HETEROSIS IN BACTERIAL WILT RESISTANT TOMATO

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Heterosis in bacterial wilt resistant tomato"** 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 to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
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CERTIFICATE

Certified that this thesis, entitled "**Heterosis in bacterial wilt resistant tomato**" is a record of research work done independently by **Miss. P.R.Rani,** 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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In memory of my beloved

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INTRODUCTION

INTRODUCTION

Tomato is one of the most important vegetable crops grown throughout the world for it's edible fruits. It is important both for fresh market and the processed food industries. It is an important source of minerals and vitamins. The main tomato growing countries in the world are USA, Russia, Netherlands, China, Italy, Egypt, Turkey and India, with a global production of 88.22 million tonnes. In India, tomato is grown in almost all parts of the country covering about 4.18 lakh hectares with an annual production of 62.18 lakh metric tonnes during 1997-98 (Negi and Mitra, 1999). The area under tomato cultivation in Kerala is meagre due to the incidence of bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.* The warm humid tropical climate and acidic soil conditions in Kerala favour the incidence of bacterial wilt. Attempts on disease management and control have not made substantial impact, necessitating the development of resistant lines to this pathogen.

Resistance breeding taken up in the Kerala Agricultural University, Vellanikkara has resulted in the identification of resistant genotypes like Sakthi, Mukthi, LE-415, LE-214, LE-421, LE-470 and LE-474. But the problem with these genotypes is that their yield level is low.

F_1 hybrids are found to be high yielding. So production of bacterial wilt resistant F_1 hybrids will be beneficial for getting higher yields in tomato in wilt sick areas. But studies on genetics of bacterial wilt resistance have shown that the source of resistance available are either recessive or partially dominant in nature. So for getting an F_1 hybrid resistant to bacterial wilt, the only way out is crossing resistant parents. Eventhough high yielding F_1 hybrids are available in the market, they cannot be cultivated in many parts of Kerala due to their susceptibility to bacterial wilt. To achieve the twin needs of high yield and resistance to bacterial wilt in tomato, the present study was undertaken with the following specific objectives:

1) To develop bacterial wilt resistant F_1 hybrids in tomato.
2) To estimate heterosis in terms of standard heterosis, relative heterosis and heterobeltiosis.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The review of literature on causal organism of bacterial wilt of tomato, it's symptomatology, sources of resistance, combining ability and heterosis of bacterial wilt resistant tomato is briefly dealt in this chapter.

2.1 Pathogen

Bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.* is one of the most destructive plant diseases in the warm humid regions of the world. The pathogen is known to attack a wide range of host plants. The disease was first reported from Italy in 1882 (Walker, 1952).

Almost one hundred years elapsed since Erwin F. Smith published the first description of *Pseudomonas solanacearum* E.F. Smith, that causes a wilt disease of solanaceous plants (Smith, 1896). In India, the first report on bacterial wilt of tomato was given by Hedayathullah and Saha (1941).

Pseudomonas solanacearum is a complex pathogen differing in host range and pathogenecity. Geographical variation occurs in the organism. Based on host range, pathogenicity and colony appearance on TTC medium, Buddenhagen *et al.* (1962) classified *Pseudomonas solanacearum* isolates from a wide range of hosts in Central and South America into 3 races i.e., race 1, race 2 and race 3.

1. Race 1 (Solanaceous strain) - Wide host range, distributed throughout the lowlands of tropics and subtropics. They attack tomato, tobacco and many solanaceous and other weeds.
2. Race 2 (Musaceous strain) - Restricted to *Musa* and a few perennial hosts initially limited to American tropics and spreading to Asia.
3. Race 3 (Potato strain) - Restricted to potato and few alternate hosts in tropics and subtropics.

Hayward (1964) took a classical bacteriological approach to classify *Pseudomonas solanacearum* into biotypes or biochemical types based on their ability to oxidise various carbon sources and on other bacteriological reactions. Hayward called them biotype I, biotype II, biotype III and biotype IV.

1. Biotype I - does not oxidise disaccharides and sugar alcohols
2. Biotype II - Oxidises only disaccharides
3. Biotype III - Oxidises both disaccharides and alcohols
4. Biotype IV - Oxidises only hexahydric alcohols

In this, biotype II was potato race of Buddenhagen. No such generalisation could be made in other cases. Later two new races have been proposed one from ginger ornamental as race 4 (Aragaki and Quinon, 1965) and one from mulberry as race 5 (He *et al.*, 1983).

Addy *et al.* (1980) in a study of thirty tomato isolates of *P. solanacearum* from Assam and Orissa concluded that all isolates belonged to race 1.

Survival of *Pseudomonas solanacearum* in the rhizosphere has been documented by Granada and Sequeira (1983) who reported that the bacterium invades the roots of presumed non-hosts such as bean and maize. Long term survival was associated with localised or systemic infection of plants that did not express symptoms of bacterial wilt.

He *et al.* (1983) obtained a series of isolates from China which oxidised mannitol but not sorbitol or dulcitol, and these were designated as biovar V.

Cook and Sequeira (1988) used RFLP technique to study the relationship between biotypes I to IV of Hayward and races 1, 2 and 3 of Buddenhagen *et al.* The main conclusion was that *P. solanacearum* could be divided into two distinct groups. Group I includes strains of race 1, biovars III and

IV and Group II includes strains of race 1 biovar I and races 2 and 3. In addition, they were able to distinguish strains of the pathogen both by race and biotype. For example, race 3 strains produced a very distinct gel pattern which suggests that race 3 is a homogeneous group. Similarly race 2 strains fell into three distinct groups. These three groups represented strains from different geographical origin. In contrast, race 1 strains exhibited highly variable RFLP patterns suggesting that race 1 is highly heterogeneous.

Kumar *et al.* (1993) differentiated twelve isolates of *P. solanacearum* from solanaceous hosts into biovars following Haywards classification. All the isolates from tomato, potato, aubergine and bell pepper (Capsicum) were identified as biovar III or a subtype in biovar III. All the isolates utilized glucose, fructose, sucrose, galactose and glycerol.

Hayward (1994) differentiated biovar III of *P. solanacearum* from biovar V of *P. solanacearum* based on it's ability to utilise the sugar alcohols, sorbitol and dulcitol.

Yabuuchi *et al.* (1992) transferred several species of the rRNA homology group II *Pseudomonas* including. *P. solanacearum* to the genus *Burkholderia*. Later work based on sequencing of 16sd rRNA genes and polyphasic taxonomy led to the proposal of genus *Ralstonia* and the pathogen has been renamed as *Ralstonia solanacearum* (Yabuuchi *et al.*, 1995).

From the studies conducted at All India Co-ordinated Vegetable Improvement Project, Vellanikkara on the identification of race and biovar of *Ralstonia solanacearum* affecting solanaceous vegetables, it was found that *R. solanacearum* affecting tomato belonging to race 1 and biovar 3 and 5 (Kalloo, 1999).

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2.2 Symptomatology

Generally, the first expression of the disease is wilting of the lower leaves of the plants (Walker, 1952). This led to the entire wilting of the plants. Dwarfing or stunting of the plants may also occur.

The pathogen enters through the root system and it was believed that a wound is necessary for the entry (Walker, 1952; Kelman, 1953; Chupp and Sherf, 1960). Hildebrant (1950) reported entry of the bacterium through natural opening of the plant. The pathogen enters into the uninjured roots also (Libman *et al.*, 1964). Bacteria can enter at the points of origin of secondary roots. The roots and the lower parts of the stem show a browning of vascular bundles and a water soaked appearance in the root (Chupp and Sherf, 1960).

Eventually dark brown to black areas develop due to decay of root systems and the whole plant dies off. A very distinct and characteristic indication of bacterial wilt is the appearance of bacterial ooze from the injured vascular regions (Ashrafuzzaman and Islam, 1975).

Breakdown of plant tissues by pathogen is attributed to the cellulose and polygalacturonase enzyme produced by the pathogen (Hussain and Kelman, 1957). Continued tissue decay and plugging finally result in the death of the plant.

