52 12**	48 61**	-1 51	14 05**	28 60**	26 95**	16 96**	2 58
LE 3 x Manulekshmi	18 39**	5 35	-10 46*	3 69	28 97**	26 73**	14 11**	6 09
LE 3x V Vijai	15 95**	1 67	-6 37	8 42	11 65*	1 92	15 24**	4 71
LE 12x Anagha	37 83**	14 47**	9 46*	26 76**	32 95**	21 98**	6 88	15 03**
LE 12x Manulekshmi	23 09**	16 25**	11 16*	28 73**	40 49**	32 61**	1 24	25 05**
LE 12x V Vijai	14 92**	14 67**	9 65*	26 98**	23 43**	16 24**	0 45	24 08**
LE 13x Anagha	31 60**	27 89**	14 33**	-0 79	28 95**	22 67**	-13 37**	7 01
LE 13x Manulekshmi	47 83**	32 18**	12 34**	30 09**	44 93**	42 01**	0 29	23 88**
LE 13x V Vijai	24 71**	6 23	1 15	17 13**	22 81**	11 59*	-3 57	19 12**
LE 16x Anagha	39 66**	24 60**	0 43	16 30**	30 20**	18 77**	-8 18	13 42*
LE 16x Manulekshmi	10 05*	7 21	-8 88*	5 52	16 85**	9 65	15 24**	4 71
LE 16x V Vijai	15 61**	6 74	1 63	17 69**	23 04**	16 55**	0 72	24 42**
LE 19x Anagha	37 61**	34 36**	-10 86*	3 23	26 27**	23 87**	17 92**	1 39
LE 19x Manulekshmi	42 42**	26 80**	7 77	24 80**	30 70**	29 24**	-12 41**	8 20
LE 19x V Vijai	22 12**	3 61	-1 35	14 24**	14 61**	1 25	12 50**	8 08
LE 20x Anagha	33 06**	25 57**	-10 55*	3 59	19 30**	14 84*	-20 88**	-2 26
LE 20x Manulekshmi	40 90**	29 49**	10 06*	27 45**	52 40**	51 15**	4 15	28 65**
LE 20x V Vijai	18 71**	3 76	-1 20	14 41**	12 85*	1 41	-12 36**	8 26
LE 26x Anagha	18 07**	3 56	-13 19**	0 53	23 26**	19 23**	18 68**	0 46
LE 26x Manulekshmi	6 97	6 23	-9 71*	4 56	31 83**	31 41**	-10 37*	10 72
LE 26x V Vijai	3 94	-2 28	6 95	7 75	13 44**	1 49	-12 30**	8 34

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

Table 19 Heterosis (%) for days to first flowering and days to fruit set

Crosses	Days to first flowering				Days to fruit set			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	-17 62**	22 37**	16 01**	14 79**	20 71**	-32 38**	6 12	6 90
LE 3 x Manulekshmi	0 00	-1 00	7 11**	8 66**	-17 76**	-25 01**	4 10	18 55**
LE 3x V Vijai	3 45	-6 26**	1 42	2 89	1 81	-19 14**	12 25*	27 82**
LE 12x Anagha	-8 57**	8 91**	12 81**	11 55**	4 41	16 90**	10 23	25 52**
LE 12x Manulekshmi	-8 67**	-13 42**	-8 19**	-6 86**	7 41*	0 00	32 64**	51 05**
LE 12x V Vijai	4 28*	7 87**	12 46**	-11 19**	2 86	16 90**	10 23	25 52**
LE 13x Anagha	-8 91**	15 56**	5 35*	3 97	2 75	13 13**	8 21	23 22**
LE 13x Manulekshmi	-6 69**	-9 21**	1 77	3 25	-2 59	-6 59	16 35**	32 50**
LE 13x V Vijai	2 14	-8 89**	2 14	3 62	10 87*	8 21	14 33**	30 20**
LE 16x Anagha	-24 61**	29 81**	22 07**	20 94**	14 80**	23 34**	-6 06	6 97
LE 16x Manulekshmi	-17 70**	-19 55**	-10 68**	-9 38**	-18 98**	-21 69**	-4 04	9 27
LE 16x V Vijai	0 53	10 89**	1 07	0 37	18 02**	31 68**	16 29**	-4 67
LE 19x Anagha	-14 28**	21 00**	10 32**	9 02**	12 82**	26 09**	4 10	18 55**
LE 19x Manulekshmi	5 02**	-8 14**	4 27*	5 78**	-16 77**	-24 61**	6 18	20 92**
LE 19x V Vijai	13 07**	0 31	13 87**	15 52**	-2 75	23 17**	8 21	23 22**
LE 20x Anagha	-3 80*	-10 03**	-1 07	0 37	-27 15**	-38 60**	-12 25*	-0 07
LE 20x Manulekshmi	6 42**	-8 09**	1 07	2 53	-30 16**	37 15**	10 17	2 30
LE 20x V Vijai	4 31*	6 16**	3 19	4 69*	27 32**	42 89**	-18 37**	-7 04
LE 26x Anagha	-6 12**	-13 48**	1 78	-0 36	-17 87**	-28 13**	-6 12	6 90
LE 26x Manulekshmi	9 24**	-12 23**	-0 36	1 08	-18 35**	-23 44**	0 00	13 88*
LE 26x V Vijai	1 41	-12 54**	-0 72	0 73	5 74	14 06**	12 25*	27 82**

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

4.3.8 Days to Fruit set

Twelve hybrids revealed significant negative heterosis over mid parent with LE 20 x Manulekshmi recording the highest (-30.16%). Eighteen hybrids recorded significant negative heterobeltiosis with a range of -42.89% (LE 20 x Vellayani Vijai) to -13.13% (LE 13 x Anagha). Three hybrids displayed significant negative heterosis over standard check Indam 9802 with maximum in LE 20 x Vellayani Vijai (-18.37%) followed by LE 16 x Vellayani Vijai (-16.29%). None of the crosses showed significant negative heterosis over standard check Lekshmi.

4.3.9 Flowers Cluster^{1}

The magnitude of heterosis varied from -23.70% (LE 3 x Vellayani Vijai) to 27.37% (LE 20 x Anagha) over mid parent, -44.47% (LE 3 x Vellayani Vijai) to 22.58% (LE 16 x Anagha and LE 20 x Anagha) over better parent, -21.05% (LE 13 x Manulekshmi) to 22.84% (LE 20 x Vellayani Vijai) over standard check Indam 9802 and -26.25% (LE 13 x Manulekshmi) to 14.75% (LE 20 x Vellayani Vijai) over standard check Lekshmi.

4.3.10 Inflorescence Plant^{1}

Relative heterosis ranged from -13.15% (LE 12 x Manulekshmi) to 33.35% (LE 20 x Manulekshmi) and heterobeltiosis ranged from -21.55% (LE 12 x Manulekshmi) to 23.77% (LE 20 x Manulekshmi). Significant positive relative heterosis was exhibited by 13 hybrids and heterobeltiosis by eight hybrids. None of the hybrids exhibited significant positive heterosis over both the checks.

4.3.11 Fruit set (%)

The estimates of relative heterosis revealed that 12 crosses showed positive significant relative heterosis for fruit set with a maximum of 35.95% (LE 20 x Anagha). Heterobeltiosis ranged from -12.13% (LE 13 x Manulekshmi) to 28.53% (LE 16 x Manulekshmi) of which nine were significant and positive

Table 20 Heterosis (%) for flowers cluster [1] and inflorescence plant [1]

Crosses	Flowers cluster [1]				Inflorescence plant [1]			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	21 25*	7 53	0 00	6 59	1 80	-11 05**	37 64**	-40 91**
LE 3 x Manulekshmi	12 91	9 07	-15 79*	-21 34**	-3 41	13 81**	42 43**	45 45**
LE 3x V Vijai	-23 70**	-44 47**	-12 32	18 09*	3 38	14 20**	42 06**	-45 10**
LE 12x Anagha	-0 90	9 42	1 74	-4 97	1 78	-10 01**	36 91**	40 22**
LE 12x Manulekshmi	5 53	-20 29**	-10 47	16 37*	13 15**	-21 55**	47 60**	-50 35**
LE 12x V Vijai	-14 30**	26 67**	15 79*	8 16	6 40*	-4 36	-35 41**	-38 80**
LE 13x Anagha	14 83*	12 77	8 79	1 62	20 79**	11 57**	-21 78**	-25 88**
LE 13x Manulekshmi	-9 09	-18 17*	-21 05**	26 25**	22 82**	16 05**	22 50**	-26 56**
LE 13x V Vijai	-15 87**	32 23**	7 00	-0 05	12 22**	5 48	-28 77**	-32 51**
LF 16x Anagha	24 95**	22 58**	14 00	6 49	31 66**	23 69**	13 28**	17 83**
LE 16x Manulekshmi	1 04	-5 88	15 79*	21 34**	18 98**	14 37**	-23 61**	-27 62**
LE 16x V Vijai	-9 23	28 90**	12 26	4 87	28 01**	22 41**	-17 34**	-21 67**
LE 19x Anagha	12 37	11 32	3 53	-3 29	16 58**	7 37*	24 72**	-28 67**
LE 19x Manulekshmi	-2 16	9 69	17 58*	-23 01**	17 31**	10 51**	-26 19**	-30 06**
LE 19x V Vijai	-16 94**	34 47**	3 47	-3 34	-4 96	-10 93**	-39 85**	-43 01**
LE 20x Anagha	27 37**	22 58**	14 00	6 49	6 69*	3 14	32 09**	35 66**
LE 20x Manulekshmi	20 35*	14 20	1 79	8 26	33 35**	23 77**	-17 34**	-21 67**
LE 20x V Vijai	0 73	-22 20**	22 84**	14 75*	6 52*	-1 64	-33 58**	-37 06**
LE 26x Anagha	24 77**	21 42**	19 32*	11 46	7 36*	-7 90**	-35 43**	-38 81**
LE 26x Manulekshmi	17 94*	5 30	3 47	-3 34	4 73	8 29**	38 75**	-41 96**
LE 26x V Vijai	-17 81**	33 33**	5 26	-1 67	-4 07	-16 39**	-43 54**	-46 50**

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

Table 21 Heterosis (%) for fruit set and pollen viability

Crosses	Fruit set %				Pollen viability %			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	21 84**	17 78**	11 94*	6 80	21 30**	10 16**	-0 04	1 73
LE 3 x Manulekshmi	2 05	-2 40	-13 43*	-17 40**	12 76**	8 41**	-19 70**	-21 06**
LE 3x V Vijai	5 30	9 47	11 94*	-15 98**	8 03**	18 96**	21 27**	22 60**
LE 12x Anagha	-1 40	5 05	9 75	13 90**	-5 71*	14 23**	22 17**	23 49**
LE 12x Manulekshmi	7 63	7 60	-5 24	9 60*	23 39**	18 43**	-11 96**	-13 45**
LE 12x V Vijai	1 01	5 73	-8 29	-12 50*	-3 78	-15 08**	-17 50**	18 90**
LE 13x Anagha	6 58	3 98	3 90	-0 87	5 23*	1 97	7 47**	9 03**
LE 13x Manulekshmi	-6 58	12 13*	12 19*	16 22**	6 61*	3 89	18 19**	-19 58**
LE 13x V Vijai	8 88*	7 44	7 36	2 43	0 96	5 28*	7 99**	-9 54**
LE 16x Anagha	14 44**	11 17*	5 66	0 80	22 26**	13 71**	3 18	1 44
LE 16x Manulekshmi	29 65**	28 53**	15 17**	9 88*	46 18**	37 11**	7 00**	5 20*
LE 16x V Vijai	18 77**	14 08**	10 97*	5 88	18 25**	6 62**	3 58	1 83
LE 19x Anagha	21 22**	19 67**	13 74**	8 51	29 62**	18 99**	7 97**	6 15**
LE 19x Manulekshmi	9 74*	7 05	-0 86	-5 42	25 89**	19 66**	-9 23**	10 76**
LE 19x V Vijai	3 89	1 39	-1 37	-5 90	0 51	-10 51**	13 06**	14 53**
LE 20x Anagha	35 95**	16 12**	10 37*	5 30	20 97**	6 76**	-3 12	-4 76*
LE 20x Manulekshmi	26 47**	11 58*	-1 74	-6 25	30 70**	29 68**	-9 95**	-11 48**
LE 20x V Vijai	31 50**	11 25*	8 23	3 26	20 33**	3 17	0 22	1 47
LE 26x Anagha	14 19**	4 03	1 13	5 67	9 26**	5 68*	-14 41**	-15 86**
LE 26x Manulekshmi	0 58	5 09	-16 42**	20 26**	9 55**	7 60*	-26 45**	-27 70**
LE 26x V Vijai	26 91**	14 42**	11 30*	6 19	25 84**	5 62*	2 60	0 87

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

Six hybrids exhibited significant positive heterosis over standard check Indam 9802 The standard heterosis ranged from -16 42% (LE 26 x Manulekshmi) to 15 17% (LE 16 x Manulekshmi) Only one hybrid LE 16 x Manulekshmi registered positive and significant heterosis over standard check Lekshmi with a value of 9 88%

4.3.12 Pollen Viability (%)

The magnitude of heterosis varied from -8 03% (LE 3 x Vellayani Vijai) to 46 18% (LE 16 x Manulekshmi) over mid parent, -18 96% (LE 3 x Vellayani Vijai) to 37 11% (LE 16 x Manulekshmi) over better parent, -26 45% (LE 26 x Manulekshmi) to 7 97% (LE 19 x Anagha) over standard check Indam 9802 and -27 70% (LE 26 x Manulekshmi) to 6 15% (LE 19 x Anagha) over standard check Lekshmi Out of 21 crosses, positive significant heterosis was exhibited by 16 over mid parent, 12 over better parent and only two over both the checks

4.3.13 Fruits Cluster^{1}

Nineteen hybrids exhibited significant positive relative heterosis with a maximum of 81 04% (LE 26 x Anagha) Heterobeltiosis ranged from -11 93% (LE 3 x Vellayani Vijai) to 50 08% (LE 26 x Anagha) of which 12 crosses were significant and positive Twelve hybrids registered significant positive heterosis over standard check Indam 9802 with a maximum of 58 33% (LE 26 x Anagha) followed by 55 50% (LE 20 x Vellayani Vijai) and 52 83% (LE 13 x Vellayani Vijai) while, 16 crosses showed positive standard heterosis over Lekshmi with maximum of 72 73% (LE 26 x Anagha) followed by 69 64% (LE 20 x Vellayani Vijai) and 66 73% (LE 13 x Vellayani Vijai) (Plate 8)

4.3.14 Fruits Plant^{1}

Twenty hybrids had positive heterosis over mid parent with 18 being significant and LE 16 x Anagha recording the maximum relative heterosis (167 63%) None of the hybrids had significant negative relative heterosis The

Table 22 Heterosis (%) for fruits cluster^{-1} and fruits plant^{-1}

Crosses	Fruits cluster^{-1}				Fruits plant^{-1}			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	11 44*	2 69	8 33	18 18**	4 51	23 76**	16 43	15 86
LE 3 x Manulekshmi	22 01**	12 46*	0 00	9 09	39 42**	34 26**	22 35	11 58
LE 3x V Vijai	0 04	-11 93**	2 75	12 09*	34 53**	28 83*	28 26*	7 31
LE 12x Anagha	2 68	0 00	5 50	15 09**	7 16	17 55*	25 91*	- 9 01
LE 12x Manulekshmi	14 29**	0 00	0 00	9 09	29 11*	27 49*	7 58	- 22 25*
LE 12x V Vijai	10 31*	2 43	19 50**	30 36**	23 82*	13 07	12 57	- 18 65*
LE 13x Anagha	36 05**	34 28**	41 67**	54 55**	111 42**	108 02**	228 24**	137 21**
LE 13x Manulekshmi	12 52*	2 68	0 00	9 09	92 67**	47 85**	133 30**	68 60**
LE 13x V Vijai	39 31**	31 00**	52 83**	66 73**	101 97**	64 70**	159 88**	87 81**
LE 16x Anagha	37 16**	26 38**	33 33**	45 45**	167 63**	160 51**	320 20**	203 67**
LE 16x Manulekshmi	22 01**	12 46*	0 00	9 09	57 30**	19 80**	93 23**	39 64**
LE 16x V Vijai	26 96**	11 86**	30 50**	42 36**	112 85**	72 11**	177 61**	100 62**
LE 19x Anagha	23 95**	15 88**	22 25**	33 36**	68 54**	57 47**	140 48**	73 79**
LE 19x Manulekshmi	33 23**	21 07**	11 08*	21 18**	87 78**	53 61**	103 77**	47 26**
LE 19x V Vijai	14 67**	2 43	19 50**	30 36**	17 00	2 40	35 84**	1 83
LE 20x Anagha	27 75**	21 09**	27 75**	39 36**	20 85**	10 50	68 75**	21 95*
LE 20x Manulekshmi	17 99**	5 82	0 00	9 09	124 00**	86 67**	136 26**	70 74**
LE 20x V Vijai	47 28**	33 29**	55 50**	69 64**	87 32**	67 33**	111 78**	53 05**
LE 26x Anagha	81 04**	50 08**	58 33**	72 73**	32 99**	3 60	58 21**	14 33
LE 26x Manulekshmi	49 91**	44 33**	8 25	18 09**	49 76**	49 03**	27 00*	8 22
LE 26x V Vijai	22 44**	-2 36	13 92**	24 27**	39 28**	29 25*	28 68*	-7 01