Following entry of the pathogen into the host plant, visible symptoms occur within 2 to 8 days (Kelman, 1953; Chupp and Sherf, 1960). The pathogen first enters into the intercellular spaces of cortex. From there, it moves to pith and xylem vessels. Wilting of the plants is due to vascular plugging (Walker, 1952).

Kelman (1954) noted that virulence might be explained, atleast in part by the quantitative differences in EPS (extra cellular polysaccharides). The bacterium also produces IAA which can initiate tylose formation and increases cell wall plasticity. Ethylene production is also associated with it.

Allen *et al.* (1993) have shown that total galacturonase activity of the bacteria increases in the presence of the plant but that this induction involves mostly two additional PGs, Peh B and Peh C.

There is no cytological evidence for how the bacterium reaches the vascular system. It is assumed that the bacterium has to digest its way through the primary wall of the weakened cortical cells as well as of the tracheary elements, where it is exposed between the spiral thickenings (Sequeira, 1993).

2.3 Sources of resistance

In field trials carried out at North Carolina in USA, cultivars Louisiana pink and T-414 from Puerto Rico showed good resistance to bacterial wilt (Schaub and Baver, 1944).

A further source of resistance was reported in *Lycopersicon pimpinellifolium* (PI 127805A) which had partial dominance at seedling stage and the resistance was controlled by recessive genes (Abeygunawardena and Siriwardena, 1963). The expression of the resistance in a variety is a function of the age of the plant and changes in temperature (Acosta *et al.*, 1964).

In an experiment conducted by Henderson and Jenkins (1972) to evaluate resistance in several genotypes, they found that genotypes such as Venus, Saturn and Beltsville-3814 to be resistant to bacterial wilt. Similarly from the work carried out by Ahuja and Waite (1974) they observed more than 90% survival of the seedlings in BWN-514, BWN-16, BWN-17 and BWN-7755 against the attack from pathogen *P. solanacearum*.

Mew and Ho (1976) found that the line VC-8-1-2-1 was resistant to *P. solanacearum* regardless of the inoculum density.

Ramachandran *et al.* (1980) evaluated 36 tomato lines for their resistance to bacterial wilt in Kerala. They observed resistance in La-Bonita and CL-132 d-0-1-19GS cultivars.

Celine (1981) reported field tolerance in the line CL 32 d-0-1-19GS.

Tikoo *et al.* (1983) reported the presence of two independent gene systems for wilt resistance. The resistance was governed by multiple recessive genes in CRA66 Sel A from Hawaii and by single dominant gene in 663-12-3 from Taiwan. Sreelathakumari (1983) reported a complimentary and hypostatic type of digenic recessive gene system for wilt resistance.

Goth *et al.* (1983) found wilt resistance in cultivar Venus and the line CL-32d-0-1-19GS from Taiwan and was broken down when *Meloidogyne incognita* larvae were added at the rate of 100/10 cm pot at the time of inoculation with bacteria. He also suggested that nematode should be considered as a factor in the development of bacterial wilt resistant lines.

Bosch *et al.* (1985) reported back cross progeny of the cultivar Rodade showed the resistance of 72 to 100 per cent. Narayanankutty (1985) reported that out of four non-segregating lines (Saturn, LE 79, Pusa Ruby and Pusa Ruby x LE 79 F_1) and two segregating lines (Pusa Ruby x LE 79 F_2, Saturn x LE 79 F_2) evaluated, the F_2 hybrids of Saturn x LE 79 were resistant. In a repeated trial, F_3s were evaluated along with the F_2s and non segregating populations (Saturn x LE 79). Resistance was observed in Saturn x LE 79 F_3 and Saturn x LE 79 F_2.

Moffett (1986) reported resistance in cultivars Scorpio, Redlander and Redlands Summer taste. Rajan and Peter (1986) reported a monogenic incompletely dominant gene action in the resistant line LE-79.

Hanudin (1987) reported resistance in cultivars Intan, Ratna, CI 32-6-125-d-O, AV 22 and AV 15. Venus, Bonset, Gerldton were moderately resistant to

P. solanacearum. Nirmaladevi (1987) reported that resistance to bacterial wilt in CRA 66 Sel A was under polygenic control.

Girard *et al.* (1988) reported satisfactory source of resistance in cultivars MST 32-1, MST 21-23 and King-Kong F_1 from Taiwan and Caraibo from France.

Denoyes *et al.* (1989) evaluated 25 varieties for bacterial wilt resistance and among them 15 were found to be resistant including three hybrids. Four varieties were moderately resistant and six varieties were susceptible.

Sathyanarayana (1992) conducted studies on bacterial wilt resistant tomato for processing and yield. It was found that the hybrids BWR-15 x 1614, BWR-15 x 1032-1 and BWR-5 x 674 showed high resistance to bacterial wilt.

Anand *et al.* (1992) reported dominant gene action in the F_1s of BWR-1, BWR-5, 1661, 15 SB and 1836 and incomplete dominance in the F_1s of 1881 and Sonali for resistance to bacterial wilt.

Peter *et al.* (1992) reported resistance in the lines LE-214, LE-217, LE-79, LE-79 LFG, LE-79 DG and LE 79 SPF.

In an experiment on screening genotypes resistant to *Ralstonia solanacearum* biovar 1 and III Quezado-Soares and Lopes (1994) found that lines Caraibo, C-38D, CL-1131-0-0-13-0-6 and 72-TR-4-4 were resistant to isolates of both biovars, but the level of resistance depended on the virulence of the isolate.

Chellemi *et al.* (1995) evaluated 30 tomato genotypes for resistance to *R. solanacearum* and observed that the disease incidence ranged from zero in Hawaii 7997, GA 219 and GA 1565 to 83 per cent in Solarset.

Williams and Williams (1995) compared *R. solanacearum* resistant tomato cultivars as hybrid parents and it was found that hybrids with Hawaii 7998

as one of their resistant parents transmitted greater resistance than the other resistant parents used.

Grimault *et al.* (1995) reported a monogenic dominant resistance in Hawaii 7996.

Sadhankumar (1995) screened 68 tomato genotypes for resistance to bacterial wilt and found that Sakthi, LE-79-5, LE-415, LE-214, CAV-5 and LE-382-1 were resistant and he also found that the genes responsible for resistance in these lines were recessive.

Vudhivanich and Soontarasingh (1995) in an effort to screen for bacterial wilt resistance of tomato, it was found that among 9 genotypes, CL-5915 and 233D4-2-1-0 showed resistance while CL-184 and CL-5915-206D4-2-5-0 had moderate resistance and Seedathip-2, CI-153, Mishou, Seedathip-502 and VF 134-1-2 were moderately susceptible. In an experiment to find out variable reaction of tomato lines to bacterial wilt at several locations in South East Asia by Hanson *et al.* (1996) they recorded that mean survival (70%) of CRA-66 derived entries was significantly better than the mean of entries with resistance derived from UPCA 1169 or UPCA 1169 plus Venus or Saturn. In a work carried out by In-Mooseong *et al.* (1996) to identify resistance among 31 tomato cultivars, they found that the cultivars Naebyongchangsu, Kwangmying and Seojin were mildly resistant to *Ralstonia solanacearum* and the remaining cultivars were susceptible. Studies on the genetic nature of bacterial wilt resistance in tomato conducted by Mohamed *et al.* (1997) suggested that resistance identified in *L. esculentum* var. *cerasiformae*. LA 1421 was different from that derived from *L. pimpinellifolium*. Results suggested that selection for resistance from crosses between LA 1421 and Cascade was delayed with a high level of fixation of genes.

Chellemi *et al.* (1997) reported for the first time the suppression of bacterial wilt of tomato through the addition of magnesium to soil. He also

suggested that for plants not receiving additional applications of calcium or magnesium, total amino acids in the highly susceptible 'Bonny Best' (1.8 mM) were over twice as concentrations in the xylem fluid of the resistant Hawaii 7997 (0.9 mM). Concentrations of amino acids in the cultivar with intermediate levels of resistance were also intermediate.

Bhattarai *et al.* (1998) observed 100 per cent survival in genotypes such as FMTT-268, FMTT 301, FMTT 115, FMTT 264, Hawaii 7996, Hawaii 7997, Hawaii 7998, F1-80-465, 10-Pink, L 285, BL 31, BL 33, BL 350, CLN 475-BC1-F7-265-4-19, CRA 66, GA 219 and GA 1565. Paul (1998) reported resistance to wilt in tomato cultivars like BT 18, LE 79-5, LE 296, Sakthi and LE 453.

In another study, 141 tomato lines were evaluated for identification of bacterial wilt resistant genotypes. Eight lines namely LE 415, Sakthi, CAV-5, LE 474, LE 457, LE 79-5, LE 447 and LE 435 were found to be resistant to bacterial wilt and the lines LE 214 and LE 470 were identified as moderately resistant (Rajan and Sadhankumar, 1998). Sood *et al.* (1998) reported stable source of resistance in the cultivars BWR-5, BT-18, LE-79-5, BL-312, Hawaii 7997, Hawaii 7998 (USA), BF-Okitsu 101 (Japan), CRA 66 (Guadeloupe), Rodade (Australia), R 3034-3-10 N-UG, TML-46-N-12-Nearly NT (Philippines) and Caraibo (Guadeloupe).

Bose (1999) observed protein bands PPO-1, PPO-4, PPO-7, PPO-10, PPO-11 and PPO-12 in the root and leaf samples of resistant genotypes namely Sakthi, Mukthi, LE-214 and LE-474 which could be considered as a marker for resistance to bacterial wilt in tomato. He also noticed high total phenol and OD phenol content in the resistant lines.

2.4 Combining ability

Combining ability may be general combining ability or specific combining ability. The general combining ability (gca) is the average performance

of a genotype in cross combinations involving a set of other genotypes. Specific combining ability (sca) is the relative performance of a specific cross combination.

Kalloo *et al.* (1973) reported high variance component due to sca than that due to gca for locule number indicating excess of non-additive type gene action.

Nandapuri and Tyagi (1978) reported additive gene action to be controlling pericarp thickness.

The studies of Peter and Rai (1980) revealed the role of both additive and non-additive gene actions in controlling the expression of days to fruit maturity.

Dixit *et al.* (1980) in a study with line x tester analysis involving 15 lines and 3 testers reported highly significant sca variance for pericarp thickness.

Moya *et al.* (1986) have observed additive gene action to be controlling plant height, where as contradicting non-additive gene action for this character has been reported by Sonone *et al.* (1986) and Rajput (1987).

Chandrasekhar and Rao (1989) in a 6 x 6 diallel experiment observed the prominence of additive gene action for fruit firmness.

The genetic analysis of pericarp thickness was studied by Yadav *et al.* (1991) indicated additive gene effects to control the inheritance of this trait.

The variance component due to gca was higher than that due to sca showing preponderance of an additive type of gene action for yield (Srivastava *et al.*, 1993). The predominance of non-additive component for yield was reported by Dod and Kale (1992), Kurien and Peter (1995) and Rai *et al.* (1997).

Sadhankumar (1995) in a combining ability analysis for yield and yield components of tomatoes resistant to bacterial wilt, it was found that the lines CAV-5, LE-386 and LE 296 were good general combiners for fruits/plant.

Chadha *et al.* (1997) in a combining ability analysis for yield and yield components of tomatoes resistant to bacterial wilt, observed the lines Sonali for days to 50 per cent flowering, BWR-5HR, LE-79-5W and EC 129156 for marketable fruits/plant, BT-10, BWR-5HR and EC 191540 for average fruit weight and BT-10 and HR for marketable yield/plant as good general combiners. The crosses EC 129156 x EC 191538 and EC 179906 x EC 191538 were found to be best specific combiners.

Shrivastava (1998) in a diallel analysis observed additive gene effects in both the generations for fruit weight, total soluble solids, reducing sugar content and seed weight. The best specific combiners identified were Pusa Ruby x Money Maker for total soluble sugars and reducing sugars and Pusa Ruby x Pusa Early Dwarf for low seed weight.

2.5 Heterosis

The genetic system of tomato offers several advantages for exploiting heterosis. Heterosis in tomato was first observed by Hedrick and Booth (1908) for higher yield and more fruits.

Though tomato is a highly self-pollinated crop, the high heterosis observed in this crop has been attributed to the fact that tomato was basically a highly outcrossing genus which was later evolved into a self-pollinating one (Rick, 1956).

Khanna and Misra (1977) reported that high heterosis for yield in tomato was due to inter-cluster crossing than intra-cluster crossing, it means higher the taxonomic distance greater will be the heterosis.

Gowda (1979) reported that negative heterosis for locule number is a desirable expression in hybrids. Ashwathappa (1980) reported highly significant heterosis over mid parent (112.06%) for fruit yield, where as it was non-significant over better parent (35.99%). Dixit *et al.* (1980) observed highest heterosis for yield over better parent in the cross Kalyanpur Kuber x Pusa Ruby. Sheela (1986) reported heterosis in the hybrid LE 214 x LE 206 for fruit yield/plant. Sonone *et al.* (1986) tested 157 hybrids of which 13 gave 80-155 per cent higher yield than the control Pusa Ruby.

Valicek and Obeidat (1987) observed highest heterosis for fruit number in the cross Rutgers x Marmande.

Patil and Bojappa (1988) noticed that no consistent relationship between heterosis and genetic diversity in crosses between ten genotypes of Lycopersicon esculentum. Pusa Ruby x Sweet 72 showed the highest fruit yield and recorded the highest heterotic effect.

Patil and Patil (1988) analysed tomato fruits from twenty crosses and noted high heterosis in most crosses for total soluble solids, titrable acidity and pericarp thickness. Two superior crosses were identified, namely PC x SW 72 and S 14 x PR.

Dod and Kale (1992) evaluated 66 F_1 hybrids of tomato for quality traits and highest values of heterosis were observed in the crosses Punjab Chuuhara x Punjab Kesari for number of locules/fruit, Pusa Early Dwarf x S_{12} for pericarp thickness, Pusa Ruby x AC 238 for total soluble solids and Punjab Chuuhara x S_{12} for ascorbic acid content.

Dod *et al.* (1992) evaluated 66 F_1 hybrids and their parents from a 12 x 12 diallel cross for six yield related traits and pronounced heterosis was observed for yield/plant, days to first harvest, number of fruits/plant and plant height the best

specific combiner was HS 101 x S_{12}. Bora *et al.* (1993) reported highest heterosis for yield in the hybrids BT_{10} x LE-79, BT_1 x BT_{10} and BT_{10} x K_{10}.

Natarajan (1993) reported that the hybrids LE 75 x LE 76 and LE 76 x LE 22 gave the highest heterosis for yield and positive heterosis for five other characters.

Sidhu and Surjansingh (1993) observed heterosis for yield ranged from 0.7 per cent in AceVF x F_{24} to 71.7 per cent in Chio 7663 x Rossol.

Dev *et al.* (1994) reported heterosis in the F_1 hybrids EC 156 x Marglobe which gave 83.18 per cent higher yield than the better parent.

Hegazi *et al.* (1995) observed heterosis in 21 hybrid combinations for total yield, with a maximum value of 58.5 per cent and positive heterosis for number of fruits/plant.

In a study on heterosis and combining ability in tomato by Dod *et al.* (1995) found that the parents Pusa Ruby, Marglobe, Pusa Early Dwarf, S-12 and Sioux were best general combiners. The crosses HS 101 x S-12, Pusa Early Dwarf x S_{12} and Pusa Ruby x S-12 exhibited significant heterosis along with significant SCA effects for yield and it's contributing characters.

Singh *et al.* (1995) reported maximum heterosis in the cross NDT-120 x Kalyanpur Kuber (79.72%) and NDT-5 x NDT-21 (57.86%). Some other crosses like NDT-90 x NDT-21, NDT-5 x NDT-21 and NDT-120 x NDT-5 exhibited heterosis for number of fruits, NDT-120 x NDT-121, NDT-5 x NDT-21, NDT-120 x NDT-5 and NDT-120 x Kalyanpur Kuber for average fruit weight. Suresh *et al.* (1995) reported highest heterosis in the crosses namely Hisar Arun x Sel-30, Hisar Arun x Ace and Hisar Arun x Flora-dade for plant height, branches/plant, average fruit weight, fruit number and total yield.