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

magnitude of heterobeltiosis varied from -23 76% (LE 3 x Anagha) to 160 51% (LE 16 x Anagha) with 15 hybrids in significant positive direction and two in negative direction All the hybrids showed positive heterosis over the check Indam 9802, 17 being significant with a maximum of 320 20% (LE 16 x Anagha) followed by 228 24% (LE 13 x Anagha) The estimates of standard heterosis over check Lekshmi varied from -22 25% (LE 12 x Manulekshmi) to 203 67% (LE 16 x Anagha) with 11 hybrids in significant positive direction

4.3.15 Fruit Length (cm)

Fifteen hybrids showed significant relative heterosis in positive direction with a maximum of 37 05% (LE 26 x Anagha) followed by 28 00% (LE 13 x Vellayani Vijai) Heterobeltiosis ranged from -16 49% (LE 12 x Vellayani Vijai) to 25 67% (LE 26 x Anagha), 11 hybrids recording significant positive heterosis None of the hybrids registered significant heterosis over check Indam 9802 in positive direction Only one hybrid LE 13 x Vellayani Vijai (7 06%) showed significant positive heterosis over check Lekshmi while, most of the hybrids exhibited significant negative standard heterosis

4.3.16 Fruit Girth (cm)

Relative heterosis for fruit girth varied from -5 77% (LE 16 x Anagha) to 21 20% (LE 19 x Manulekshmi) with 13 hybrids exhibiting significant heterosis in positive direction The heterobeltiosis per cent ranged from -9 56 (LE 16 x Anagha) to 20 77 (LE 19 x Manulekshmi), seven hybrids recording significant positive heterosis None of the crosses exhibited significant standard heterosis over both the checks in positive direction

4.3.17 Fruit Weight (g)

All the 21 crosses exhibited positive heterosis over mid parent with 13 being significant and LE 19 x Manulekshmi (88 55%) registering the maximum followed by LE 13 x Manulekshmi (66 39%) The cross LE 19 x Manulekshmi

Table 23 Heterosis (%) for fruit length and fruit girth

Crosses	Fruit length (cm)				Fruit girth (cm)			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	19.40**	17.31**	-19.84**	-18.21**	0.32	1.27	-28.85**	35.85**
LE 3 x Manulekshmi	13.55**	10.03**	-19.84**	-18.21**	2.65	2.25	-25.73**	33.04**
LE 3x V Vijai	6.09*	7.93**	14.48**	12.73**	3.06	2.43	25.26**	32.62**
LE 12x Anagha	0.10	2.35	35.62**	34.30**	-4.88	6.87*	35.01**	-41.41**
LE 12x Manulekshmi	9.11**	1.51	26.05**	24.54**	2.32	-1.74	28.64**	-35.66**
LE 12x V Vijai	-0.29	-16.49**	-22.43**	-20.84**	1.58	5.69	-31.19**	37.96**
LE 13x Anagha	16.75**	12.56**	-20.04**	-18.40**	5.05	1.35	-23.92**	31.41**
LE 13x Manulekshmi	21.38**	19.88**	-12.67**	-10.88**	19.39**	17.45**	-11.83**	20.51**
LE 13x V Vijai	28.00**	12.94**	4.91	7.06*	5.87*	4.39	21.64**	-29.35**
LE 16x Anagha	-2.30	6.22	32.77**	31.40**	-5.77*	-9.56**	31.36**	-38.12**
LE 16x Manulekshmi	18.96**	18.01**	-14.03**	-12.27**	17.68**	15.16**	-12.61**	21.21**
LE 16x V Vijai	2.59	-9.12**	-15.58**	13.85**	5.55*	3.52	21.44**	29.17**
LE 19x Anagha	0.18	7.48*	-27.99**	26.52**	7.14**	5.41	23.98**	-31.46**
LE 19x Manulekshmi	24.15**	20.18**	6.46*	4.55	21.20**	20.77**	-12.28**	-20.91**
LE 19x V Vijai	16.85**	7.38*	-0.26	1.78	5.76*	5.16	-23.27**	30.83**
LE 20x Anagha	-1.96	-10.33**	-28.70**	-27.24**	7.50**	6.15	-25.93**	33.22**
LE 20x Manulekshmi	9.46**	4.88	16.61**	14.91**	9.84**	6.36*	22.75**	-30.35**
LE 20x V Vijai	13.91**	5.71*	1.81	0.20	10.41**	6.68*	-22.16**	-29.82**
LE 26x Anagha	37.05**	25.67**	0.65	1.39	9.38**	8.88**	-23.31**	-30.86**
LE 26x Manulekshmi	10.89**	6.54	-15.77**	-14.05**	7.37**	5.74	-23.20**	-30.76**
LE 26x V Vijai	17.74**	8.98**	1.23	3.30	12.91**	10.95**	-19.04**	-27.01**

RH – Relative heterosis   HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802   SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level   **Significant at 1 per cent level

Table 24 Heterosis (%) for fruit weight and yield plant[-1]

Crosses	Fruit weight (g)				Yield plant[-1]			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	4 95	0 35	66 74**	-63 38**	46 88**	31 77**	- 43 31**	48 33**
LE 3 x Manulekshmi	9 65	4 43	61 75**	-57 88**	37 74**	27 24*	-56 52**	60 76**
LE 3x V Vijai	1 48	3 78	64 42**	60 82**	24 16*	18 52	-55 46**	59 80**
LE 12x Anagha	6 28	4 23	68 49**	-65 30**	57 06**	34 81**	- 42 00**	47 65**
LE 12x Manulekshmi	0 54	9 84	66 97**	63 63**	73 90**	68 61**	- 48 01**	- 53 07**
LE 12x V Vijai	7 36	4 12	64 55**	60 96**	70 80**	55 47**	- 41 57**	47 26**
LE 13x Anagha	25 05**	18 97**	60 16**	56 13**	151 20**	135 44**	15 83**	4 54
LE 13x Manulekshmi	66 39**	59 26**	41 67**	35 77**	163 15**	109 02**	2 83	-7 18
LE 13x V Vijai	42 08**	35 38**	49 94**	44 88**	155 55**	125 39**	10 88*	0 08
LE 16x Anagha	1 26	-4 39	67 46**	64 17**	154 44**	123 16**	27 32**	14 92**
LE 16x Manulekshmi	43 27**	38 19**	-49 38**	44 26**	110 84**	58 93**	9 33*	18 16**
LE 16x V Vijai	21 55**	16 71**	-56 84**	52 48**	112 82**	76 51**	0 70	9 11*
LE 19x Anagha	22 93**	17 54**	-61 05**	-57 11**	83 05**	80 30**	-20 02**	27 81**
LE 19x Manulekshmi	88 55**	79 57**	-34 23**	-27 57**	171 81**	124 62**	-0 35	10 06**
LE 19x V Vijai	37 75**	30 60**	-51 71**	46 82**	26 23**	16 59	-48 28**	53 32**
LE 20x Anagha	20 38**	18 80**	63 12**	-59 39**	28 61**	28 48**	-44 61**	50 00**
LE 20x Manulekshmi	20 27**	11 10*	59 30**	-55 19**	140 38**	100 91**	-13 38**	21 81**
LE 20x V Vijai	30 48**	20 02**	55 62**	-51 13**	96 35**	83 76**	-20 77**	-28 49**
LE 26x Anagha	13 51*	6 77	63 37**	-59 67**	21 48*	12 01	51 81**	-56 50**
LE 26x Manulekshmi	2 62	-0 64	63 60**	59 92**	20 27	8 08	60 74**	-64 57**
LE 26x V Vijai	12 33*	8 26	-59 97**	55 92**	50 40**	47 87**	44 43**	-49 84**

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

recorded the maximum heterosis over better parent (79 57%) followed by LE 13 x Manulekshmi (59 26%) with 11 hybrids being significant and in positive direction None of the hybrids exhibited significant positive heterosis over both the checks

4.3.18 Yield Plant^{-1} (g)

All the 21 hybrids revealed positive relative heterosis with 20 being significant which ranged from 21 48% (LE 26 x Anagha) to 171 81% (LE 19 x Manulekshmi) The magnitude of heterobeltiosis ranged from 27 24% (LE 3 x Manulekshmi) to 135 44% (LE 13 x Anagha) for 17 hybrids which were positively significant over better parent The magnitude of standard heterosis ranged from -60 74% (LE 26 x Manulekshmi) to 27 32% (LE 16 x Anagha) over check Indam 9802 while, it ranged from -64 57% (LE 26 x Manulekshmi) to 14 92% (LE 16 x Anagha) over check Lekshmi Three hybrids showed significant positive standard heterosis over Indam 9802

4.3.19 Yield Plot^{-1} (kg)

Eleven crosses recorded significant positive heterosis over mid parent which ranged from 44 25% (LE 12 x Anagha) to 328 25% (LE 13 x Manulekshmi) Heterosis over better parent ranged from -45 63% (LE 19 x Vellayani Vijai) to 270 89% (LE 13 x Manulekshmi) Standard heterosis over Indam 9802 ranged from -39 34% (LE 19 x Vellayani Vijai) to 220 03% (LE 13 x Manulekshmi) with ten hybrids showing positive significant heterosis while, it ranged from -57 35% (LE 19 x Vellayani Vijai) to 125 01% (LE 13 x Manulekshmi) with nine hybrids towards significant positive direction

4.3.20 TSS (%)

The hybrids exhibited heterosis for TSS in the range of -20 09% (LE 12 x Anagha) to 28 12% (LE 16 x Anagha), -25 24% (LE 12 x Anagha) to 18 87% (LE 16 x Anagha), -26 49% (LE 12 x Anagha) to 16 89% (LE 16 x Anagha), -28 36%

Table 25 Heterosis (%) for yield plot [1] and TSS

Crosses	Yield plot [1] (kg)				TSS (%)			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	15 32	-21 82	-3 80	32 36**	3 44	1 85	-3 49	5 95*
LE 3 x Manulekshmi	44 73	9 09	-5 87	-33 82**	13 28**	16 65**	-20 22**	-22 26**
LE 3x V Vijai	2 77	32 31*	24 47	46 90**	14 54**	-21 27**	17 53**	19 63**
LE 12x Anagha	44 25*	3 50	18 74	16 52	20 09**	-25 24**	26 49**	28 36**
LE 12x Manulekshmi	37 83	2 12	-11 88	-38 04**	13 69**	18 23**	-21 73**	23 72**
LE 12x V Vijai	5 94	-27 29	-18 87	42 96**	13 62**	21 50**	-17 76**	19 86**
LE 13x Anagha	183 70**	114 68**	164 15**	85 73**	1 64	4 76	6 34*	8 73**
LE 13x Manulekshmi	328 25**	270 89**	220 03**	125 01**	-15 06**	-19 39**	22 84**	-24 81**
LE 13x V Vijai	196 43**	132 13**	159 00**	82 10**	22 00**	11 05**	16 34**	13 37**
LE 16x Anagha	85 35**	69 91**	150 88**	76 40**	28 12**	18 87**	16 89**	13 91**
LE 16x Manulekshmi	120 60**	74 76**	158 04**	81 43**	17 64**	22 62**	-25 93**	-27 82**
LE 16x V Vijai	95 84**	71 91**	153 84**	78 47**	1 93	8 10**	3 73	-6 18*
LE 19x Anagha	110 68**	58 84**	95 45**	37 42**	14 30**	2 18	0 48	-2 09
LE 19x Manulekshmi	252 13**	203 58**	161 95**	84 18**	12 36**	1 66	-2 70	5 18
LE 19x V Vijai	30 30	-45 63**	-39 34*	57 35**	13 23**	-1 51	3 17	0 54
LE 20x Anagha	-1 34	-23 59	-5 97	-33 89**	6 46*	1 61	0 08	-2 63
LE 20x Manulekshmi	242 01**	204 88**	163 07**	84 96**	-14 91**	17 73**	21 25**	-23 26**
LE 20x V Vijai	59 83**	28 29	43 14*	0 64	18 79**	10 07**	15 31**	12 36**
LE 26x Anagha	10 66	-23 70	-6 11	33 99**	15 55**	2 18	0 48	-2 09
LE 26x Manulekshmi	-6 64	-28 09	-37 95*	-56 37**	-3 15	13 34**	-17 05**	-19 17**
LE 26x V Vijai	18 04	16 31	6 62	34 34**	7 30*	-7 65**	3 25	-5 72

RH – Relative heterosis   HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802   SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level   **Significant at 1 per cent level

(LE 12 x Anagha) to 13 91% (16 x Anagha) respectively over mid parent, better parent, standard check Indam 9802 and standard check Lekshmi

4.3.21 Lycopene (mg/ 100 g)

Four hybrids exhibited significant positive heterosis over mid parent, one over better parent and none of the hybrids over both the checks for lycopene content Relative heterosis for lycopene ranged from -27 79% (LE 16 x Manulekshmi) to 30 34% (LE 16 x Anagha) and heterobeltiosis from -37 18% (LE 12 x Anagha) to 23 65% (LE 16 x Anagha)

4.3.22 Ascorbic acid (mg/ 100 g)

The hybrid LE 19 x Anagha recorded the highest significant heterosis over mid parent and better parent with 84 64% and 80 56% respectively The magnitude of standard heterosis ranged from -25 66 (LE 12 x Anagha) to 41 06% (LE 19 x Anagha) and -34 52% (LE 12 x Anagha) to 24 24% (LE 19 x Anagha) over both the checks respectively

4.3.23 Incidence of bacterial wilt

The cross LE 13 x Manulekshmi exhibited highest significant negative heterosis over mid parent (-70 21%) followed by LE 20 x Manulekshmi (-61 90%) Eleven hybrids recorded significant heterobeltiosis in negative direction with a maximum of LE 13 x Manulekshmi (-81 58%) followed by LE 20 x Manulekshmi (-75 76%) The cross LE 13 x Manulekshmi exhibited significant negative standard heterosis over both the checks with -83 72% and -81 58% respectively, which was followed by LE 20 x Manulekshmi with -81 40% and -78 95% respectively Among the 21 crosses, 20 and 17 crosses recorded negative standard heterosis over both the checks respectively

Table 26 Heterosis (%) for lycopene and ascorbic acid

Crosses	Lycopene (mg/ 100 g)				Ascorbic acid (mg/100 g)			
	RH	HB	SH (I)	SH (L)	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	8 45**	14 51**	29 29**	32 90**	12 30*	9 42	18 30**	28 04**
LE 3 x Manulekshmi	1 96	2 52	29 24**	32 85**	3 99	-5 11	18 53**	28 25**
LE 3x V Vijai	-9 05**	-21 68**	-22 18**	26 15**	23 02**	11 03	-2 30	13 95**
LE 12x Anagha	-23 90**	-37 18**	-48 04**	50 69**	1 65	0 44	-25 66**	-34 52**
LE 12x Manulekshmi	-10 07**	-21 69**	-43 15**	-46 05**	5 26	3 48	-17 13**	-27 02**
LE 12x V Vijai	10 91**	-31 32**	-31 75**	-35 24**	11 65*	1 25	10 91*	-21 54**
LE 13x Anagha	9 01**	20 52**	34 26**	37 62**	55 53**	54 85**	15 63**	1 83
LE 13x Manulekshmi	3 13	10 34**	34 91**	38 24**	14 20*	6 32	8 72	-19 60**
LE 13x V Vijai	25 13**	1 47	0 84	-4 32*	37 66**	26 73**	11 51*	1 79
LE 16x Anagha	30 34**	23 65**	2 28	2 95	36 55**	27 05**	10 20*	2 95
LE 16x Manulekshmi	-27 79**	28 58**	46 99**	49 70**	4 70	-5 18	-17 76**	27 57**
LE 16x V Vijai	-5 42*	-17 39**	-17 91**	-22 11**	33 54**	32 59**	16 67**	2 75
LF 19x Anagha	-4 48*	-7 68**	-23 64**	-27 54**	84 64**	80 56**	41 06**	24 24**
LE 19x Manulekshmi	-2 64	-5 52*	-27 09**	-30 82**	37 68**	31 48**	12 88*	0 58
LE 19x V Vijai	6 83**	5 11*	5 70**	-10 52**	24 36**	17 38**	3 29	-9 03*
LE 20x Anagha	13 21**	19 73**	33 60**	37 00**	47 89**	43 76**	7 35	-5 46
LE 20x Manulekshmi	17 61**	18 91**	-41 13**	-44 14**	54 14**	40 36**	20 50**	6 13
LE 20x V Vijai	-17 54**	-29 61**	-30 05**	33 62**	32 69**	19 50**	5 15	-7 39
LE 26x Anagha	-1 04	-5 34*	-21 71**	-25 71**	43 72**	36 85**	12 99*	0 48
LE 26x Manulekshmi	-20 97**	-22 51**	41 47**	-44 47**	48 63**	45 79**	25 16**	10 24*
LE 26x V Vijai	12 80**	-0 74	-1 36	-6 40**	5 05	1 81	-10 42*	-21 10**