Sadhankumar (1995) reported heterosis in the hybrid CAV-5 x LE-296 for fruits/plant. He also reported heterosis in the hybrid CAV-5 x LE 386 for fruit yield/plant and the hybrid LE 214 x LE 388 recorded heterosis for average fruit weight.

Amaral *et al.* (1996) evaluated tomato cultivars Angela I.5100, Floradade, IPA 05, IPA 06, Jumbo and Santa and their diallelic crosses for commercial fruit weight, average thickness of pulp, number of locules per fruit and content of soluble solids. It was found that the commercial fruit weight was controlled by non-additive effects, average pulp thickness by additive effects and number of locules per fruit by equal proportions of additive and non-additive effects.

Singh (1996) evaluated nine F_1 hybrids in brinjal and found that Surya x SM-116 and Arkakesav x SM-71 exhibited maximum heterosis for yield and were highly resistant to bacterial wilt. Cheema *et al.* (1996) evaluated thirteen tomato cultivars and their F_1 hybrids and observed that WIR 4329, Nemadoro and Castle Rock were good general combiners and WIR 4285 x Nemadoro recorded maximum heterosis for yield.

Singh *et al.* (1996) reported heterosis over the better parent for yield ranged from 31.1 per cent for NDT x Kalyanpur Kuber to 57.9 per cent for NDTS x NDT-21.

Vidyasagar *et al.* (1997) in a line x tester analysis of tomatoes involving bacterial wilt resistant parents, highest heterosis was observed in the hybrids BWR-HR x EC 179913 and EC 129156 x EC 191538 for marketable yield/plant and marketable fruits/plant over the best parent.

Bhatt *et al.* (1998) evaluated 66 F_1 hybrids for vitamin C content and the hybrids Marglobe x Sakti, Punjab Kesari x Bahar and T1 x Azad Kranti were identified as the best heterotic combinations.

Wang *et al.* (1998) reported heterosis in the cross combination 9596-25 x Meidong for fruit shape, yield and earliness.

Subburamu *et al.* (1998) observed heterosis in F_1 hybrids PKM-1 and Marutham for 100 seed weight and vigour index and found that fruit yield was significantly and positively related to 100 seed weight, seed length, vigour index and dehydrogenase activity.

Shrivastava (1998) observed highest heterosis in the crosses Marglobe x Hisar Arun for acidity, NT-3 x HS-1 for total soluble solids. The best hybrids identified were Marglobe x HS-101, Marglobe x Hisar Arun, Marglobe x NT-3 and NT-3 x HS 101.

Kujur *et al.* (1998) evaluated ten F_1 hybrids of tomato and found that the hybrids Rashmi and Karnataka recorded maximum heterosis for TSS, locule number per fruit and acid and sugar per centage under Ranchi condition.

Chaurasia and Kalloo (1998) observed highest yield in the hybrids TH-2312 and TO-230 under Varanasi condition.

Dhaliwal *et al.* (1998) reported highest heterosis in the crosses P-256 x P-253 for average fruit weight, 1181 x P 257, X 331 x 1181 and X 331 x U 301 for pericarp thickness, W 321 x U 301 and S 287 x U 301 for total yield.

Patil *et al.* (1998) observed maximum heterosis in the cross 32-2 x 85-1 over better parent and the cross 6-1 x Suit for yield over the commercial hybrid Avinash-2.

Biswas *et al.* (1998) evaluated nineteen tomato hybrids and found that the hybrid DARL-303 recorded highest yield.

Kumar *et al.* (1998) reported highest heterosis in the hybrid Pusa Sheetal x Chiku for most of the processing characters.

Kalloo *et al.* (1998) reported the tomato hybrids Avinash-2, Hemlata, TH-2312 and Ratna were suitable for Varanasi region, TH-2312, ARTH-13, Avinash-2 and DTH-6 for Bangalore, ARTH-3 for Hisar and Avinash-2 for Coimbatore region.

Source of resistance to viral diseases

In the recent years, virus diseases have become serious problem in the tomato growing areas. So resistant sources becomes utmost important.

Mishra *et al.* (1998) reported resistance to tomato leaf curl virus in the tomato crosses of Anand T-1 x BT-12 and H-24 x BT-12. Resistance to leaf curl virus was also reported in tomato genotypes viz. H-11, H-22, H-106 and H-107 (Banerjee and Kalloo, 1998).

Rajan and Sadhankumar (1998) reported tolerance to TMV in the lines LE 470, LE 474 and LE 471.

Resistance to tomato spotted wilt virus was reported in the cultivars Red Cheri small and Italian Red Pear by Joi and Summanwar (1986).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiments were conducted in the vegetable Research farm of the Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara which is located at an altitude of 23 M above MSL and between 10°32" and 76°16"E longitude. The experiments were conducted during June, 1999 to March, 2000. The project consisted of the following experiments.

1. Development of F_1 hybrids in tomato
2. Evaluation of F_1 hybrids for bacterial wilt resistance and heterosis

3.1 Development of F_1 hybrids in tomato

Five known sources of bacterial wilt resistance namely LE-415, Sakthi, Mukthi, LE-421 and BWR-1 were used as the parents. The genetic cataloguing of the genotypes are given in Table 1. They were crossed in a diallel fashion to produce ten F_1 hybrids (without reciprocals).

3.2 Evaluation of F1 hybrids for bacterial wilt resistance and heterosis

The F_1 hybrids along with the parents were grown in a bacterial wilt sick field for studying their reaction to bacterial wilt. The experiment was laid out in a randomised block design with twenty plants per treatment and the experiment was replicated twice. Spot planting was resorted to with the known suscept, Pusa Ruby, which confirmed the efficacy of testing. Incidence of bacterial wilt was also confirmed by ooze test. Management practices were followed as per package of practices recommendations of Kerala Agricultural University (1996). Incidence of bacterial wilt was recorded at ten days interval. The genotypes were classified into four groups as suggested by Mew and Ho (1976). The following observations were recorded.

Table 1. Genetic cataloguing of tomato genotypes used as parents

Genotypes	Sources	Genetic cataloguing						
Sakthi	Department of Olericulture, Kerala Agricultural University, Vellanikkara	sp^+-	j^+-	n^+-	bk^+-	f^+-	o^+-	u^+-
Mukthi	-do-	sp^+-	j^+-	n^+-	bk^+-	f^+-	o^+-	uu
BWR-1	IIHR, Bangalore	sp^+-	j^+-	n^+-	bk^+-	ff	o^+-	uu
LE-415	Heinz, U.S.A.	sp^+-	j^+-	n^+-	bk^+-	f^+-	o^+-	uu
LE-421	Port Blair	sp^+-	j^+-	n^+-	bk^+-	f^+-	o^+-	uu

i) Plant height (cm)

ii) Days to flowering

iii) Days to first harvest

iv) Fruits/plant

v) Fruit yield/plant (g)

vi) Average fruit weight (g)

vii) Fruit shape index (Fruit shape index was derived by dividing polar diameter by equitorial diameter)

viii) Locules/fruit

ix) Fruit flesh thickness

x) Total soluble solids (TSS) (°Brix)

Total soluble solids in the fruit was recorded using Erma refractometer.

xi) Acidity

Acidity was estimated by titration with standard NaOH solution and expressed as citric acid.

xii) Vitamin C (Ascorbic acid)

Ascorbic acid content was estimated by the visual titration method based on the reduction of 2,6 dichlorophenol indophenol dye (Sadasivam and Manickam, 1991).

xiii) Reducing sugars

Reducing sugar content was estimated as per Lane and Eynon method suggested by Ranganna (1977).

xiv) Total sugars

Total sugar content was determined as per Lane and Eynon method outlined by Ranganna (1977).

3.3 Statistical analysis

3.3.1 Analysis for combining ability

The mean values of F_1 hybrids and parents for all the characters were analysed for combining ability using the method suggested by Griffing (1956).

3.3.2 Heterosis

The mean values of parents and hybrids for each character were taken for the estimation of heterosis in terms of three parameters, heterosis over mid parent (Relative heterosis), heterosis over the better parent (Heterobeltiosis) and heterosis over standard parent (Standard heterosis) and these were worked out as suggested by Briggle (1963) and Hayes *et al.* (1965). For calculating the standard heterosis, the genotype Sakthi was taken as the standard parent.

Relative heterosis is the deviation of hybrid mean from the mid-parent value

$$RH = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Heterobeltiosis is the deviation of hybrid mean from the better parent values

$$HB = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Heterosis over the standard variety was calculated as

$$SH = \frac{\overline{F_1} - \overline{SP}}{\overline{SP}} \times 100$$

For each character the average value of the two parents in each cross was taken as the mid-parental value (MP) and that of the superior parent as the better parent value (BP).

To test the significance of difference of F_1 mean over mid and better parent, critical difference (CD) was calculated from their standard error of difference as given below (Briggle, 1963).

Heterobeltiosis was tested using standard error

$$SE = \frac{2\sigma^2 e}{r}$$

where $\sigma^2 e$ = error mean square

r = number of replications

Relative heterosis was tested using standard error

$$SE = \frac{3/2\sigma^2 e}{r}$$

3.3.3 Incidence of fruit cracking

a) Incidence of radial cracking (%)

b) Incidence of concentric cracking (%)

3.3.4 Reaction of genotypes/hybrids to virus diseases

Fifteen genotypes/hybrids were screened against virus diseases like, leaf curl, mosaic and tomato spotted wilt. Disease incidence and severity were recorded using appropriate score chart.

(a) Reaction of genotypes/hybrids to leaf curl virus disease was recorded using the score chart 0-4 scale and were categorised into 5 groups (PDVR, 1997).

Scale for classifying disease reaction to tomato leaf curl virus in tomato

Disease Grade	Symptoms
0	Symptoms absent
1	Very mild curling (upto 25% leaves)
2	Curling, puckering of 26-50% leaves
3	Curling, puckering of 51 to 75% leaves
4	Severe curling, puckering of >75% leaves

Coefficient of disease index was calculated as suggested by Datar and Mayee (1981).

$$\text{CODEX} = \frac{\text{Per cent disease incidence x Per cent disease severity}}{100}$$

b) Reaction of genotypes/hybrids to mosaic disease. Per cent mosaic incidence was calculated by using the following formula.

$$\text{Per cent disease incidence} = \frac{\text{Number of plants infected}}{\text{Total number of plants observed}} \times 100$$

RESULTS

4. RESULTS

Results of the investigation are presented under the following heads.

1. Development of F_1 hybrids
2. Evaluation of hybrids and parents for bacterial wilt resistance
3. Estimation of combining ability and heterosis

4.1 Development of F_1 hybrids

Five bacterial wilt resistant genotypes namely LE-415, Sakthi, Mukthi, LE 421 and BWR-1 were crossed in a diallel fashion without reciprocals to produce ten F_1 hybrids (Plate 1). Their genetic cataloguing is given in Table 2.

4.2 Evaluation of F1 hybrids and parents for bacterial wilt resistance

The reaction of F1 hybrids and parents to bacterial wilt is given in Table 3. The hybrids LE 415 x Mukthi, LE 415 x Sakthi, LE 415 x BWR-1 and Sakthi x Mukthi were found resistant with survival percentage of 97.5 per cent, 95 per cent, 90 per cent and 82.5 per cent respectively. The genotypes LE 415, Sakthi and Mukthi were resistant to bacterial wilt with survival percentage of 90 per cent, 90 per cent and 80 per cent 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 moderately resistant to bacterial wilt. The genotype LE 421 was moderately resistant and BWR-1 was found susceptible to bacterial wilt. All the Pusa Ruby plants (used for spot planting) succumbed to the bacterial wilt.

Plate: 1. PARENTS USED FOR HYBRIDISATION

MUKTHI

SAKTHI

LE - 415

Plate 1. continued...

LE-421

BWR-1

Table 2. Genetic cataloguing of tomato F_1 hybrids

Hybrids	Genetic cataloguing						
LE 415 x Sakthi	sp+-	j+-	n+-	bk+-	f+-	o+-	u+-
LE 415 x Mukthi	sp+-	j+-	n+-	bk+-	f+-	o+-	uu
LE 415 x LE 421	sp+-	j+-	n+-	bk+-	f+-	o+-	uu
LE 415 x BWR-1	sp+-	j+-	n+-	bk+-	f+-	o+-	uu
Sakthi x Mukthi	sp+-	j+-	n+-	bk+-	f+-	o+-	u+-
Sakthi x LE 421	sp+-	j+-	n+-	bk+-	f+-	o+-	u+-
Sakthi x BWR-1	sp+-	j+-	n+-	bk+-	f+-	o+-	u+-
Mukthi x LE 421	sp+-	j+-	n+-	bk+-	f+-	o+-	u+-
Mukthi x BWR-1	sp+-	j+-	n+-	bk+-	f+-	o+-	uu
LE 421 x BWR-1	sp+-	j+-	n+-	bk+-	f+-	o+-	uu

Table 3. Evaluation of tomato genotypes for resistance to bacterial wilt

Genotypes	Survival (%)	Disease reaction
LE-415	90.0	R
Sakthi	90.0	R
Mukthi	80.0	R
LE-421	75.0	MR
BWR-1	25.0	S
LE-415 x Sakthi	95.0	R
LE-415 x Mukthi	97.5	R
LE-415 x LE-421	70.0	MR
LE-415 x BWR-1	90.0	R
Sakthi x Mukthi	82.5	R
Sakthi x LE-421	75.0	MR
Sakthi x BWR-1	67.5	MR
Mukthi x LE-421	67.5	MR
Mukthi x BWR-1	75.0	MR
LE-421 x BWR-1	77.5	MR

R = Resistant - Survival 80% or above
MR = Moderately resistant - Survival 60-80%
MS = Moderately susceptible - Survival 40-60%
S = Susceptible - Survival less than 40%

4.3 Estimation of combining ability and heterosis

4.3.1 Estimation of combining ability

Based on partial diallel analysis general and specific combining ability effects were estimated (Table 4 and 5).

4.3.1.1 Plant height

Highest gca effect for plant height was observed for Sakthi (1.81), followed by BWR-1 (1.60). All the other genotypes except LE 415 had negative gca effects for plant height (0.39). Mukthi had a negative gca effect of -3.19.

The cross LE 415 x Mukthi showed highest positive sca effect (5.33), followed by Sakthi x BWR-1 (2.62). Negative sca effects were observed in Mukthi x BWR-1 (-8.88), Mukthi x LE 421 (-5.17) and LE 415 x LE 421 (-4.24).

4.3.1.2 Days to flowering

LE 415 had a negative gca effect (-0.46). Sakthi, Mukthi and LE 421 showed positive gca effects of 0.11, 0.19 and 0.19 respectively.

The cross LE 415 x BWR-1 showed maximum positive sca effect. The hybrid LE 415 x LE 421 showed maximum negative sca effect (-1.10), followed by Mukthi x BWR-1 (-1.02).

4.3.1.3 Days to first harvest

LE 421 had maximum positive gca effect (0.61), followed by BWR-1 (0.40). LE 415 showed a negative gca effect (-0.60) followed by Mukthi (-0.53).

Positive sca effects were shown by Sakthi x Mukthi (3.71), Mukthi x LE 421 (2.21) and Sakthi x BWR-1 (1.79). Mukthi x BWR-1 had a negative sca effect (-1.57).

Table 4. Estimates of general combining ability effects of genotypes for yield and it's components in tomato

Lines	Plant height (cm)	Days to flowering	Days to first harvest	Fruits/plant	Fruit yield/plant	Average fruit weight
LE 415	0.39	-0.46	-0.60	4.16	188.90	1.34
Sakthi	1.81	0.11	0.11	3.71	12.87	-2.18
Mukthi	-3.19	0.19	-0.53	0.20	81.84	1.87
LE 421	-0.61	0.19	0.61	-2.33	-132.08	-4.33
BWR-1	1.60	-0.03	0.40	-5.74	-151.54	3.30
SE (GI)	1.13	0.21	0.43	1.52	27.11	1.04
SE (GI-GJ)	1.79	0.32	0.68	2.40	42.86	1.65

Contd.