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

Table 27 Heterosis (%) for bacterial wilt incidence

Crosses	Bacterial wilt incidence (%)			
	RH	HB	SH (I)	SH (L)
LE 3 x Anagha	26 53*	18 42*	27 91**	18 42*
LE 3 x Manulekshmi	-2 13	39 47**	46 51**	39 47**
LE 3x V Vijai	31 91*	18 42*	27 91**	-18 42*
LE 12x Anagha	4 17	-32 43**	41 86**	-34 21**
LE 12x Manulekshmi	34 78**	-16 22	-27 91**	-18 42*
LE 12x V Vijai	56 52**	-2 70	-16 28*	-5 26
LE 13x Anagha	14 29	44 74**	-51 16**	44 74**
LE 13x Manulekshmi	70 21**	81 58**	83 72**	81 58**
LE 13x V Vijai	14 89	47 37**	53 49**	-47 37**
LE 16x Anagha	92 59**	62 50**	39 53**	-31 58**
LE 16x Manulekshmi	-12 00	-31 25	-74 42**	-71 05**
LE 16x V Vijai	36 00	6 25	-60 47**	-55 26**
LE 19x Anagha	-23 40	-50 00**	-58 14**	-52 63**
LE 19x Manulekshmi	33 33*	58 33**	65 12**	60 53**
LE 19x V Vijai	77 78**	11 11	-6 98	5 26
LE 20x Anagha	40 91**	6 06	27 91**	18 42*
LE 20x Manulekshmi	61 90**	75 76**	81 40**	78 95**
LE 20x V Vijai	38 10**	12 12	-32 56**	-23 68*
LE 26x Anagha	10 20	-28 95**	-37 21**	-28 95**
LE 26x Manulekshmi	40 43**	-13 16	-23 26**	-13 16
LE 26x V Vijai	36 17**	-15 79	-25 58**	-15 79

RH – Relative heterosis HB – Heterobeltiosis

SH (I) – Standard heterosis over Indam 9802 SH (L) – Standard heterosis over Lekshmi

*Significant at 5 per cent level **Significant at 1 per cent level

4 4 COMBINING ABILITY ANALYSIS

The data on different characters were subjected to line x tester analysis to study the general combining ability and specific combining ability effects

4.4.1 General combining ability effects

The general combining ability effects calculated for ten parents (seven lines and three testers) are presented in Table 28

4.4.1.1 Plant Height (cm)

Estimates of *gca* effects of lines revealed that three parents LE 13 (13 68), LE 16 (8 87) and LE 20 (3 90) registered significant and positive *gca* effect indicating that they were good general combiners for tallness Three parents showed significant negative *gca* effect for this trait *i e* LE 26 (-10 58), LE 19 (-10 10) and LE 12 (-5 96) indicating that they were good combiners for dwarfness

Among the testers, significant and positive *gca* effect was exhibited by Manulekshmi (5 88) whereas, Anagha (-3 45) and Vellayani Vijai (-2 43) exhibited significant negative *gca* effect

4.4.1.2 Height at Flowering (cm)

Among the lines, negative and significant *gca* effect was shown by LE 19 (-5 29) and LE 26 (-3 96) while, positive significant *gca* effect was shown by LE 12 (6 86) and LE 20 (3 57)

Among the testers Vellayani Vijai (-1 41) and Anagha (-1 29) exhibited significant negative *gca* effects while, Manulekshmi (2.69) recorded positive significant *gca* effect for the trait

Table 28 General combinıng abılıty effects of parents

Parents	Plant heıght (cm)	Heıght at flowerıng (cm)	Node to first ınflorescence	Prımary branches plant '	Leaf length (cm)	Leaf wıdth (cm)	Days to first flowerıng	Days to fruıt set
				Lınes				
LE 3	0 18	-0 12	0 50**	0 28	1 35*	1 19**	0 23	0 03
LE 12	5 96**	6 86**	0 31*	-2 05**	3 41**	1 66**	-2 47**	0 81**
LE 13	13 68**	1 07	-0 46**	0 47	0 36	0 86*	0 86**	0 55**
LE 16	8 87**	0 01	0 35*	2 84**	-0 22	0 45	-2 51**	-0 63**
LE 19	10 10**	-5 29**	-0 53**	-1 02**	0 01	0 95*	1 83**	0 18
LE 20	3 90*	3 57**	1 06**	0 39	0 28	0 00	1 34**	-0 89**
LE 26	10 58**	3 96**	0 39*	-0 35	2 48**	0 84*	0 71**	0 04
S E +_	1 55	0 63	0 15	0 26	0 51	0 36	0 25	0 11
CD (0 05)	3 15	1 29	0 31	0 54	1 04	0 74	0 52	0 23
				Testers				
Anagha	3 45**	-1 29**	0 17	0 43*	1 26**	-1 03**	2 08**	0 22**
Manulekshmı	5 88**	2 69**	0 18	1 13**	0 96**	0 64*	0 79**	0 20*
Vellayanı Vıjaı	-2 43*	1 41**	-0 01	-0 70**	0 30	0 39	1 30**	0 02
S E +_	1 01	0 41	0 10	0 17	0 33	0 24	0 16	0 07
CD (0 05)	2 06	0 84	0 20	0 35	0 68	0 49	0 34	0 15

*Sıgnıficant at 5 per cent level

**Sıgnıficant at 1 per cent level

Table 28 Continued

Parents	Flowers cluster [1]	Inflorescence plant [1]	Fruit set %	Pollen viability %	Fruits cluster [1]	Fruits plant [1]	Fruit length (cm)	Fruit girth (cm)
				Lines				
LE 3	0 70**	2 78**	3 91*	-4 14**	0 64**	18 40**	0 13*	0 53**
LE 12	0 04	-2 56**	-6 36**	6 96**	-0 45**	-20 24**	0 65**	1 39**
LE 13	-0 22	2 14**	0 81	2 18**	0 48**	21 49**	0 32**	0 75**
LE 16	0 11	4 03**	7 31**	10 41**	0 07	27 60**	0 27**	0 29
LE 19	-0 33	0 36	2 28	2 95**	0 08	0 30	0 20**	0 62**
LE 20	0 63**	1 14**	3 60*	3 34**	0 33**	3 53**	-0 01	-0 02
LE 26	0 48*	-2 34**	-2 13	-3 41**	0 29**	-14 29**	0 54**	0 28
S E +_	0 19	0 23	1 51	0 71	0 08	1 22	0 05	0 15
CD (0 05)	0 39	0 48	3 06	1 45	0 16	2 48	0 11	0 30
				Testers				
Anagha	0 44**	0 79**	3 12**	2 65**	0 34**	8 01**	0 42**	-0 68**
Manulekshmi	0 83**	0 08	-4 27**	-3 32**	-0 67**	-4 59**	0 02	0 67**
Vellayani Vijai	0 38**	-0 87**	1 15	0 67	0 33**	-3 42**	0 44**	0 01
S E +_	0 12	0 15	0 99	0 47	0 05	0 80	0 03	0 09
CD (0 05)	0 26	0 31	2 00	0 95	0 11	1 63	0 07	0 20

*Significant at 5 per cent level **Significant at 1 per cent level

Table 28 Continued

Parents	Fruit weight (g)	Yield plant⁻¹ (g)	Yield plot⁻¹ (kg)	TSS (%)	Lycopene (mg/100g)	Ascorbic acid (mg/100g)	Bacterial wilt incidence (%)
Lines							
LE 3	5 46**	445 89**	-7 32**	-0 26**	-0 03	3 78**	6 59**
LE 12	7 72**	309 83**	-6 60**	-0 61**	-1 82**	4 96**	10 48**
LE 13	7 64**	614 58**	11 57**	0 14*	0 50**	0 88	13 97**
LE 16	0 66	552 32**	8 94**	0 14**	0 74**	0 13	-10 63**
LE 19	9 17**	51 18	0 93	0 33**	1 00**	4 03**	-0 08
LE 20	-0 73	6 79	0 35	0 23**	1 05**	2 07**	2 86
LE 26	-3 56**	- 455 58**	-7 87**	0 04	0 66**	1 64**	10 48**
S E +_	0 77	31 40	0 67	0 05	0 10	0 48	2 30
CD (0 05)	1 57	63 47	1 37	0 10	0 21	0 98	4 66
Testers							
Anagha	5 50**	55 11*	0 41	0 20**	0 03	0 89**	1 98
Manulekshmi	4 53**	11 06	2 87**	0 48**	1 41**	0 73*	-10 16**
Vellayani Vijai	0 97	44 06*	2 47**	0 27**	1 43**	-0 16	8 17**
S E +_	0 51	20 56	0 44	0 03	0 06	0 31	1 50
CD (0 05)	1 03	41 55	0 90	0 07	0 14	0 64	3 05

*Significant at 5 per cent level **Significant at 1 per cent level

4.4.1.3 Node to First Inflorescence

Four lines *viz*, LE 19 (-0 53), LE 3 (-0 50), LE 13 (-0 46) and LE 12 (-0 31) exhibited significant negative *gca* effect for node to first inflorescence and three lines LE 20 (1 06), LE 26 (0 39) and LE 16 (0 35) exhibited significant positive *gca* effect

None of the testers showed significant positive or negative *gca* effect for the trait

4.4.1 4 Primary Branches Plant^{-1}

The line LE 16 (2 84) recorded significant positive *gca* effect while, LE 12 (-2 05) and LE 19 (-1 02) recorded significant negative *gca* effect for the trait

The tester Manulekshmi (1 13) exhibited significant *gca* effect in positive direction while, Vellayani Vijai (-0 70) and Anagha (-0 43) showed significant *gca* effect in negative direction for the trait

4.4.1.5 Leaf Length (cm)

Among the lines, LE 12 (3 41) recorded significant and positive *gca* effect while, LE 26 (-2 48) and LE 3 (-1 35) had significant *gca* effect in negative direction for the trait

Among the testers, Manulekshmi (0 96) had significant positive *gca* effect while, Anagha (-1 26) recorded significant *gca* effect in negative direction

4.4.1 6 Leaf Width (cm)

Significant positive *gca* effect for leaf width was exhibited by the lines LE 12 (1 66) and LE 13 (0 86) while, significant *gca* effect in negative direction was exhibited by LE 3 (-1 19), LE 19 (-0 95) and LE 26 (-0 84)

The tester Manulekshmi (0 64) had significant positive *gca* effect while, Anagha (-1 03) recorded significant *gca* effect in negative direction

4.4.1.7 Days to First Flowering

The estimates of *gca* effects implied that two lines, LE 16 (-2 51) and LE 12 (-2 47) recorded significant negative *gca* effect in the desirable direction These are the good general combiners for earliness among the lines

Significant negative *gca* effect in the desirable direction was exhibited by Anagha (-2 08) among the testers

4.4.1.8 Days to Fruit set

Among the lines, LE 20 (-0 89) and LE 16 (-0 63) showed negative significant *gca* effect in the desirable direction

Among the testers, Anagha (-0 22) exhibited significant *gca* effect in negative direction indicating earliness to fruit set

4.4 1.9 Flowers Cluster^{1}

The lines LE 20 (0 63) and LE 26 (0 48) exhibited positive and significant *gca* effect while, LE 3 (-0 70) recorded significant negative *gca* effect

Among the testers, Anagha (0 44) and Vellayani Vijai (0 38) had positive and significant *gca* effect while, Manulekshmi (-0 83) had significant *gca* effect in negative direction

4.4.1.10 Inflorescence Plant^{1}

Among the seven lines, LE 16 (4 03), LE 13 (2 14) and LE 20 (1 14) had significant positive *gca* effect while, LE 3 (-2 78), LE 12 (-2 56) and LE 26 (-2 34) had significant negative *gca* effect for inflorescence plant^{1}

Among three testers, Anagha (0 79) recorded positive and significant *gca* effect while, Vellayani Vijai (-0 87) exhibited significant *gca* effect in negative direction

4.4.1.11 Fruit set %

Significant positive *gca* effect for fruit set % was exhibited by LE 16 (7 31) and LE 20 (3 60) while, LE 12 (-6 36) and LE 3 (-3 91) revealed significant negative *gca* effect among the lines

Anagha (3 12) recorded positive and significant *gca* effect while, Manulekshmi (-4 27) showed significant *gca* effect in negative direction among the testers for the trait

4.4.1.12 Pollen Viability %

The lines LE 16 (10 41), LE 20 (3 34) and LE 19 (2 95) recorded significant positive *gca* effect while rest of the lines exhibited negative significant *gca* effect

Among the testers, Anagha (2 65) recorded positive and significant *gca* effect while, Manulekshmi (-3 32) exhibited significant negative *gca* effect for the trait

4.4.1.13 Fruits Cluster ^{1}

Among the lines, LE 13 (0 48), LE 20 (0 33) and LE 26 (0 29) recorded positive and significant *gca* effect while, LE 3 (-0 64) and LE 12 (-0 45) revealed significant *gca* effect in negative direction for fruits cluster ^{1}

Among the testers, Anagha (0 34) and Vellayani Vijai (0 33) exhibited significant positive *gca* effect while, Manulekshmi (-0 67) showed significant *gca* effect in negative direction for the trait

4.4.1.14 Fruits Plant^{1}

Among the seven lines, LE 16 (27 60), LE 13 (21 49) and LE 20 (3 53) were the good general combiners for fruits plant^{1} by exhibiting significant positive *gca* effect while three lines recorded significant negative *gca* effect

Among the testers, Anagha (8 01) was the good general combiner for fruits plant^{1} while, Manulekshmi (-4 59) and Vellayani Vijai (-3 42) exhibited significant *gca* effect in negative direction

4.4.1.15 Fruit Length (cm)

The line LE 26 (0 54), LE 13 (0 32) and LE 19 (0 20) were the best general combiners for fruit length by exhibiting significant *gca* effect in positive direction while, LE 12 (-0 65), LE 16 (-0 27) and LE 3 (-0 13) had significant *gca* effect in negative direction

The tester Vellayani Vijai (0 44) was the best combiner for fruit length by exhibiting significant positive *gca* effect while, Anagha (-0.42) recorded significant negative *gca* effect for the trait

4.4.1.16 Fruit Girth (cm)

The *gca* effects were positive and significant for LE 13 (0 75) and LE 19 (0 62) among the lines, while LE 12 (-1 39) and LE 3 (-0 53) showed significant negative *gca* effects

Among the testers, Manulekshmi (0 67) recorded significant positive *gca* effect while, Anagha (-0 68) exhibited significant *gca* effect in negative direction

4.4.1.17 Fruit Weight (g)

The *gca* effect of lines were positively significant for LE 19 (9 17) and LE 13 (7 64) and negatively significant for LE 12 (-7 72), LE 3 (-5 46) and LE 26 (-3 56) for fruit weight

Among the testers, only Manulekshmi (4 53) showed significant positive *gca* effect while, significant *gca* effect in negative direction was exhibited by Anagha (-5 50)

4.4.1.18 Yield Plant^{-1} (g)

Significant positive *gca* effect was observed for LE 13 (614 58) and LE 16 (552 32) and significant negative *gca* effect was observed for LE 26 (-455 58), LE 3 (-445 89) and LE 12 (-309 83) among the lines

The tester Anagha (55 11) had significant positive *gca* effect while, Vellayani Vijai (-44 06) had significant negative *gca* effect for the trait

4 4.1 19 Yield Plot^{-1} (kg)