Table 4. Continued

Lines	Fruit shape index	Locules/ fruit	Fruit flesh thickness	T.S.S. of fruits	Acidity	Ascorbic acid	Reducing sugars	Total sugars
LE 415	-0.03	-0.15	-0.01	0.04	-0.10	2.25	0.00	-0.03
Sakthi	0.04	-0.09	0.10	-0.06	-0.08	-3.50	-0.04	0.01
Mukthi	0.03	0.06	0.14	0.21	0.00	-4.66	0.11	0.15
LE 421	-0.02	-0.09	-0.27	-0.35	-0.08	1.64	-0.04	-0.22
BWR-1	-0.01	0.28	0.04	0.06	0.25	4.27	-0.02	0.10
SE (GI)	0.02	0.09	0.11	0.11	0.03	0.48	0.02	0.03
SE (GI-GJ)	0.03	0.15	0.18	0.17	0.05	0.75	0.03	0.04

Table 5. Estimates of specific combining ability effects for fruit yield and it's components in tomato hybrids

Hybrids	Plant height	Days to flowering	Days to first harvest	Fruits/ plant	Fruit yield/ plant	Average fruit weight	Fruit shape index
LE 415 x Sakthi	-3.67	-0.52	-0.21	-2.84	-73.40	2.20	-0.05
LE 415 x Mukthi	5.33	-0.60	-0.07	17.86	735.93	5.51	0.10
LE 415 x LE 421	-4.24	-1.10	-0.71	-3.47	-51.78	3.19	0.00
LE 415 x BWR-1	0.05	1.12	1.00	-0.47	-40.79	-3.27	-0.04
Sakthi x Mukthi	-3.10	0.33	3.71	-9.64	-98.04	-3.94	-0.02
Sakthi x LE 421	-2.67	0.83	0.57	4.64	107.29	3.44	0.13
Sakthi x BWR-1	2.62	-0.45	1.79	-4.94	-133.71	-4.44	0.00
Mukthi x LE 421	-5.17	0.76	2.21	-7.94	-161.18	2.37	-0.05
Mukthi x BWR-1	-8.88	-1.02	-1.57	-2.69	-57.90	1.36	0.04
LE 421 x BWR-1	-0.45	-0.02	-0.21	2.09	3.30	-2.89	-0.11
SE (SIJ)	2.92	0.53	1.10	3.91	69.99	2.70	0.05
SE (SIJ - SIK)	4.38	0.79	1.66	5.87	104.98	4.05	0.08

Contd.

Table 5. Continued

Hybrids	Locules/ fruit	Fruit flesh thickness	T.S.S. of fruits	Acidity	Ascorbic acid	Reducing sugars	Total sugars
LE 415 x Sakthi	-0.18	0.41	-0.21	-0.22	0.04	-0.25	-0.21
LE 415 x Mukthi	0.06	-0.49	-0.37	0.24	5.45	0.45	0.85
LE 415 x LE 421	-0.08	-0.22	0.73	0.26	-3.35	0.09	0.45
LE 415 x BWR-1	-0.15	0.58	-0.03	-0.19	7.45	-0.05	-0.01
Sakthi x Mukthi	0.20	0.14	-0.37	0.55	1.77	0.10	-0.11
Sakthi x LE 421	0.16	0.11	0.23	-0.05	-3.10	-0.31	0.13
Sakthi x BWR-1	-0.11	-0.36	1.17	0.55	5.52	0.18	-0.06
Mukthi x LE 421	0.30	0.96	0.27	-0.31	3.31	-0.05	0.21
Mukthi x BWR-1	-0.07	-0.41	-0.05	0.31	-2.44	-0.26	-0.26
LE 421 x BWR-1	-0.31	0.34	-0.59	0.07	-1.37	0.20	0.22
SE (SIJ)	0.24	0.29	0.27	0.08	1.23	0.04	0.06
SE (SIJ - SIK)	0.36	0.44	0.47	0.11	1.85	0.07	0.10

4.3.1.4 Fruits/plant

LE 415 and Sakthi had maximum gca effects (4.16 and 3.71 respectively). BWR-1 showed maximum negative gca effect for fruits/plant (-5.74), followed by LE 421 (-2.33).

LE 415 x Mukthi showed maximum positive sca effect for fruits/plant (17.86) followed by Sakthi x LE 421 (4.64) and LE 421 x BWR-1 (2.09). Sakthi x Mukthi had maximum negative sca effect for fruits/plant (-9.64) followed by Mukthi x LE 421 (-7.94).

4.3.1.5 Fruit yield/plant

The good general combiners for fruit yield/plant were LE 415 (188.90) and Mukthi (81.84). LE 421 and BWR-1 showed maximum negative gca effects for fruit yield/plant (-132.08 and -151.54 respectively).

Hybrid LE 415 x Mukthi showed maximum positive sca effect (735.93), followed by Sakthi x LE 421 (107.29). Mukthi x LE 421, Sakthi x BWR-1 and Sakthi x Mukthi showed negative sca effects for fruit yield/plant (-161.18, -133.71 and -98.04 respectively).

4.3.1.6 Average fruit weight

BWR-1 had maximum positive gca effect (3.30) for average fruit weight, followed by Mukthi (1.87) and LE 415 (1.34), LE 421 has maximum negative gca effect (-4.33).

Hybrid LE 415 x Mukthi showed maximum positive sca effect (5.51) followed by Sakthi x LE 421 (3.44) and LE 415 x LE 421 (3.19). Sakthi x BWR-1 had maximum negative sca effect (-4.44).

4.3.1.7 Fruit shape index

The genotypes Sakthi and Mukthi had positive gca effects (0.04 and 0.03 respectively). Others showed negative gca effects.

Sakthi x LE 421 had maximum sca effect (0.13), followed by LE 415 x Mukthi (0.10). LE 421 x BWR-1 had a negative sca effect of -0.11.

4.3.1.8 Locules/fruit

BWR-1 had maximum gca effect (0.28) for locules/fruit. LE 415 had a negative gca effect (-0.15).

Mukthi x LE 421 showed maximum sca effect (0.30), followed by Sakthi x Mukthi (0.20). LE 415 x Sakthi had negative sca effect (-0.18).

4.3.1.9 Fruit flesh thickness

Mukthi had maximum gca effect for fruit flesh thickness (0.14), followed by Sakthi (0.10).

The hybrid Mukthi x LE 421 had maximum positive sca effect (0.96), followed by LE 415 x BWR-1 (0.58).

4.3.1.10 T.S.S. of fruits

Mukthi showed maximum gca effect for T.S.S. (0.21), followed by LE 415 (0.14).

The hybrid Sakthi x BWR-1 had maximum positive sca effect (1.17) followed by LE 415 x LE 421 (0.73). The hybrid LE 421 x BWR-1 showed maximum negative sca effect (-0.59).

4.3.1.11 Acidity

BWR-1 showed maximum gca effect (0.25) for acidity. Hybrids, Sakthi x BWR-1 and Mukthi x BWR-1 showed maximum positive sca effects (0.55 and 0.31 respectively).

4.3.1.12 Ascorbic acid

BWR-1 had maximum gca effect for ascorbic acid (4.27), followed by LE 415 (2.25). Mukthi showed maximum negative gca effect (-4.66), followed by Sakthi (-3.50). The hybrid LE 415 x BWR-1 had maximum positive sca effect (7.45), followed by Sakthi x BWR-1 (5.52) and LE 415 x Mukthi (5.45).

4.3.1.13 Reducing sugars

Mukthi showed maximum gca effect (0.11) for reducing sugar. The hybrid LE 415 x Mukthi had maximum positive sca effect (0.45). Sakthi x LE 421 had a negative sca effect of -0.31.

4.3.1.14 Total sugars

Mukthi had maximum gca effect (0.15) for total sugars. LE 421 showed a negative gca effect of -0.22. LE 415 x Mukthi had maximum positive sca effect (0.85), followed by LE 415 x LE 421 (0.45).