The *gca* effects were significant and positive for LE 13 (11 57) and LE 16 (8 94) while, it was significant and negative for LE 26 (-7 87) followed by LE 3 (-7 32) and LE 12 (-6 60) among the lines

Among the testers, Manulekshmi (2 87) had significant positive *gca* effect while, Vellayani Vijai (-2 47) had significant *gca* effect in negative direction

4.4.1.20 TSS (%)

Among the seven lines, four lines exhibited significant positive *gca* effect *i e*, LE 19 (0 33), LE 20 (0 23), LE 13 (0 14) and LE 16 (0 14) while, LE 12 (-0 61) and LE 3 (-0 26) recorded significant *gca* effect in negative direction

Among the testers, Vellayam Vijai (0.27) followed by Anagha (0.20) showed significant positive *gca* effect while, negative significant *gca* effect was exhibited by Manulekshmi (-0.48)

4.4.1.21 Lycopene (mg/ 100 g)

Significant positive *gca* effect was observed for four lines with maximum for LE 19 (1.00) followed by LE 16 (0.74), LE 26 (0.66) and LE 13 (0.50) while, significant negative *gca* effect was observed for LE 12 (-1.82) and LE 20 (-1.05) among the lines for lycopene content

Among the testers, Vellayam Vijai (1.43) recorded significant *gca* effect in positive direction while it was negatively significant for Manulekshmi (-1.41)

4.4.1.22 Ascorbic acid (mg/ 100 g)

The lines LE 19, LE 20 and LE 26 exhibited significant positive *gca* effect with values of 4.03, 2.07 and 1.64 respectively while, it was negatively significant for LE 12 (-4.96) and LE 3 (-3.78)

The tester, Anagha (0.89) had positive and significant *gca* effect while, Manulekshmi (-0.73) had significant negative *gca* effect for the trait

4.4.1.23 Incidence of bacterial wilt (%)

Among the lines, significant *gca* effect in negative direction was exhibited by LE 13 (-13.97) and LE 16 (-10.63) while, LE 3, LE 12 and LE 26 had significant positive *gca* effect for bacterial wilt incidence

Among the testers, significant negative *gca* effect was exhibited by Manulekshmi (-10.16) while, Vellayani Vijai (8.17) recorded positive and significant *gca* effect for the trait

4.4.2 Specific combining ability effects

The specific combining ability effects of hybrids for the characters studied are given in Table 29

4.4.2.1 Plant Height (cm)

Significant positive *sca* effect for plant height was shown by the hybrids LE 20 x Manulekshmi (9 12), LE 16 x Anagha (7 49), LE 13 x Manulekshmi (6 12), LE 13 x Vellayani Vijai (5 98) and LE 3 x Anagha (5 45) Significant negative *sca* effect was shown by LE 13 x Anagha (-12 10), LE 26 x Manulekshmi (-6 95) and LE 20 x Vellayani Vijai (-6 46)

4.4.2.2 Height at Flowering (cm)

Significant negative *sca* effect for height at flowering was exhibited by LE 19 x Anagha (-3 23), LE 26 x Manulekshmi (-2 98) and LE 20 x Vellayani Vijai (-2 89) while, significant positive *sca* effect was recorded in LE 20 x Manulekshmi (2 98), LE 13 x Manulekshmi (2 96), LE 3 x Anagha (2 88) and LE 26 x Anagha (2 61)

4.4.2.3 Node to First Inflorescence

The *sca* effects were significant and negative for LE 3 x Vellayani Vijai (-0 69) and LE 16 x Manulekshmi (-0 62) whereas, it was positively significant for LE 16 x Vellayani Vijai (1 12) followed by LE 3 x Anagha (0 80), LE 26 x Vellayani Vijai (0 64) and LE 19 x Manulekshmi (0 60)

4.4.2.4 Primary Branches Plant^{-1}

Among the 21 crosses, only two crosses showed significant *sca* effects in positive direction *i e* LE 20 x Manulekshmi (2 91) and LE 19 x Anagha (1 76) whereas, four crosses recorded significant *sca* effects in negative direction *i e*

Table 29 Specific combining ability effects of hybrids

Crosses	Plant height (cm)	Height at flowering (cm)	Node to first inflorescence	Primary branches plant [1]	Leaf length (cm)	Leaf width (cm)	Days to first flowering	Days to fruit set
LE 3 x Anagha	5 45*	2 88*	0 80**	0 35	2 61**	0 72	-2 14**	-0 30
LE 3 x Manulekshmi	-1 93	2 21	-0 11	-0 98*	2 24*	0 37	2 21**	-0 16
LE 3x V Vijai	-3 52	0 67	-0 69*	0 62	0 38	-0 35	-0 07	0 46*
LE 12x Anagha	-0 79	0 32	-0 16	0 80	1 07	-0 04	1 57**	-0 19
LE 12x Manulekshmi	-2 31	-1 47	-0 18	-1 42**	0 64	0 02	0 14	0 62**
LE 12x V Vijai	3 10	1 80	0 34	0 63	0 43	0 06	-1 70**	-0 43*
LE 13x Anagha	-12 10**	-1 87	0 21	-0 16	2 87**	0 59	0 56	-0 04
LE 13x Manulekshmi	6 12*	2 96*	0 30	0 06	2 75**	0 57	-0 09	-0 01
LE 13x V Vijai	5 98*	1 09	-0 51	0 11	0 12	0 02	-0 48	0 05
LE 16x Anagha	7 49**	0 03	-0 50	-0 09	2 05*	0 90	-1 29**	0 37
LE 16x Manulekshmi	-4 73	1 45	-0 62*	0 13	2 90**	2 23**	-0 60	0 06
LE 16x V Vijai	-2 76	1 43	1 12**	-0 04	0 85	1 33*	1 89**	-0 43*
LE 19x Anagha	0 12	3 23**	-0 17	1 76**	1 50	0 28	-1 95**	0 10
LE 19x Manulekshmi	0 68	2 18	0 60*	0 13	1 76	0 25	-0 27	0 19
LE 19x V Vijai	-0 80	1 05	-0 43	1 63**	-0 26	-0 02	2 22**	0 09
LE 20x Anagha	-2 66	-0 09	0 24	2 65**	-1 68	-1 29	1 42**	0 29
LE 20x Manulekshmi	9 12**	2 98*	0 23	2 91**	2 16*	2 23**	-0 79	-0 01
LE 20x V Vijai	-6 46*	-2 89*	-0 47	0 26	-0 49	-0 94	-0 63	-0 28
LE 26x Anagha	2 49	2 61*	-0 42	0 01	0 31	0 02	1 83**	-0 23
LE 26x Manulekshmi	-6 95*	-2 98*	-0 22	0 57	-0 89	0 07	-0 60	-0 31
LE 26x V Vijai	4 46	0 37	0 64*	0 59	0 58	-0 08	-1 22**	0 53**
S E+_	2 69	1 10	0 26	0 46	0 89	0 63	0 44	0 19
CD (0 05)	5 45	2 23	0 54	0 93	1 80	1 29	0 90	0 40

*Significant at 5 per cent level **Significant at 1 per cent level

Table 29 Continued

Crosses	Flowers cluster ^{1}	Inflorescence plant ^{1}	Fruit set %	Pollen viability %	Fruits cluster ^{1}	Fruits plant ^{1}	Fruit length (cm)	Fruit girth (cm)
LE 3 x Anagha	0 15	0 13	9 10**	8 21**	-0 16	9 56**	0 33**	0 30
LE 3 x Manulekshmi	0 42	-0 60	2 40	1 49	0 52**	4 59*	0 07	0 52
LE 3x V Vijai	-0 57	0 47	6 71*	6 72**	0 37*	4 97*	0 26**	0 22
LE 12x Anagha	0 48	0 13	-4 60	6 60**	0 46**	-5 23*	0 03	0 10
LE 12x Manulekshmi	0 01	2 38**	6 14*	7 50**	0 34*	2 54	0 12	0 16
LE 12x V Vijai	0 47	2 25**	1 55	0 90	0 12	2 68	0 15	0 06
LE 13x Anagha	0 22	0 02	0 02	0 34	0 06	6 33**	0 13	0 14
LE 13x Manulekshmi	-0 40	0 48	-4 58	2 24	0 59**	6 08**	0 15	0 58*
LE 13x V Vijai	0 17	0 46	4 56	1 90	0 52**	0 25	0 29**	-0 44
LE 16x Anagha	0 22	0 65	-6 80*	-3 77**	0 14	24 44**	-0 20*	0 95**
LE 16x Manulekshmi	-0 40	1 75**	7 67**	5 24**	-0 18	-22 75**	0 37**	0 90**
LE 16x V Vijai	0 17	1 10*	0 87	1 48	0 04	1 69	0 17	0 05
LE 19x Anagha	0 00	0 87*	4 26	7 51**	0 16	4 40*	0 43**	-0 03
LE 19x Manulekshmi	0 06	1 14**	0 77	-0 23	0 41**	7 33**	0 29**	0 62*
LE 19x V Vijai	0 06	2 02**	-5 03	-7 28**	-0 25	-11 73**	0 14	0 60*
LE 20x Anagha	0 30	2 12**	0 42	1 72	-0 34*	-17 71**	0 25*	0 29
LE 20x Manulekshmi	-0 03	3 03**	1 21	1 20	0 44**	12 66**	0 02	0 52
LE 20x V Vijai	0 33	0 91*	0 79	2 92*	0 78**	5 05*	0 27**	0 24
LE 26x Anagha	0 19	0 36	-2 41	-3 97**	0 92**	-2 67	0 65**	0 43
LE 26x Manulekshmi	0 45	0 07	-6 40*	-7 59**	-0 07	1 70	-0 53**	-0 90**
LE 26x V Vijai	-0 64	0 42	8 81**	11 56**	0 85**	0 97	0 12	0 47
S E+_	0 33	0 40	2 61	1 24	0 14	2 12	0 09	0 26
CD (0 05)	0 68	0 83	5 29	2 52	0 28	4 30	0 19	0 53

*Significant at 5 per cent level **Significant at 1 per cent level

Table 29 Contınued

Crosses	Fruit weight (g)	Yield plant[1] (g)	Yield plot[1] (kg)	TSS (%)	Lycopene (mg/100g)	Ascorbic acid (mg/100g)	Bacterial wilt incidence (%)
LE 3 x Anagha	3 17*	90 42	1 15	0 23*	-0 28	2 17*	2 46
LE 3 x Manulekshmi	-2 09	-70 88	2 33	0 20*	1 11**	0 60	1 27
LE 3x V Vijai	-1 08	19 54	1 18	-0 43**	-0 83**	2 77**	3 73
LE 12x Anagha	3 76**	-23 08	2 64*	0 39**	0 87**	2 78**	-11 43**
LE 12x Manulekshmi	-4 82**	-60 35	3 65**	0 49**	1 13**	0 92	10 71*
LE 12x V Vijai	1 06	83 43	1 01	-0 09	-0 26	1 86*	0 71
LE 13x Anagha	3 65*	47 81	-1 25	0 29**	-1 44**	1 41	6 35
LE 13x Manulekshmi	3 99**	-109 68	0 95	0 30**	0 14	2 88**	4 84
LE 13x V Vijai	-0 35	61 87	0 30	0 60**	1 58**	1 47	1 51
LE 16x Anagha	3 64*	307 85**	0 08	0 68**	2 98**	0 85	11 35**
LE 16x Manulekshmi	3 60*	-256 76**	2 50*	0 44**	1 92**	4 32**	-1 51
LE 16x V Vijai	0 04	-51 09	2 43*	-0 25**	-1 05**	3 47**	9 84*
LE 19x Anagha	6 02**	5 78	2 64*	0 20*	-0 59**	4 45**	12 54**
LE 19x Manulekshmi	9 58**	398 84**	5 89**	0 35**	0 35	0 77	-5 40
LE 19x V Vijai	-3 56*	-393 06**	8 53**	0 15	0 24	3 68**	17 94**
LE 20x Anagha	1 90	371 04**	6 73**	-0 12	0 20	-1 78*	11 90**
LE 20x Manulekshmi	4 49**	232 69**	6 58**	-0 33**	0 61**	3 05**	-14 29**
LE 20x V Vijai	2 60	138 35*	0 15	0 46**	0 81**	1 26	2 38
LE 26x Anagha	4 49**	46 18	1 47	0 09	0 00	0 02	-8 10*
LE 26x Manulekshmi	5 77**	133 86*	-4 94**	0 04	-1 14**	4 61**	14 05**
LE 26x V Vijai	1 28	180 03**	3 48**	-0 13	1 14**	4 62**	-5 95
S E+_	1 34	54 39	1 17	0 08	0 18	0 84	3 99
CD (0 05)	2 73	109 94	2 38	0 18	0 37	1 70	8 07

*Significant at 5 per cent level

**Significant at 1 per cent level

LE 20 x Anagha (-2.65), LE 19 x Vellayani Vijai (-1.63), LE 12 x Manulekshmi (-1.42) and LE 3 x Manulekshmi (-0.98).

4.4.2.5 Leaf Length (cm)

The crosses LE 13 x Manulekshmi (2.75), LE 3 x Anagha (2.61), LE 20 x Manulekshmi (2.16) and LE 16 x Anagha (2.05) exhibited positive and significant *sca* effects whereas LE 16 x Manulekshmi (-2.90), LE 13 x Anagha (-2.87) and LE 3 x Manulekshmi (-2.24) exhibited significant negative *sca* effects for leaf length.

4.4.2.6 Leaf Width (cm)

Significant positive *sca* effects were exhibited by only two crosses *i.e.* LE 20 x Manulekshmi (2.23) and LE 16 x Vellayani Vijai (1.33) while, the cross LE 16 x Manulekshmi (-2.23) exhibited significant negative *sca* effect for the trait.

4.4.2.7 Days to First Flowering

The crosses LE 3 x Anagha (-2.14), LE 19 x Anagha (-1.95), LE 12 x Vellayani Vijai (-1.70), LE 16 x Anagha (-1.29) and LE 26 x Vellayani Vijai (-1.22) were good specific combiners for early flowering by exhibiting significant negative *sca* effects in the desirable direction.

4.4.2.8 Days to Fruit set

Among the 21 hybrids, only two hybrids LE 12 x Vellayani Vijai (-0.43) and LE 16 x Vellayani Vijai (-0.43) recorded significant negative *sca* effects in desirable direction for days to fruit set.

4.4.2.9 Flowers Clustei [1]

None of the hybrids exhibited significant *sca* effect The *sca* effect varied from -0 64 (LE 26 x Vellayani Vijai) to 0 47 (LE 12 x Vellayani Vijai)

4.4.2.10 Inflorescence Plant[1]

Five hybrids *viz*, LE 20 x Manulekshmi (3 03), LE 12 x Vellayani Vijai (2 25), LE 19 x Manulekshmi (1 14), LE 16 x Vellayani Vijai (1 10) and LE 19 x Anagha (0 87) exhibited significant positive *sca* effect while, LE 12 x Manulekshmi (-2 38), LE 20 x Anagha (-2 12), LE 19 x Vellayani Vijai (-2 02), LE 16 x Manulekshmi (-1 75) and LE 20 x Vellayani Vijai (-0 91) exhibited significant *sca* effect in negative direction

4.4.2.11 Fruit set %

The *sca* effect was positive and significant for four hybrids *i e* LE 3 x Anagha (9 10), LE 26 x Vellayani Vijai (8 81), LE 16 x Manulekshmi (7 67) and LE 12 x Manulekshmi (6 14) while, it was negatively significant for the crosses LE 16 x Anagha (-6 80), LE 3 x Vellayani Vijai (-6.71) and LE 26 x Manulekshmi (-6 40) for fruit set %

4.4.2.12 Pollen Viability %

Significant positive *sca* effect was exhibited by the crosses, LE 26 x Vellayani Vijai (11 56), LE 3 x Anagha (8 21), LE 19 x Anagha (7 51), LE 12 x Manulekshmi (7 50), LE 16 x Manulekshmi (5 24) and LE 20 x Vellayani Vijai (2 92) while, significant negative *sca* effect was exhibited by the crosses, LE 26 x Manulekshmi (-7 59), LE 19 x Vellayani Vijai (-7 28), LE 3 x Vellayani Vijai (-6 72), LE 12 x Anagha (-6 60), LE 26 x Anagha (-3 97), LE 16 x Anagha (-3 77) for pollen viability %

4 4.2.13 Fruits Cluster

Among the 21 crosses, twelve crosses exhibited significant *sca* effect of which six crosses were positively significant *viz* LE 26 x Anagha (0 92) followed by LE 20 x Vellayani Vijai (0 78), LE 3 x Manulekshmi (0 52), LE 13 x Vellayani Vijai (0 52), LE 19 x Manulekshmi (0 41) and LE 12 x Manulekshmi (0 34) while, six crosses were negatively significant *viz* LE 26 x Vellayani Vijai (-0 85), LE 13 x Manulekshmi (-0 59), LE 12 x Anagha (-0 46), LE 20 x Manulekshmi (-0 44), LE 3 x Vellayani Vijai (-0 37) and LE 20 x Anagha (-0 34) for fruits cluster^{1}

4.4.2.14 Fruits Plant^{1}

The crosses LE 16 x Anagha (24 44), LE 20 x Manulekshmi (12 66), LE 19 x Manulekshmi (7 33), LE 13 x Anagha (6 33), LE 20 x Vellayani Vijai (5 05), LE 3 x Vellayani Vijai (4 97), LE 3 x Manulekshmi (4 59) and LE 19 x Anagha (4 40) were the good specific combiners for fruits plant^{1} by exhibiting significant positive *sca* effect Six crosses revealed significant negative *sca* effect *viz* LE 16 x Manulekshmi (-22 75), LE 20 x Anagha (-17 71), LE 19 x Vellayani Vijai (-11 73), LE 3 x Anagha (-9 56), LE 13 x Manulekshmi (-6 08) and LE 12 x Anagha (-5 23) for the trait

4.4.2.15 Fruit Length (cm)

The *sca* effect was significant and positive for LE 26 x Anagha (0 65), LE 16 x Manulekshmi (0 37), LE 3 x Anagha (0 33), LE 13 x Vellayani Vijai (0 29), LE 19 x Manulekshmi (0 29) and LE 20 x Vellayani Vijai (0 27) indicating that they were good combiners for fruit length Five hybrids recorded significant *sca* effect in negative direction for the trait

4.4 2.16 Fruit Girth (cm)

The results revealed significant positive *sca* effect for three crosses and significant negative *sca* effect for three crosses The highest *sca* effect was observed in the cross LE 16 x Manulekshmi (0 90) followed by LE 19 x Manulekshmi (0 62) and LE 13 x Manulekshmi (0 58)

4.4.2.17 Fruit Weight (g)

The highest significant *sca* effect in positive direction was exhibited by LE 19 x Manulekshmi (9 58) followed by LE 26 x Anagha (4 49), LE 13 x Manulekshmi (3 99), LE 12 x Anagha (3 76), LE 16 x Manulekshmi (3 60) and LE 3 x Anagha (3 17) indicating that these crosses were the best combiners for fruit weight while, seven crosses had negative significant *sca* effect for the trait

4.4.2.18 Yield Plant^{-1} (g)

Among the 21 hybrids, five hybrids had significant positive *sca* effect and four hybrids recorded significant negative *sca* effect The cross LE 19 x Manulekshmi (398 84) followed by LE 16 x Anagha (307 85), LE 20 x Manulekshmi (232 69), LE 26 x Vellayani Vijai (180 03) and LE 20 x Vellayani Vijai (138 35) were the good specific combiners for yield plant^{-1}

4.4.2.19 Yield Plot^{-1} (kg)

Six hybrids recorded significant positive *sca* effect with highest value exhibited by LE 20 x Manulekshmi (6 58) followed by LE 19 x Manulekshmi (5 89), LE 26 x Vellayani Vijai (3 48), LE 12 x Anagha (2 64), LE 19 x Anagha (2 64) and LE 16 x Vellayani Vijai (2 43) while, five hybrids had significant *sca* effect in negative direction

4.4.2.20 TSS (%)

Significant *sca* effect for TSS was shown by seven hybrids in positive direction and eight hybrids in negative direction The *sca* effect for TSS ranged from -0 44 (LE 16 x Manulekshmi) to 0 68 (LE 16 x Anagha)

4.4 2.21 Lycopene (mg/ 100 g)

Six hybrids exhibited significant positive *sca* effect for lycopene with maximum value of 2 98 (LE 16 x Anagha) followed by 1 58 (LE 13 x Vellayani Vijai), 1 14 (LE 26 x Vellayani Vijai), 1 13 (LE 12 x Manulekshmi), 1 11 (LE 3 x Manulekshmi) and 0 61 (LE 20 x Manulekshmi) while, eight hybrids recorded significant negative *sca* effect for the trait

4.4.2.22 Ascorbic acid (mg/ 100 g)

Six crosses had significant and positive *sca* effect with maximum of 4 61 (LE 26 x Manulekshmi) followed by 4 45 (LE 19 x Anagha), 3 47 (LE 16 x Vellayani Vijai), 3 05 (LE 20 x Manulekshmi), 2 77 (LE 3 x Vellayani Vijai), 1 86 (LE 12 x Vellayani Vijai) while, seven hybrids recorded significant *sca* effect in negative direction for the trait

4.4.2.23 Incidence of bacterial wilt

Among the 21 crosses, five crosses recorded significant negative *sca* effect in desirable direction for the incidence of bacterial wilt *viz*, LE 20 x Manulekshmi (-14 29), LE 19 x Anagha (-12 54), LE 12 x Anagha (-11 43), LE 16 x Vellayani Vijai (-9 84) and LE 26 x Anagha (-8 10) and five crosses recorded significant positive *sca* effect

4 5 COMPONENTS OF GENETIC VARIANCE

Components of genetic variance are given in the Table 30 The ratio of additive variance to dominance variance was less than unity for the traits like

Table 30 Components of genetic variance (F=1)

Character	σ^2_A	σ^2_D	σ^2_A / σ^2_D	Gene action
Plant height (cm)	70 54	40 63	1 73	Additive
Height at flowering (cm)	15 22	5 95	2 55	Additive
Node to first inflorescence	0 09	0 35	0 26	Non additive
Primary branches plant^{-1}	1 85	2 00	0 92	Non additive
Leaf length (cm)	1 89	3 97	0 47	Non additive
Leaf width (cm)	1 25	0 98	1 27	Additive
Days to first flowering	5 26	2 96	1 77	Additive
Days to fruit set	0 21	0 11	1 80	Additive
Flowers cluster^{-1}	0 76	0 07	9 90	Additive
Inflorescence plant^{-1}	3 93	2 94	1 33	Additive
Fruit set %	16 63	35 89	0 46	Non additive
Pollen viability %	14 02	48 23	0 29	Non additive
Fruits cluster^{-1}	0 43	0 32	1 33	Additive
Fruits plant^{-1}	252 85	192 44	1 31	Additive
Fruit length (cm)	0 29	0 13	2 27	Additive
Fruit girth (cm)	0 80	0 35	2 25	Additive
Fruit weight (g)	49 56	26 16	1.89	Additive
Yield plant^{-1} (g)	146346 26	62500 39	2 34	Additive
Yield plot^{-1} (kg)	47 48	21 76	2 18	Additive
TSS (%)	0 22	0 19	1 10	Additive
Lycopene (mg/ 100 g)	2 60	2 17	1 19	Additive
Ascorbic acid (mg/ 100 g)	1 93	12 56	0 15	Non additive
Bacterial wilt incidence (%)	122 38	127 33	0 96	Non additive

node to first inflorescence, primary branches plant^{-1}, leaf length, fruit set %, pollen viability %, ascorbic acid and bacterial wilt incidence (%), hence exhibited non additive gene action The ratio of *gca/ sca* was more than unity for the traits like plant height, height at flowering, leaf width, days to first flowering, days to fruit set, flowers cluster^{-1}, inflorescence plant^{-1}, fruits cluster^{-1}, fruits plant^{-1}, fruit length, fruit girth, fruit weight, yield plant^{-1}, yield plot^{-1}, TSS and lycopene which indicated the influence of additive gene action

4 6 PROPORTIONAL CONTRIBUTION

The propoitional contribution of lines, testers and crosses to total variance of the characters under study are given in Table 31 and Fig 7

The value ranged from 25 79 for fruits cluster^{-1} to 86 66 for yield plant^{-1} among the lines Among the testers, the value ranged from 0 17 for yield plant^{-1} to 53 63 for flowers cluster^{-1} In the case of crosses, the value ranged from 13 15 for yield plant^{-1} to 45 99 for fruit set %

The crosses had no significant contribution to any of the traits whereas the lines had contributed more than 50% for plant height, height at flowering, node to first inflorescence, primary branches plant^{-1}, days to fruit set, inflorescence plant^{-1}, fruits plant^{-1}, fruit weight, yield plant^{-1}, yield plot^{-1} and ascorbic acid content

4 7 INCIDENCE OF PESTS AND DISEASES OTHER THAN BACTERIAL WILT

The crop was monitored for the incidence of pests and diseases There was no incidence of other diseases like fusarium wilt and spotted wilt virus but mild incidence of fruit borer (*Spodoptera litura*) was noticed (Table 32) Among the lines, LE 20 had maximum incidence of fruit borer of 8 55% followed by LE 26 (8 23%) while, there was no incidence in LE 12 Among the testers, only Manulekshmi had mild incidence of 1 57% Among the crosses, the incidence ranged from zero to 5 70% (LE 3 x Manulekshmi) The incidence of 4 90% was noticed in check Indam 9802 whereas, Lekshmi had no incidence of fruit borer

Table 31 Proportional contribution of lines, testers and L x T to total variance

Sl No	Characters	Lines (%)	Testers (%)	Line x Tester (%)
1	Plant height (cm)	62 83	14 47	22 69
2	Height at flowering (cm)	65 91	16 00	18 07
3	Node to first inflorescence	54 71	3 47	41 81
4	Primary branches plant ^{1}	50 83	16 62	32 53
5	Leaf length (cm)	44 15	13 44	42 39
6	Leaf width (cm)	41 72	23 64	34 62
7	Days to first flowering	40 05	32 98	26 95
8	Days to fruit set	72 41	6 61	20 96
9	Flowers cluster ^{1}	29 14	53 63	17 22
10	Inflorescence plant ^{1}	72 79	5 63	21 56
11	Fruit set %	35 65	18 36	45 99
12	Pollen viability %	46 44	9 53	44 02
13	Fruits cluster ^{1}	25 79	39 43	34 77
14	Fruits plant ^{1}	74 63	4 46	20 90
15	Fruit length (cm)	39 69	36 64	23 65
16	Fruit girth (cm)	46 45	29 81	23 73
17	Fruit weight (g)	51 35	25 23	23 41
18	Yield plant ^{1} (g)	86 66	0 17	13 15
19	Yield plot ^{1} (kg)	78 22	6 05	15 71
20	TSS (%)	28 29	35 19	36 50
21	Lycopene (mg/ 100 g)	26 74	37 74	35 50
22	Ascorbic acid (mg/ 100 g)	52 78	2 66	44 54
23	Bacterial wilt incidence (%)	37 17	26 04	36 77

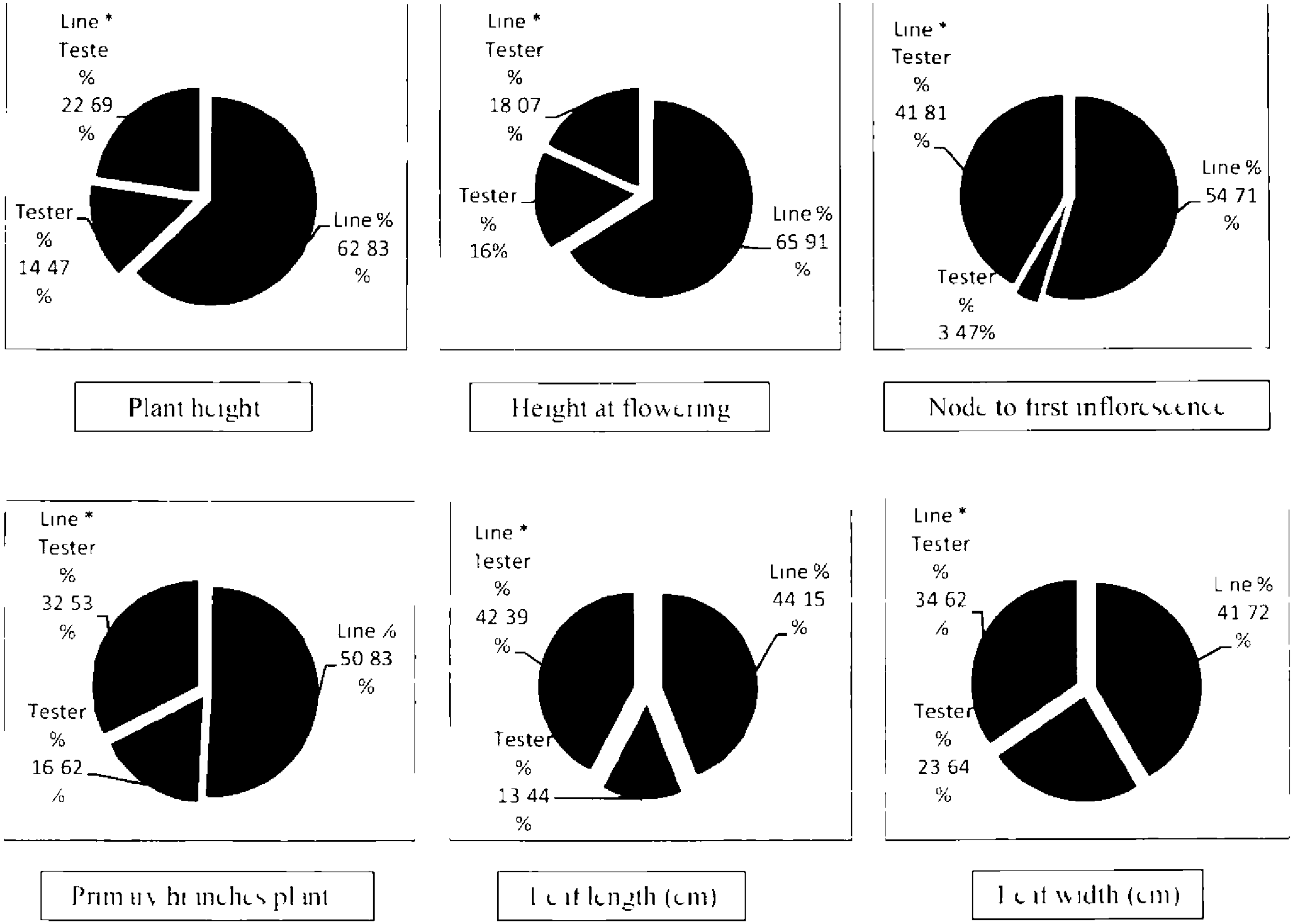


Fig 7 Proportional contribution (%) of lines, testers and line x tester to the total variance