4.3.2 Heterosis in bacterial wilt resistant tomatoes

Analysis of variance showed significant differences for characters like plant height, fruits per plant, fruit yield per plant, average fruit weight, T.S.S. of fruits, ascorbic acid, acidity, reducing sugars and total sugars (Appendix I & II).

The mean performance of parents and the relative heterosis (RH), Heterobeltiosis (HB) and Standard heterosis (SH) for all the characters were calculated. These are presented in Table 6.

Table 6. Mean performance of parental lines and heterosis of F_1 hybrids for yield and its components in tomato

Genotypes Parents/hybrids	Plant height				Days to flowering			
	Mean (cm)	RH (%)	HB (%)	SH (%)	Mean	RH (%)	HB (%)	SH (%)
LE-415	67.0				57.0			
Sakthi	72.0				57.5			
Mukthi	64.5				58.0			
LE-421	70.0				57.5			
BWR-1	71.5				57.5			
LE-415 x Sakthi	63.5	-8.63*	-11.81	-11.81	56.5	-1.31	-1.74	-1.74
LE-415 x Mukthi	67.5	2.66	0.75	-6.25	56.5	-1.74	-2.59	-1.74
LE-415 x LE-421	60.5	-11.68**	-13.57*	-15.97*	56.0	-2.18	-2.61	-2.66
LE-415 x BWR-1	67.0	-3.25	-6.29	-6.94	58.0	1.31	0.87	0.87
Sakthi x Mukthi	60.5	-11.36**	-15.97*	-15.97*	58.0	0.43	0.00	0.87
Sakthi x LE-421	63.5	-10.56**	-11.81	-11.81	58.5	1.74	1.74	1.74
Sakthi x BWR-1	71.0	-1.05	-1.39	-13.89	57.0	-0.87	-0.87	-0.87
Mukthi x LE-421	56.0	-16.73*	-20.00**	-22.22**	58.5	1.30	0.86	1.74
Mukthi x BWR-1	54.5	-19.85**	-23.78**	-24.31**	56.5	-2.16	-2.59	-1.74
LE-421 x BWR-1	65.5	-7.42	-8.39	-9.03	57.5	0.00	0.00	0.00
SE		4.13	4.28	4.28		0.77	0.90	0.90
CD(0.05)		8.86	9.18	9.18		1.65	1.93	1.93
CD(0.01)		12.31	12.75	12.75		2.29	2.68	2.68

Contd.

Table 6. Continued

Genotypes Parents/hybrids	Days to first harvest				Fruits/plant			
	Mean	RH (%)	HB (%)	SH (%)	Mean	RH (%)	HB (%)	SH (%)
LE-415	99.0				28.75			
Sakthi	97.5				39.79			
Mukthi	97.0				27.59			
LE-421	100.5				23.67			
BWR-1	100.5				17.50			
LE-415 x Sakthi	99.5	1.27	0.51	2.05	31.00	-9.54	-22.09	-22.09
LE-415 x Mukthi	99.0	1.02	0.00	1.54	48.20	71.12**	67.65**	21.14
LE-415 x LE-421	99.5	-0.25	-1.00	2.05	24.34	-7.14	-15.36	-38.83*
LE-415 x BWR-1	101.0	1.25	0.50	3.59*	23.92	3.42	-16.82	-39.88*
Sakthi x Mukthi	103.5	6.43**	6.15**	6.15**	20.25	-39.89*	-49.11**	-49.11**
Sakthi x LE-421	101.5	2.53	1.00	4.10*	32.00	0.86	-19.58	-19.58
Sakthi x BWR-1	102.5	3.54*	1.99	5.13**	19.00	-33.67	-52.25	-52.25**
Mukthi x LE-421	102.5	3.80*	1.99	5.13**	15.90	-37.89	-42.31**	-60.04**
Mukthi x BWR-1	98.5	-0.25	-1.99	1.03	17.75	-21.26	-35.65	-55.40**
LE-421 x BWR-1	101.0	0.50	0.50	3.59*	20.00	-28.36	-15.49	-49.74**
SE		1.28	1.39	1.39		4.82	5.56	5.56
CD(0.05)		2.75	2.98	2.98		10.34	11.93	11.93
CD(0.01)		3.81	4.14	4.14		14.36	16.57	16.57

Contd.

Table 6. Continued.

Genotypes Parents/hybrids	Fruit yield/plant				Average fruit weight			
	Mean (g)	RH (%)	HB (%)	SH (%)	Mean (g)	RH (%)	HB (%)	SH (%)
LE-415	585.70				33.29			
Sakthi	617.95				31.43			
Mukthi	447.10				35.52			
LE-421	279.90				22.72			
BWR-1	304.30				45.65			
LE-415 x Sakthi	621.30	3.26	0.60	0.54	35.78	10.57	7.48	13.84
LE-415 x Mukthi	1499.50	190.39**	156.04**	142.66**	43.15	25.42*	21.48	37.29*
LE-415 x LE-421	497.87	15.05	-14.99	-19.43	34.63	23.67	4.03	10.18
LE-415 x BWR-1	489.40	9.98	-16.43	-20.80	35.80	-9.30	-21.58	13.90
Sakthi x Mukthi	489.50	-8.04	-20.73	-20.79	30.17	-9.87	-15.06	-4.01
Sakthi x LE-421	480.90	7.18	-22.12	-22.18	31.35	15.80	-0.25	-0.25
Sakthi x BWR-1	220.45	-52.17*	-64.30**	64.33**	31.11	-19.29	-31.85*	-1.02
Mukthi x LE-421	281.40	-22.58	-37.06	-54.46*	34.34	17.94	-3.32	9.26
Mukthi x BWR-1	365.23	-2.79	-18.31	-40.89*	40.96	0.92	-10.27	30.32
LE-421 x BWR-1	212.50	-27.24	-30.17	-65.61**	30.52	-10.73	-33.15**	-2.89
SE		101.24	115.60	115.60		3.96	5.02	5.02
CD(0.05)		217.16	247.96	247.96		8.49	10.77	10.77
CD(0.01)		301.69	344.49	344.49		11.80	14.96	14.96

Contd.

Table 6. Continued.

Genotypes Parents/hybrids	Fruit shape index				Locules/fruits			
	Mean	RH (%)	HB (%)	SH (%)	Mean	RH (%)	HB (%)	SH (%)
LE-415	0.995				3.6			
Sakthi	1.13				3.5			
Mukthi	1.09				3.6			
LE-421	1.04				3.5			
BWR-1	1.10				4.6			
LE-415 x Sakthi	1.03	-3.06	-8.85	-8.85	3.3	-7.04	-8.33	-5.71
LE-415 x Mukthi	1.17	11.75	6.88	3.54	3.7	2.78	2.78	5.71
LE-415 x LE-421	1.02	-0.25	-2.40	-9.73	3.4	-4.23	-5.56	-2.86
LE-415 x BWR-1	0.99	-5.49	-10.00	-12.39	3.7	-9.76	-19.57	5.71
Sakthi x Mukthi	1.12	0.90	-0.88	-0.88	3.9	9.86	8.33	11.43
Sakthi x LE-421	1.22	12.44	7.96	7.96	3.7	5.71	5.71	5.71
Sakthi x BWR-1	1.11	-0.90	-2.21	-1.77	3.8	-6.17	-17.39	8.57
Mukthi x LE-421	1.02	-4.23	-6.42	-9.73	4.0	12.68	11.11	14.29
Mukthi x BWR-1	1.13	2.74	2.28	0.00	4.0	-2.44	-13.04	14.29
LE-421 x BWR-1	0.93	-13.55	-15.91*	-17.70	3.6	-11.11	-21.74	2.86
SE		0.07	0.08	0.08		0.35	0.48	0.48
CD(0.05)		0.15	0.17	0.17		0.75	1.03	1.03
CD(0.01)		0.21	0.24	0.24		1.04	1.43	1.43

Contd.