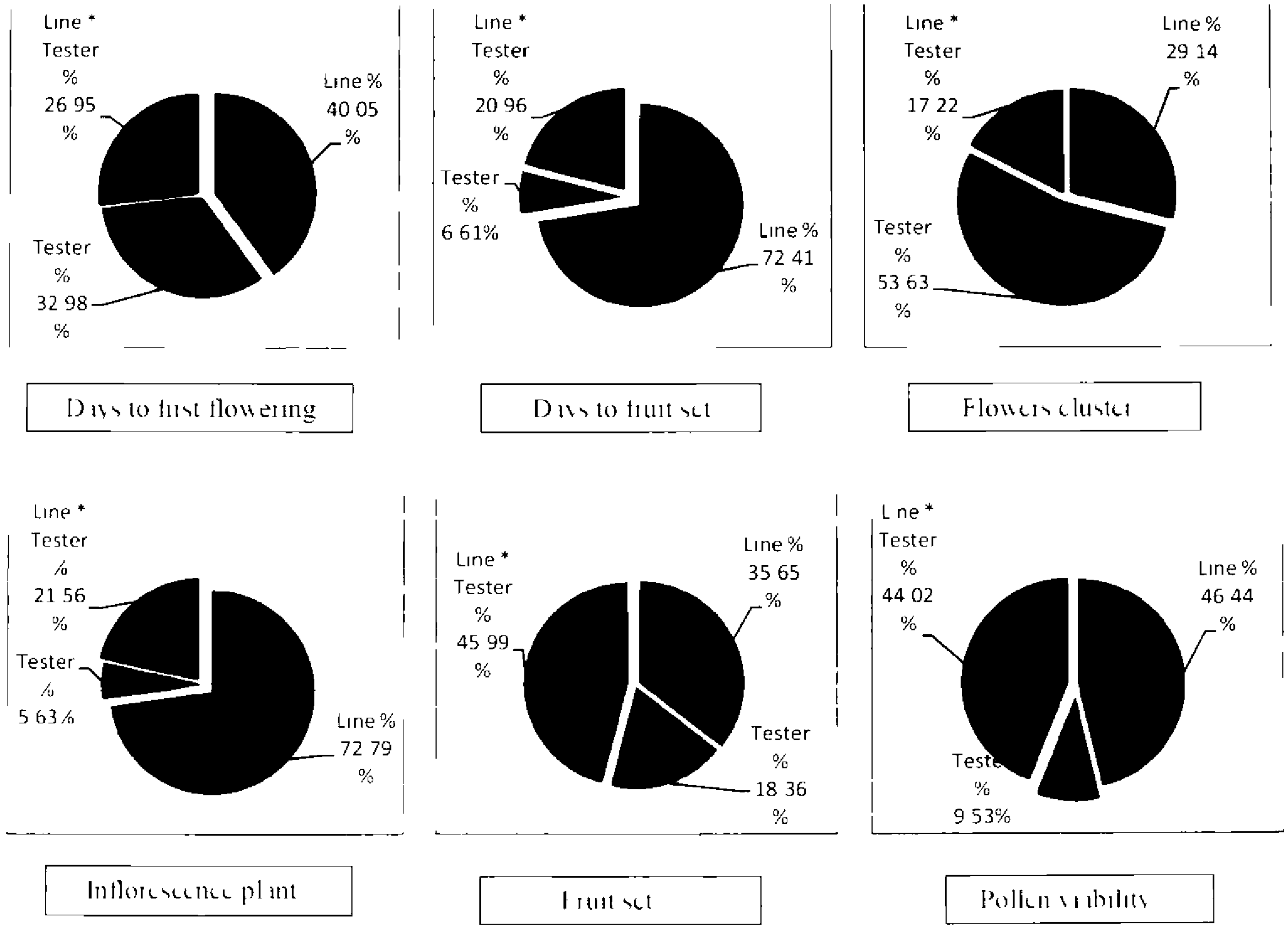
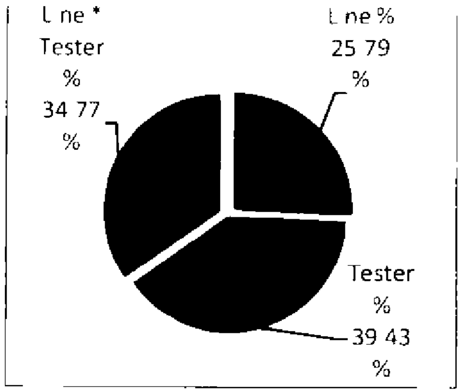
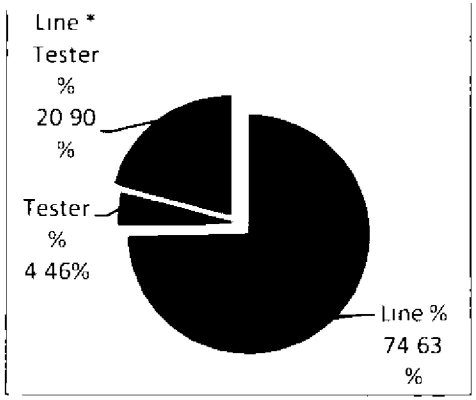


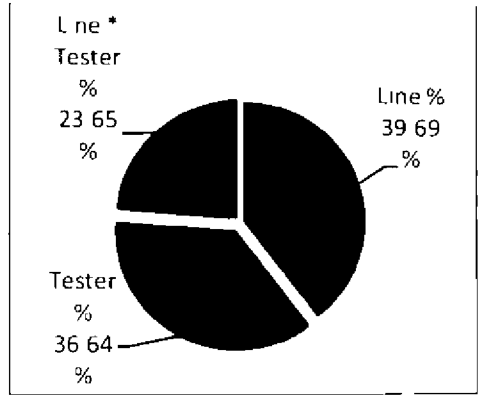
Fig 7 Continued



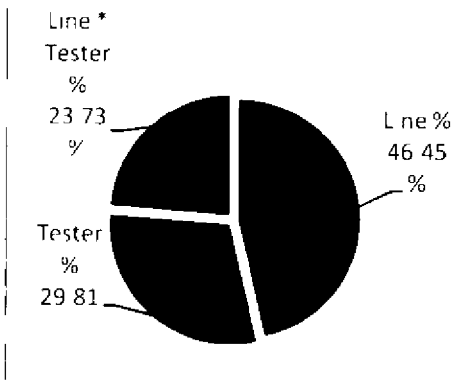
Fruits cluster



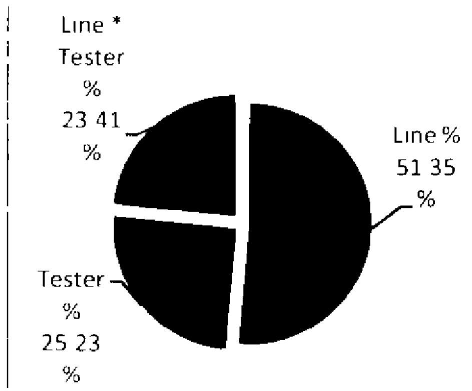
Fruits plant



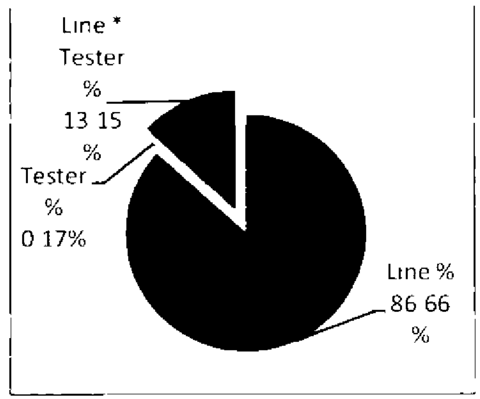
Fruit length (cm)



Fruit girth (cm)

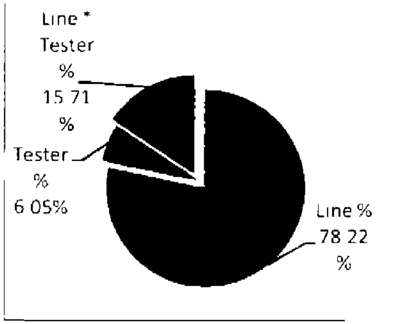


Fruit weight (cm)

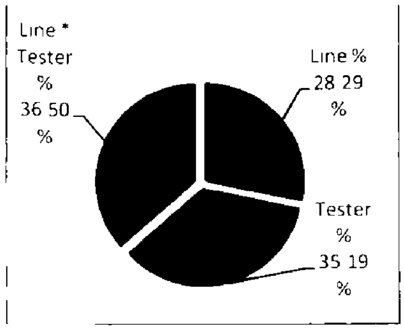


Yield plant (g)

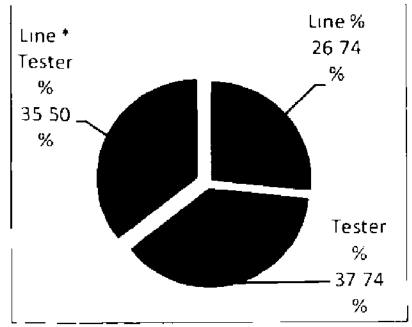
Fig 7 Continued



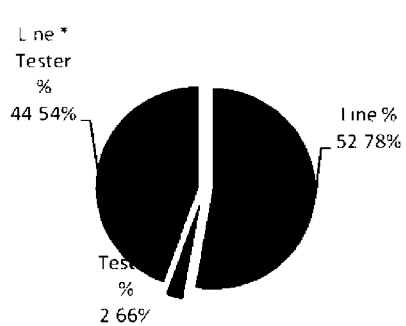
Yield plot (kg)



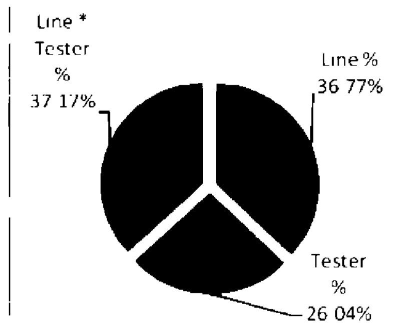
TSS ( )



Lycopene (mg 100 g)



Ascorbic acid content (mg 100 g)



Bacterial wilt incidence ( )

Fig 7 Continued

Table 32 Incidence (%) of fruit borer (*Spodoptera litura*)

Sl No	Parents and crosses	Incidence (%)	Score value
1	LE 3	6 1	1
2	LE 12	0 00	0
3	LE 13	5 47	1
4	LE 16	3 40	1
5	LE 19	6 39	1
6	LE 20	8 55	1
7	LE 26	8 23	1
8	Anagha	0 00	0
9	Manulekshmi	1 57	1
10	Vellayani Vijai	0 00	0
11	LE 3 x Anagha	0 00	0
12	LE 3x Manulekshmi	5 70	1
13	LE 3x V Vijai	4 95	1
14	LE 12x Anagha	0 00	0
15	LE 12x Malulekshmi	0 00	0
16	LE 12x V Vijai	0 00	0
17	LE 13x Anagha	0 00	0
18	LE 13x Manulekshmi	0 00	0
19	LE 13x V Vijai	0 00	0
20	LE 16x Anagha	4 39	1
21	LE 16x Manulekshmi	3 79	1
22	LE 16x V Vijai	4 9	1
23	LE 19x Anagha	3 49	1
24	LE 19x Manulekshmi	0 00	0
25	LE 19x V Vijai	0 00	0
26	LE 20x Anagha	5 02	1
27	LE 20x Manulekshmi	0 00	0
28	LE 20x V Vijai	0 00	0
29	LE 26x Anagha	0 00	0
30	LE 26x Manulekshmi	0 00	0
31	LE 26x V Vijai	4 20	1
32	Indam 9802 (check)	4 90	1
33	Lekshmi (check)	0 00	0
Mean		2 45	1

Discussion

5. DISCUSSION

Proper choice of parents based on their combining ability is a prerequisite in any sound breeding programme, which also provides information regarding the nature and magnitude of gene action involved in the expression of desirable traits. Line x Tester analysis is one of the method for evaluating the performance of varieties or strains in terms of their combining ability. The present study was carried out in a line x tester model using seven high yielding genotypes as lines and three bacterial wilt resistant varieties as testers. The combining ability effects, gene action and heterosis for yield and resistance were studied and superior crosses were identified. A brief discussion regarding the results obtained is furnished below.

5.1 MEAN PERFORMANCE

Among the lines, LE 16 was found superior based on mean performance for plant height, primary branches plant^{-1}, leaf width, days to fruit set, inflorescence plant^{-1}, fruits plant^{-1}, fruit girth, yield plant^{-1}, yield plot^{-1} and ascorbic acid content. The line LE 12 showed high *per se* performance for leaf length, leaf width, early flowering, flowers cluster^{-1}, fruits cluster^{-1} and TSS. The line LE 13 exhibited less height at flowering, maximum leaf **width**, inflorescence plant^{-1}, fruit set %, pollen viability %, fruits cluster^{-1}, fruits plant^{-1}, fruit girth, fruit weight, yield plant^{-1} and TSS. The line LE 19 recorded maximum inflorescence plant^{-1}, fruit set %, fruit length, fruit girth, fruit weight, lycopene and ascorbic acid. The line LE 20 was found superior for leaf width, fruits cluster^{-1}, fruit length, fruit weight and TSS while, LE 26 recorded less number of nodes to first inflorescence, highest flowers cluster^{-1}, fruit length, fruit weight, lycopene and ascorbic acid.

Among the testers, Anagha exhibited the highest mean value for fruits plant^{-1}, yield plant^{-1} and yield plot^{-1}. The tester, Manulekshmi recorded less height at flowering, primary branches plant^{-1}, fruit weight and ascorbic acid. The tester, Vellayani Vijai was found superior for most of characters like, node to first inflorescence, leaf length, leaf width, days to first flowering, days to fruit set, flowers cluster^{-1}, pollen viability %, fruits cluster^{-1}, fruit length, fruit weight, yield plant^{-1}, yield plot^{-1}, TSS, lycopene and ascorbic acid content

Among the crosses, LE 16 x Anagha apart from giving high yield of 2191 44 g plant^{-1} exhibited desirable characters like days to first flowering, flowers cluster^{-1}, inflorescence plant^{-1} fruit set %, fruits plant^{-1}, TSS % and lycopene content Similar result for yield of tomato plant (2480 g) was reported by Bhatt *et al* (2004) Kumari and Sharma (2011) reported per plant yield of 2100 00 g Similar results for fruits plant^{-1} were reported by Bhatt *et al* (2004) and Farzane *et al* (2012) Shankar *et al* (2014) reported similar findings for both TSS % and lycopene

The highest mean value for plant height, leaf length, leaf width, fruit girth and yield plot^{-1} was recorded for the cross LE 13 x Manulekshmi Shankar *et al* (2014) reported similar result for plant height of tomato grown under open condition

A perusal of the data revealed that the cross, LE 20 x Vellayani Vijai is superb to earliness to fruit set, flowers cluster^{-1}, fruit set %, fruits cluster^{-1} and TSS % Highest plant height, primary branches plant^{-1}, leaf length, leaf width and early days to fruit set was observed in LE 20 x Manulekshmi The results are in agreement with Gul *et al* (2010) and Shankar *et al* (2014)

Lower height at flowering is a desirable character for earliness in tomato which was observed in the cross LE 19 x Anagha which also recorded lower node to first inflorescence, high fruit set %, pollen viability % and ascorbic acid content The cross LE 26 x Anagha exhibited the highest flowers cluster^{-1} and fruits cluster^{-1} Similar finding for fruits cluster^{-1} was also reported by Gul *et al* (2010) and Kumari and Sharma (2011) The findings of Bhatt *et al* (2004), Kumari and Sharma (2011) and Pandiarana *et al* (2015) confirms to the ascorbic acid content

The crosses, LE 3 x Vellayani Vijai, LE 19 x Vellayani Vijai, LE 13 x Vellayani Vijai, LE 12 x Anagha, LE 13 x Anagha and LE 3 x Manulekshmi had less number of nodes to first inflorescence The cross LE 16 x Manulekshmi recorded maximum number of primary branches plant^{-1} Highest leaf length was recorded by LE 12 x Manulekshmi, LE 12 x Vellayani Vijai, LE 12 x Anagha and LE 19 x Manulekshmi which were on par There was no significant difference among the crosses LE 12 x Manulekshmi, LE 16 x Vellayani Vijai, LE 12 x Vellayani Vijai and LE 13 x Vellayani Vijai for leaf width Early days to fruit set was also observed in the crosses LE 16 x Vellayani Vijai and LE 20 x Anagha The crosses LE 12 x Vellayani Vijai, LE 20 x Anagha, LE 16 x Vellayani Vijai and LE 13 x Anagha also produced maximum number of flowers cluster^{-1} The crosses LE 16 x Manulekshmi, LE 3 x Anagha, LE 26 x Vellayani Vijai, LE 16 x Vellayani Vijai, LE 20 x Anagha, LE 13 x Vellayani Vijai and LE 16 x Anagha recorded high fruit set % Highest pollen viability % was also exhibited by the cross LE 16 x Manulekshmi Highest number of fruits cluster^{-1} and fruit length was exhibited by the cross LE 13 x Vellayani Vijai which was on par with LE 26 x Vellayani Vijai for fruit length Maximum fruit girth and fruit weight was recorded by the cross LE 19 x Manulekshmi (15 00 cm and 62 85 g respectively) which was on par with LE 16 x Manulekshmi (14 94 cm) for fruit girth Similar results were obtained in the findings of Bhatt *et al* (2004), Gul *et al* (2010) and Baban *et al* (2015) for fruit weight with mean values of 62 33 g, 59 g and 53 99 g respectively The cross LE 26 x Vellayani Vijai also recorded highest lycopene content (12 57 mg/ 100 g)

5 2 HETEROSIS

Heterosis breeding makes use of the hybrid vigour in the crosses for attaining noticeable increase in production and productivity of crop plants Existence of significant amount of dominance variance is essential for undertaking heterosis breeding programme Even, the expression of small magnitude of heterosis for certain characters may be much rewarding in breeding

In the present study, relative heterosis, heterobeltiosis and standard heterosis over checks Indam 9802 and Lekshmi were estimated for the 21 crosses with respect to the different characters

Positive heterosis indicates the superiority of the hybrids for characters such as plant height, primary branches plant^{-1}, leaf length, leaf width, flowers cluster^{-1}, inflorescence plant^{-1}, fruit set %, pollen viability %, fruits cluster^{-1}, fruits plant^{-1}, fruit length, fruit girth, fruit weight, yield plant^{-1}, yield plot^{-1}, TSS, lycopene and ascorbic acid content

Plant height is an important growth parameter from productivity point of view and was measured at final harvest stage The cross LE 13 x Manulekshmi exhibited significant positive relative heterosis, heterobeltiosis and standard heterosis over both the checks for plant height Positive and significant heterosis for plant height was also reported by Mahendrakar (2004), Premalakshme *et al* (2005), Akram *et al* (2013), Sunil *et al* (2013) and Mali and Patel (2014)

Negative heterosis is desirable for characters like height at flowering, node to first inflorescence, days to first flowering and days to fruit set which indicates earliness The hybrid LE 19 x Anagha recorded significant negative heterosis over better parent and standard checks for height at flowering while, the hybrid LE 3 x Vellayani Vijai exhibited significant heterosis over both the checks in desirable negative direction for node to first inflorescence Significant relative heterosis, heterobeltiosis and standard heterosis over both the checks in the desirable negative direction was recorded by LE 16 x Anagha for days to first flowering Significant negative heterosis for days to first flowering was reported by Singh *et al* (2008), Ahmad *et al* (2011), Kumari and Sharma (2011), Islam *et al* (2012), Droka *et al* (2013), Basavaraj (2014) and Chauhan *et al* (2014) The hybrid LE 20 x Manulekshmi recorded significant negative heterosis over mid parent while, the cross LE 20 x Vellayani Vijai exhibited significant negative heterosis over better parent and standard check Indam 9802 for days to fruit set Significant heterosis in desirable direction for days to fruit set was reported by Mulge *et al* (2012)

Heterosis in positive direction for primary branches plant^{1}, leaf length and leaf width is desirable In the present study, high heterotic effects for primary branches plant^{1} over mid parent, better parent and standard checks was observed in the cross LE 20 x Manulekshmi This result is in line with the findings of Virupannavar (2009), Singh and Mishra (2010) and Narasimhamurthy and Gowda (2013) The magnitude of heterosis over mid and better parent for leaf length was high in LE 3 x Anagha while, the cross LE 13 x Manulekshmi exhibited high standard heterosis over both the checks for the same trait The cross LE 20 x Manulekshmi showed higher magnitude of relative heterosis, heterobeltiosis and standard heterosis for leaf width

Number of flowers cluster^{1} and inflorescence plant^{1} also contributes to total yield plant^{1}, hence positive heterosis for the trait is preferred High relative heterosis for flowers cluster^{1} was exhibited by the cross LE 20 x Anagha while heterobeltiosis by LE 16 x Anagha and LE 20 x Anagha The hybrid LE 20 x Vellayani Vijai showed higher magnitude of standard heterosis over both the checks for the same trait In earlier studies of Sajjan (2002), Patil (2003) and Gul *et al* (2010) similar results have been mapped Significant heterosis for inflorescence plant^{1} in positive direction over both mid and better parent was exhibited by LE 20 x Manulekshmi Aswathappa (1981) and Dhaliwal *et al* (2000) reported good level of heterosis for inflorescence plant^{1}

Maximum heterobeltiosis and standard heterosis over both the checks for fruit set % was recorded in the cross LE 16 x Manulekshmi, which is in agreement with the earlier findings of Babu (1978), Gowda (1981), Konstantinova and Molle (1984) and Singh *et al* (2012) for per cent fruit set The cross LE 16 x Manulekshmi revealed high heterosis over mid and better parent while the cross LE 19 x Anagha registered the desirable standard heterosis over both the checks for pollen viability % The results are in conformity with the findings of Popova (1977) that higher biological quality of pollen of heterotic plants is the reason for higher fruit set which substantiate the higher adaptability of hybrids to unfavourable conditions

Positive and significant relative heterosis and heterobeltiosis for fruits cluster ^{1} was observed in LE 26 x Anagha and the same cross followed by LE 20 x Vellayani Vijai and LE 13 x Vellayani Vijai recorded significant standard heterosis over both the checks in desirable positive direction for fruits cluster ^{1} High level of heterosis for fruits cluster ^{1} was also reported by Sajjan (2001), Kulkarni (2003), Duhan *et al* (2005 a), Virupannavar (2009) and Singh (2010)

Number of fruits plant ^{1} is directly linked with the ultimate yield plant ^{1} This is the most important character which directly contributes to total plant yield The cross LE 16 x Anagha exhibited significant desirable heterosis over mid parent, better parent and standard checks for fruits plant ^{1} Significant and desirable heterosis for fruits plant ^{1} was in conformity with the reports of Souza *et al* (2012), Droka *et al* (2013), Garg *et al* (2013), Solieman *et al* (2013), Basavaraj (2014) and Hasan *et al* (2014)

Fruit length, fruit girth and fruit weight are the important yield attributing characters where positive and significant heterosis is desirable In the present study, the hybrid LE 26 x Anagha had significant positive relative heterosis and heterobeltiosis for fruit length whereas, the hybrid LE 13 x Vellayani Vijai alone registered significant and positive standard heterosis over check Lekshmi for fruit length Gul *et al* (2010), Chattopadhyay and Paul (2012), Islam *et al* (2012), Yadav *et al* (2013) and Shankar *et al* (2014) reported positive and significant heterosis for fruit length The hybrid LE 19 x Manulekshmi recorded maximum heterosis over mid parent and better parent for fruit girth and fruit weight None of the hybrids showed significant and positive standard heterosis over both the checks for fruit girth and fruit weight Similarly, high magnitude of heterosis for fruit weight was also reported by several workers, Asati *et al* (2007), Kumar *et al* (2009), Gul *et al* (2010), Ahmad *et al* (2011), Kumari and Sharma (2011), Islam *et al* (2012), Souza *et al* (2012), Shalaby (2013), Solieman *et al* (2013), Marbhal *et al* (2016)

Fruit yield plant ^{1} is the ultimate and most important trait However yield of a crop cannot be taken as a single entity, since it is associated with many yield attributing characters In tomato, the main yield contributing characters are fruits plant^{1} (Nandpuri, 1997), primary branches plant^{1}, plant height and fruit weight (Chadha and Kumar, 2001) Similar reports were made by Padma *et al* (2002), Pandey *et al* (2006) and Natarajan (2008)

High magnitude of relative heterosis was shown by LE 19 x Manulekshmi, heterobeltiosis by LE 13 x Anagha and standard heterosis over both the checks by the cross LE 16 x Anagha for yield plant^{1} This was in conformity with the reports of Asati *et al* (2007), Singh *et al* (2008), Kumar *et al* (2009), Dhaliwal and Cheema (2011), Islam *et al* (2012), Garg *et al* (2013), Yadav *et al* (2013), Agarwal *et al* (2014) and Shankar *et al* (2014) The hybrid LE 13 x Manulekshmi recorded the significant positive heterosis over mid parent, better parent and both the checks for yield plot^{1} The results for yield plot^{1} were on par with the findings of Asati *et al* (2007), Hannan *et al* (2007), Roy (2007), Rahmani *et al* (2010) and Ahmad *et al* (2011)

Tomato ranks first among the processed vegetables in the world High total soluble solids (TSS), lycopene and ascorbic acid are the major factors considered for the preparation of processed products One per cent increase in TSS content of fruits results in 20 per cent increase in recovery of processed product (Berry and Uddin, 1991)

Higher magnitude of relative heterosis, heterobeltiosis and standard heterosis over both the checks for TSS was recorded in the cross LE 16 x Anagha Positive and significant heterosis for TSS was also reported by Ashwini (2005), Shende *et al* (2012) and Brajendra *et al* (2013) The same cross *ie*, LE 16 x Anagha recorded maximum heterosis over mid and better parent for lycopene content and similar result for the trait was reported by Narasimhamurthy and Gowda (2013) The hybrid LE 19 x Anagha exhibited high heterotic effects over mid, better and standard checks for ascorbic acid content Similar reports have been presented by Duhan *et al* (2005 b)

5.3 COMBINING ABILITY ANALYSIS

Estimation of combining ability effects is done to assess the relative ability of a genotype to transmit its desirable performance to its crosses. Combining ability analysis provides information about the components of genetic variance involved in the expression of various polygenic characters and thus help in the selection of desirable parents for hybridisation and also in deciding the breeding procedure for the genetic improvement of such characters.

5.3.1 General combining ability effects of parents

General combining ability is the average performance of a strain in a series of hybrid combination, which reflects the additive gene effects of parents.

In tomato, the characters *viz.*, plant height, primary branches plant^{1}, leaf length, leaf width, flowers cluster^{1}, inflorescence plant^{1}, fruit set, pollen viability, fruits cluster^{1}, fruits plant^{1}, fruit length, fruit girth, fruit weight, yield plant^{1}, yield plot^{1}, TSS, lycopene and ascorbic acid content are important demanding attention in crop improvement efforts. A parent which transmits genes for the improvement of these characters is regarded as a desirable combiner. Thus, parental strains with significant and positive *gca* effects are desirable combiners. For traits like days to first flowering and days to fruit set, a parent which transmits genes for earliness to its progeny is regarded as a desirable combiner. For traits like height at flowering and node to first inflorescence also a parent which transmits genes for lesser value to its progeny indicates earliness. Thus, parental strains with significant and negative *gca* effects are desirable combiners.

Among the lines, LE 13 and LE 16 both were good general combiners for plant height, inflorescence plant^{1}, fruits plant^{1}, yield plant^{1}, yield plot^{1}, TSS and lycopene. Bhatt *et al.* (2001), Rattan *et al.* (2008), Sekhar *et al.* (2010) and Farzane *et al.* (2012) reported high *gca* effects for fruits plant^{1} and yield plant^{1}. The line LE 12 exhibited significant positive *gca* effects for leaf length and leaf width. High *gca* effects for fruits cluster^{1} and fruit girth was recorded in the line LE 13 whereas the line LE 16 was the best general combiner for the traits like primary branches plant^{1}, days to first flowering, fruit set (%) and pollen viability (%) The preponderance of *gca* effects for days to first flowering, primary branches plant^{1}, fruits cluster^{1} and plant height was reported by Ashwini (2005) and Singh *et al* (2008)

Significant *gca* effects in desirable direction for height at flowering, node to first inflorescence, fruit weight, TSS, lycopene and ascorbic acid content was observed in the line LE 19 Kulkarni (2003), Prashanth (2004), Ashwini (2005) and Raju *et al* (2012) reported significant and positive *gca* effects for both TSS and ascorbic acid The line LE 20 was found to be good general combiner for days to fruit set and flowers cluster^{1} Amin *et al* (2012) reported significant negative *gca* effects for days to fruit set Significant *gca* effects for flowers cluster^{1} was reported by Bhatt *et al* (2001) and Hannan *et al* (2007) Significant positive *gca* effects for fruit length was observed in the line LE 26 The significance of *gca* effects for a number of the characters like plant height, primary branches plant^{1}, inflorescence plant^{1}, fruits cluster^{1}, fruit weight, fruits plant^{1} and yield plant^{1} was reported by Kumar *et al* (2013) Saleem *et al* (2013) and Muttappanavar *et al* (2014)

Among the testers, Anagha was the best general combiner for days to first flowering, days to fruit set, inflorescence plant^{1}, fruit set (%), pollen viability (%), fruits plant^{1}, yield plant^{1} and ascorbic acid content Manulekshmi showed remarkably high *gca* effects for plant height, primary branches plant^{1}, leaf length, leaf width, fruit girth, fruit weight and yield plot^{1} The tester Vellayam Vijai exhibited desirable *gca* effects for fruit length and lycopene content Both the testers Anagha and Vellayam Vijai exhibited significant *gca* effects in desirable direction for height at flowering, node to first inflorescence, flowers cluster^{1}, fruits cluster^{1} and TSS

5.3.2 Specific combining ability effects of hybrids

Specific combining ability indicates the deviation in the performance of specific cross from the performance expected on the basis of general combining ability effects of parents involved in the crosses It is an indication of non additive gene action

The hybrids LE 20 x Manulekshmi, LE 16 x Anagha, LE 13 x Manulekshmi and LE 13 x Vellayam Vijai had high *sca* effects for plant height Significant and positive *sca* effects for primary branches plant^{1} was observed in LE 20 x Manulekshmi and LE 19 x Anagha Significant *sca* effects for plant height and primary branches plant^{1} were in conformity with the reports of Kamalaveer *et al* (2006), Premalekshmi *et al* (2006), Sekhar *et al* (2010) and Shankar *et al* (2013) The *sca* effects were positive and significant for LE 13 x Manulekshmi, LE 3 x Anagha, LE 20 x Manulekshmi and LE 16 x Anagha for leaf length and LE 20 x Manulekshmi and LE 16 x Vellayani Vijai for leaf width

For the characters like days to first flowering, days to fruit set, height at flowering and node to first inflorescence, the hybrids exhibiting negative *sca* effects are the desirable combiners The crosses LE 3 x Anagha, LE 19 x Anagha, LE 12 x Vellayani Vijai, LE 16 x Anagha and LE 26 x Vellayani Vijai exhibited significant negative *sca* effects for days to first flowering whereas, the crosses LE 16 x Vellayani Vijai and LE 12 x Vellayani Vijai had significant *sca* effects in desirable negative direction for days to fruit set which indicated the earliness For height at flowering, the crosses LE 19 x Anagha, LE 26 x Manulekshmi and LE 20 x Vellayani Vijai are the desirable combiners while LE 3 x Vellayani Vijai and LE 16 x Manulekshmi showed significant negative *sca* effects for node to first inflorescence which also indicated the earliness Significant negative *sca* effects for days to first flowering was reported by Premalakshme *et al* (2005) and Rajan (2014)

None of the crosses exhibited significant positive *sca* effects for flowers cluster^{1} For inflorescence plant^{1}, the crosses LE 20 x Manulekshmi, LE 12 x Vellayani Vijai, LE 19 x Manulekshmi, LE 16 x Vellayani Vijai and LE 19 x Anagha were good specific combiners

The *sca* effects were positive and significant for LE 3 x Anagha, LE 26 x Vellayani Vijai LE 16 x Manulekshmi and LE 12 x Manulekshmi for fruit set (%) Superior *sca* effects for fruit set (%) was reported by Sirohi and Gaurav (2008) The crosses LE 26 x Vellayani Vijai, LE 3 x Anagha, LE 19 x Anagha, LE 12 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Vellayani Vijai were the best combiners for pollen viability (%)

The crosses LE 26 x Anagha followed by LE 20 x Vellayani Vijai, LE 3 x Manulekshmi, LE 13 x Vellayani Vijai, LE 19 x Manulekshmi and LE 12 x Manulekshmi were the best combiners for fruits cluster^{-1} by recording significant positive *sca* effects for the trait The crosses exhibiting significant and positive *sca* effects for fruits plant^{-1} were LE 16 x Anagha, LE 20 x Manulekshmi, LE 19 x Manulekshmi, LE 13 x Anagha, LE 20 x Vellayani Vijai, LE 3 x Vellayani Vijai, LE 3 x Manulekshmi and LE 19 x Anagha Ashwini (2005), Prashant (2004), Mondal *et al* (2009), Virupannavar (2009), Singh (2010) and Kumar *et al* (2013) also reported significant *sca* effects for both fruits cluster^{-1} and fruits plant^{-1}

The crosses LE 26 x Anagha followed by LE 16 x Manulekshmi, LE 3 x Anagha, LE 13 x Vellayani Vijai, LE 19 x Manulekshmi and LE 20 x Vellayani Vijai had high *sca* effects for fruit length High remarkable *sca* effects for fruit girth and fruit weight was recorded in the crosses LE 16 x Manulekshmi, LE 19 x Manulekshmi and LE 13 x Manulekshmi The cross LE 26 x Anagha also exhibited desirable *sca* for fruit weight The maximum *sca* effects for fruit length, fruit girth and fruit weight were in conformity with the reports of Singh *et al* (2005), Raju *et al* (2012), Saleem *et al* (2013) and Aisyah *et al* (2016)

The hybrid LE 19 x Manulekshmi followed by LE 16 x Anagha, LE 20 x Manulekshmi, LE 26 x Vellayani Vijai and LE 20 x Vellayani Vijai were the best combiners for yield plant^{-1} by recording high *sca* effects for the trait Significant and positive *sca* effects for yield plot^{-1} was exhibited by LE 20 x Manulekshmi, LE 19 x Manulekshmi, LE 26 x Vellayani Vijai, LE 12 x Anagha, LE 19 x Anagha and LE 16 x Vellayani Vijai Similar findings for yield plant^{1} was reported by Shende *et al* (2012), Souza *et al* (2012), Shankar *et al* (2013), Gabry *et al* (2014), Muttappanavar *et al* (2014), Basavaraj *et al* (2015), Chaudhari *et al* (2015) and Pandiarana *et al* (2015)

The crosses LE 16 x Anagha, LE 13 x Vellayani Vijai, LE 12 x Manulekshmi, LE 20 x Vellayani Vijai, LE 19 x Manulekshmi, LE 3 x Anagha and LE 3 x Manulekshmi had significant *sca* effects for TSS The desirable specific combiners for lycopene content were LE 16 x Anagha, LE 13 x Vellayani Vijai, LE 26 x Vellayani Vijai, LE 12 x Manulekshmi, LE 3 x Manulekshmi and LE 20 x Manulekshmi High *sca* effects for ascorbic acid was observed in the crosses LE 26 x Manulekshmi, LE 19 x Anagha, LE 16 x Vellayani Vijai, LE 20 x Manulekshmi, LE 3 x Vellayani Vijai and LE 12 x Vellayani Vijai Joshi and Kohli (2006), Mondal *et al* (2009), Kansouh and Zakher (2011) and Kumar *et al* (2013) reported higher *sca* effects for TSS, lycopene and ascorbic acid content in tomato

5 4 GENE ACTION

Analysis of variance for combining ability gives an estimate of the variances due to lines, testers and line x tester which imply the type of gene action responsible for the variation in each character Significant mean sum of squares due to lines and testers indicate that additive gene action is operative while significant mean sum of squares due to line x tester shows non additive gene action (dominance and epistatic) is controlling the character

The analysis of variance for combining ability revealed that the ratio of *gca/ sca* was more than unity for majority of the characters which clearly indicated the influence of additive gene action for the traits like plant height, height at flowering, leaf width, days to first flowering, days to fruit set, flowers cluster^{1}, inflorescence plant^{1}, fruits cluster^{1}, fruits plant^{1}, fruit length, fruit girth, fruit weight, yield plant^{1}, yield plot^{1}, TSS and lycopene content Gaikwad *et al* (2002) and Ashwini (2005) reported additive gene action for plant height

Kulkarni (1999), Roopa *et al* (2001) and Ashwini (2005) revealed the predominance of additivity for fruits cluster ^{1} and Kulkarni (2003) and Ashwini (2005) reported the significance of additivity for inflorescence plant ^{1} and fruits plant ^{1} Involvement of additive gene actions for fruit weight was reported by Pranshant (2004) and Sharma *et al* (2006) Roopa *et al* (2001), Sharma *et al* (2006) and Pandey *et al* (2006) revealed the influence of additive gene action for yield plant ^{1} Preponderance of additive gene action for TSS was in conformity with the reports of Kulkarni (2003), Pranshant (2004) and Ashwini (2005)

In the present study, non additive gene action played a prominent role in controlling the characters like node to first inflorescence, primary branches plant ^{1}, leaf length, fruit set (%), pollen viability (%) and ascorbic acid Bhatt *et al* (2004) reported the importance of non additive gene action for ascorbic acid in tomato

5 5 INCIDENCE OF BACTERIAL WILT

Among the seven lines, LE 16 was found moderately resistant to bacterial wilt with a disease incidence of 26 66% while rest of the lines were in the range of moderately susceptible to susceptible All the testers were found resistant Among the hybrids, LE 13 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Manulekshmi were found resistant to bacterial wilt with a disease incidence of 11 67%, 18 33% and 13 33% respectively while, rest of the hybrids ranged between moderately resistant to susceptible Both the checks Indam 9802 and Lekshmi were found susceptible to bacterial wilt disease with incidence of 71 67% and 63 33% respectively

Heterosis (%) for bacterial wilt incidence revealed that the cross LE 13 x Manulekshmi exhibited highest significant negative heterosis over mid parent (-70 21%) better parent (-81 58%) and standard checks (-83 72% and -81 58% respectively) which was followed by LE 20 x Manulekshmi over mid parent (-61 90%), better parent (-75 76%) and standard checks (-81 40% and -78 95% respectively) Significant negative standard heterosis over both the checks was exhibited by most of the crosses Virupannavar *et al* (2010) also estimated the heterosis for bacterial wilt resistance in tomato

Among the lines, significant negative *gca* effect was recorded in LE 13 (-13 97) and LE 16 (-10 63) Among the testers, Manulekshmi (-10 16) recorded negative and significant *gca* effect for bacterial wilt incidence Among the crosses LE 20 x Manulekshmi (-14 29), LE 19 x Anagha (-12 54), LE 12 x Anagha (-11 43), LE 16 x Vellayani Vijai (-9 84) and LE 26 x Anagha (-8 10) had significant negative *sca* effect in desirable direction for the incidence of bacterial wilt

Components of genetic variance for the incidence of bacterial wilt revealed the predominance of non additive (dominance) gene action as *gca / sca* ratio was less than unity Patil (1998), Venkataramana (2001), Swaminathan and Srinivasan (1972), Gopinath and Madalageri (1986) reported that bacterial wilt resistance was controlled by single dominant gene (non additive)

Summary

6. SUMMARY

The present investigation on "Development of hybrids with bacterial wilt resistance in tomato (*Solanum lycopersicum* L.)" was conducted at the Department of Olericulture, College of Agriculture, Vellayani, during 2015-2016 with the objective of developing F_1 hybrids of tomato with high yield, quality and resistance to bacterial wilt.

The experiment was carried out in two parts. In part I, twenty one F_1 hybrids were developed by crossing seven lines and three testers in a line x tester fashion in a crossing block. The seven lines consisted of high yielding genotypes identified and maintained in the department of Olericulture, *viz.*, LE 3, LE 12, LE 13, LE 16, LE 19, LE 20 and LE 26 and the testers were the bacterial wilt resistant varieties released from KAU *viz.*, Anagha, Manulekshmi and Vellayani Vijai. In part II, hybrids were evaluated along with their parents and checks (Indam 9802 and Lekshmi) during September 2015– January 2016 in a Randomized Block Design with 33 treatments and three replications. They were evaluated for following traits *viz.*, plant height (cm), height at flowering (cm), node to first inflorescence, primary branches plant^{-1}, leaf length (cm), leaf width (cm), days to first flowering, days to fruit set, flowers cluster^{-1}, inflorescence plant^{-1}, fruit set %, pollen viability %, fruits cluster^{-1}, fruits plant^{-1}, fruit length (cm), fruit girth (cm), fruit weight (g), yield plant^{-1}(g), yield plot^{-1} (kg), TSS (%), lycopene (mg/ 100 g), ascorbic acid (mg/ 100 g) and the incidence of bacterial wilt under field conditions.

Analysis of variance revealed significant difference among the treatments for all the traits studied. The lines were significantly different for plant height, height at flowering, primary branches plant^{-1}, days to fruit set, flowers cluster^{-1}, inflorescence plant^{-1} fruits plant^{-1}, fruit length, fruit girth, fruit weight, yield plant^{-1} and yield plot^{-1} while the testers were significantly different for height at flowering, leaf width, days to first flowering, flowers cluster^{-1}, fruits cluster^{-1}, fruit length, fruit girth, fruit weight, TSS, lycopene and bacterial wilt incidence (%)

Line x Tester interaction was significant for all the characters except flowers cluster^{-1}.

Based on mean performance and *gca* effect, superior line identified was LE 16 which recorded the highest plant height, primary branches plant^{-1}, early days to fruit set, yield plot^{-1} and bacterial wilt resistance. Superior lines for other characters were LE 12 for leaf length and days to first flowering, LE 12 and LE 13 for leaf width, LE 26 for flowers cluster^{-1}, LE 13 and LE 20 for fruits cluster^{-1}, LE 13 and LE 16 for inflorescence plant^{-1}, fruits plant^{-1} and yield plant^{-1} and LE 19 and LE 26 for fruit length and ascorbic acid. The lines LE 13 and LE 19 were the best for fruit girth and fruit weight. The lines LE 20, LE 13 and LE 16 were superior for TSS while, LE 19, LE 26 and LE 16 recorded superiority for lycopene.

Among the testers, Anagha recorded superiority for fruits plant^{-1} and yield plant^{-1}. Vellayani Vijai was superior for flowers cluster^{-1}, fruits cluster^{-1}, fruit length, TSS and lycopene while, Manulekshmi was found superior for plant height, primary branches plant^{-1}, fruit girth, fruit weight and bacterial wilt resistance.

Based on mean performance, *sca* effect and standard heterosis, superior hybrids identified were, LE 13 x Manulekshmi and LE 20 x Manulekshmi for plant height and leaf length whereas, LE 3 x Vellayani Vijai for node to first inflorescence. The crosses LE 20 x Manulekshmi and LE 16 x Vellayani Vijai recorded the maximum leaf width whereas, LE 20 x Manulekshmi recorded the superiority for primary branches plant^{-1}. The cross LE 19 x Anagha recorded the lowest height at flowering whereas, LE 16 x Vellayani Vijai recorded the early days to fruit set. For flowers cluster^{-1}, superior hybrids identified were, LE 20 x Vellayani Vijai, LE 26 x Anagha and LE 12 x Vellayani Vijai based on mean performance and standard heterosis. The crosses LE 16 x Manulekshmi and LE 3 x Anagha recorded the best for fruit set % while, LE 19 x Anagha and LE 16 x Manulekshmi for pollen viability %. The crosses LE 26 x Anagha, LE 20 x Vellayani Vijai and LE 13 x Vellayani Vijai for fruits cluster^{-1} (Plate 9) while, LE

16 x Anagha for fruits plant^{1} (Plate 10) The hybrid LE 13 x Vellayani Vijai was superior for fruit length None of the hybrids recorded superior standard heterosis for fruit girth and fruit weight However, the hybrids LE 13 x Manulekshmi, LE 19 x Manulekshmi and LE 16 x Manulekshmi were the best for fruit girth and LE 19 x Manulekshmi for fruit weight based on mean performance and *sca* effect The hybrid LE 16 x Anagha was outstanding for yield plant^{1} (Plate 10) The hybrids LE 20 x Manulekshmi and LE 19 x Manulekshmi were found to be the most promising for yield plot^{1} based on *sca* effect and standard heterosis while, LE 13 x Manulekshmi followed by LE 13 x Anagha were found to be superior for the same trait based on mean performance and standard heterosis The hybrids LE 16 x Anagha, LE 13 x Vellayani Vijai and LE 20 x Vellayani Vijai were identified as the best for TSS based on mean performance, *sca* effect and standard heterosis The crosses LE 16 x Anagha, LE 13 x Vellayani Vijai and LE 26 x Vellayani Vijai were the best for lycopene based on mean performance and *sca* effect The cross LE 19 x Anagha was found superior for ascorbic acid followed by LE 26 x Manulekshmi and LE 20 x Manulekshmi

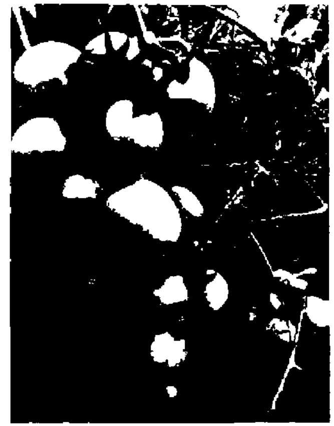
The hybrids LE 13 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Manulekshmi were resistant to bacterial wilt based on the mean performance and standard heterosis Considering the mean performance, *sca* effect and standard heterosis over both the checks, the cross LE 20 x Manulekshmi was found promising for bacterial wilt resistance The $\sigma^2 gca$ and $\sigma^2 sca$ ratio indicated preponderance of non additive gene action for bacterial wilt incidence (%)

Based on the mean performance, specific combining ability and standard heterosis, the hybrid LE 16 x Anagha was the best for fruits plant^{1}, yield plant^{1} and TSS The hybrid LE 20 x Manulekshmi was found promising for bacterial wilt resistance Considering both yield plot^{1} and bacterial wilt resistance, LE 13 x Manulekshmi was adjudjed the best

Plate 9 Promising hybrids for fruits cluster [1]

LE 26 x Anagha

LE 20 x Vellayani Vijai



LE 13 x Vellayani Vijai

Plate 10 Promising hybrid for fruits plant^{-1} and yield plant^{-1}

I F 16 x Anagha

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DEVELOPMENT OF HYBRIDS WITH BACTERIAL WILT RESISTANCE IN TOMATO (*Solanum lycopersicum* L.)

by

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ABSTRACT

The project entitled "Development of hybrids with bacterial wilt resistance in tomato (*Solanum lycopersicum* L)" was carried out at the Department of Olericulture, College of Agriculture, Vellayani, during 2015-2016 to develop F_1 hybrids of tomato with high yield, quality and resistance to bacterial wilt

The experiment was carried out in two parts In part I, twenty one F_1 hybrids were developed by crossing seven lines and three testers in a line x tester fashion in a crossing block The seven lines consisted of high yielding genotypes identified and maintained in the department of Olericulture, *viz*, LE 3, LE 12, LE 13, LE 16, LE 19, LE 20 and LE 26 and the three testers were the bacterial wilt resistant varieties *viz*, Anagha, Manulekshmi and Vellayani Vijai In part II, hybrids were evaluated along with their parents and checks (Indam 9802 and Lekshmi) during September 2015 – January 2016 in a Randomized Block Design with 33 treatments and three replications

Analysis of variance revealed significant difference among the treatments for all the traits Among the hybrids, LE 13 x Manulekshmi recorded the highest plant height (110 44 cm), LE 20 x Manulekshmi exhibited the highest primary branches plant^{-1} (12 55) The hybrid LE 16 x Anagha recorded early flowering (24 33) highest fruits plant^{-1} (110 66), yield plant^{-1} (2191 44 g), TSS (4 91%) and lycopene (13 03 mg/ 100 g) The cross LE 26 x Anagha had the highest fruits cluster^{-1} (6 33) and LE 13 x Vellayani Vijai recorded the highest fruit length (5 41 cm) The cross LE 13 x Manulekshmi was the best for fruit girth (15 07 cm) and yield plot^{-1} (31 42 kg), LE 19 x Manulekshmi for fruit weight (62 85 g) and LE 19 x Anagha for ascorbic acid (34 30 mg/ 100 g)

The estimates of general combining ability (*gca*) effects revealed that among the lines, LE 16, LE 13 and LE 20 were the best general combiners for fruits plant^{-1} while, LE 13 and LE 19 for fruit length, fruit girth and fruit weight The lines LE 16 and LE 13 exhibited good *gca* for yield plant^{-1} and yield plot^{-1} while, LE 19, LE 13 and LE 16 for TSS and lycopene For ascorbic acid, LE 19, LE 20 and LE 26 were the best general combiners Among the testers, Anagha

exhibited good *gca* effects for fruits plant^{1}, yield plant^{1} and ascorbic acid Manulekshmi was good general combiner for fruit girth, fruit weight and yield plot^{1} while, Vellayani Vijai exhibited good ***gca*** for fruit length, TSS and lycopene content The estimates of specific combining ability effects revealed that the hybrid LE 16 x Anagha was the best for fruits plant^{1}, yield plant^{1}, TSS and lycopene Significant positive *sca* effect for fruits plant^{1}, yield plant^{1}, yield plot^{1}, lycopene and ascorbic acid was recorded in the cross LE 20 x Manulekshmi while, LE 26 x Manulekshmi followed by LE 19 x Anagha recorded high *sca* for ascorbic acid The σ^2*gca* and σ^2*sca* ratio indicated preponderance of non additive gene action for bacterial wilt incidence (%)

Relative heterosis, heterobeltiosis and standard heterosis over checks were worked out for all yield and quality characters The highest standard heterosis for fruits plant^{1} (320 20% and 203 67% respectively), yield plant^{1} (27 32% and 14 92% respectively) and TSS (16 89% and 13 91% respectively) was recorded in LE 16 x Anagha Significant and positive standard heterosis for yield plot^{1} was exhibited by LE 13 x Manulekshmi (220 03% and 125 01% respectively) while, LE 19 x Anagha for ascorbic acid content (41 06 and 24 24% respectively)

Based on bacterial wilt incidence (%), LE 13 x Manulekshmi, LE 16 x Manulekshmi and LE 20 x Manulekshmi were resistant with a disease incidence of 11 67%, 18 33% and 13 33% respectively Other hybrids were in the range of moderately resistant to susceptible, while both the checks (Indam 9802 and Lekshmi) were susceptible with a disease incidence of 71 67% and 63 33% respectively

Based on the mean performance, specific combining ability and standard heterosis, the hybrid LE 16 x Anagha was the best for fruits plant^{1}, yield plant^{1} and TSS The hybrid LE 20 x Manulekshmi was found promising for bacterial wilt resistance Considering both yield plot^{1} and bacterial wilt resistance, LE 13 x Manulekshmi was adjudjed the best