Table 6. Continued

Genotypes Parents/hybrids	Fruit flesh thickness				T.S.S. of fruits			
	Mean (mm)	RH (%)	HB (%)	SH (%)	Mean (°B)	RH (%)	HB (%)	SH (%)
LE-415	3.15				5.50			
Sakthi	3.36				4.75			
Mukthi	3.49				5.95			
LE-421	2.19				4.25			
BWR-1	3.32				5.15			
LE-415 x Sakthi	3.81	16.99	13.41	13.29	5.15	0.49	-6.36	8.42
LE-415 x Mukthi	2.95	-11.23	-15.49	-12.20	5.25	-8.30	-11.76	10.53
LE-415 x LE-421	2.81	5.34	-10.79	-16.37	5.80	18.97*	5.45	22.11
LE-415 x BWR-1	3.93	21.33	18.22	16.96	5.45	2.35	-0.91	14.74
Sakthi x Mukthi	3.69	7.75	5.74	9.82	5.05	-5.61	-15.13*	6.32
Sakthi x LE-421	3.25	17.33	-3.13	-3.27	5.10	13.33	7.38	7.37
Sakthi x BWR-1	3.09	-7.57	-8.05	-8.04	6.45	30.30**	25.24**	35.79**
Mukthi x LE-421	4.15	46.21**	18.94	23.50	5.40	5.88	-9.24	13.68
Mukthi x BWR-1	3.09	-9.33	-11.48	-8.04	5.50	-0.90	-7.56	15.79
LE-421 x BWR-1	3.43	24.61	3.31	2.08	4.40	-6.38	-14.56	-7.37
SE		0.41	0.47	0.47		0.39	0.41	0.41
CD(0.05)		0.88	1.01	1.01		0.84	0.88	0.88
CD(0.01)		1.22	1.40	1.40		1.16	1.22	1.22

Contd.

Table 6. Continued

Genotypes Parents/hybrids	Ascorbic acid				Acidity			
	Mean (mg/100 g fruit)	RH (%)	HB (%)	SH (%)	Mean (%)	RH (%)	HB (%)	SH (%)
LE-415	40.25				0.98			
Sakthi	25.75				0.65			
Mukthi	21.50				0.83			
LE-421	43.25				1.09			
BWR-1	44.50				1.36			
LE-415 x Sakthi	36.50	10.61	-9.32	41.75**	0.82	0.62	-16.41	26.15
LE-415 x Mukthi	40.75	31.98**	1.24	58.25**	1.36	50.69**	39.49**	109.23**
LE-415 x LE-421	38.25	-8.38	-11.56*	48.54**	1.98	25.73*	19.35	204.62**
LE-415 x BWR-1	46.00	8.55	3.37	78.64**	1.18	1.29	-12.92	81.54**
Sakthi x Mukthi	37.00	56.61**	43.69**	43.69**	1.69	129.15**	103.61**	160.00**
Sakthi x LE-421	32.75	-5.07	-24.28**	27.18**	1.60	16.18	-7.37	146.15**
Sakthi x BWR-1	44.00	25.27	-1.12	70.87**	1.94	94.00**	43.17**	198.46**
Mukthi x LE-421	38.00	17.37**	-12.14*	45.57**	0.83	-13.32	-23.50	27.69
Mukthi x BWR-1	34.88	5.68	-21.63**	35.46**	1.79	63.84**	32.10**	175.38**
LE-421 x BWR-1	42.25	-3.70	-5.06	64.08*	1.47	20.08*	8.12	126.15**
SE		1.76	1.89	1.89		0.10	0.12	0.12
CD(0.05)		3.78	4.05	4.05		0.21	0.26	0.26
CD(0.01)		5.24	5.63	5.63		0.29	0.36	0.36

Contd.

Table 6. Continued

Genotypes Parents/hybrids	Reducing sugar				Total sugars			
	Mean (%)	RH (%)	HB (%)	SH (%)	Mean (%)	RH (%)	HB (%)	SH (%)
LE-415	2.42				2.40			
Sakthi	2.59				3.14			
Mukthi	2.64				2.95			
LE-421	2.49				2.07			
BWR-1	2.45				3.25			
LE-415 x Sakthi	2.25	-10.29**	-13.32**	-13.13**	2.76	-0.27	-12.10**	-12.10**
LE-415 x Mukthi	3.09	22.38**	17.27**	19.31**	3.96	48.18**	34.24**	26.11**
LE-415 x LE-421	2.59	5.40*	3.82	0.00	3.20	43.50**	33.61**	1.91
LE-415 x BWR-1	2.46	1.13*	0.41	-94.98	3.06	8.24*	-6.00	-2.55
Sakthi x Mukthi	2.71	3.54**	2.66**	4.63	3.05	0.00	-3.03**	-2.87
Sakthi x LE-421	2.14	-15.75**	-17.37**	17.37**	2.92	12.01**	-7.17*	-7.01*
Sakthi x BWR-1	2.65	5.16*	2.32**	2.32	3.05	-4.54	-6.15	-2.87
Mukthi x LE-421	2.56	-0.29	-3.04**	-1.16	3.14	25.02**	6.27	0.00
Mukthi x BWR-1	2.36	-7.18*	-10.44**	-8.88**	2.99	-3.55	-8.00*	-4.78
LE-421 x BWR-1	2.68	8.30**	7.43**	3.47	3.10	16.65**	-4.62	-1.27
SE		0.06	0.06	0.06		0.09	0.10	0.10
CD(0.05)		0.02	0.13	0.13		0.19	0.21	0.21
CD(0.01)		0.18	0.18	0.18		0.27	0.30	0.30

* Significant at 5% level

** Significant at 1% level

4.3.2.1 Plant height

The estimates of relative heterosis, heterobeltiosis and standard heterosis ranged from -19.85 to 2.66 per cent, -23.78 to 0.75 per cent and -24.31 to -6.25 per cent respectively. The highest positive relative heterosis was shown by LE 415 x Mukthi (2.66%). Maximum negative relative heterosis was shown by Mukthi x BWR-1 (-19.85%). This hybrid showed the maximum heterobeltiosis value of -23.78 per cent and standard heterosis of -24.31 per cent. Mukthi x BWR-1 was the dwarfest hybrid (54.5 cm) and Sakthi x BWR-1 was the tallest hybrid (72 cm).

4.3.2.2 Days to flowering

The relative heterosis, heterobeltiosis and standard heterosis for days to flowering ranged from -2.18 to 1.74 per cent, -2.61 to 1.74 per cent and -2.61 to 1.74 per cent respectively. Among the F_1 hybrids, LE 415 x LE 421 was the earliest to flower (56 days). Relative heterosis for this hybrid was -2.18 per cent, heterobeltiosis was -2.61 per cent and standard heterosis was -2.61 per cent.

4.3.2.3 Days to first harvest

The relative heterosis, heterobeltiosis and standard heterosis for days to first harvest ranged from -0.25 to 6.43 per cent, -1.99 to 6.15 per cent and 1.03 to 6.15 per cent respectively. Among the F_1 hybrids, Mukthi x BWR-1 was the earliest to harvest (98.5 days). Relative heterosis for this hybrid was -0.25 per cent and standard heterosis was 1.03.

4.3.2.4 Fruits/plant

Among the hybrids, maximum number of fruits were produced by LE 415 x Mukthi (48.20 fruits/plant). This hybrid showed significant relative heterosis (71.12%), heterobeltiosis (67.65%) and standard heterosis (21.14%).

4.3.2.5 Fruit yield/plant

LE 415 x Mukthi (1499.5 g/plant) gave the maximum yield among the hybrids and parents followed by LE 415 x Sakthi (621.3 g/plant). LE 415 x Mukthi recorded a significant and positive relative heterosis of 190.39 per cent, heterobeltiosis of 156.04 per cent and standard heterosis of 142.66 per cent (Plate 2).

4.3.2.6 Average fruit weight

The maximum fruit weight was recorded for the hybrid LE 415 x Mukthi (43.15 g) followed by Mukthi x BWR-1 (40.96 g). The relative heterosis for LE 415 x Mukthi was 25.42 per cent, heterobeltiosis 21.48 per cent and standard heterosis 37.29 per cent.

4.3.2.7 Fruit shape index

Sakthi x LE 421 exhibited maximum fruit shape index (1.22 mm). This cross exhibited a relative heterosis of 12.44 per cent, heterobeltiosis of 7.96 per cent and standard heterosis of 7.96 per cent.

4.3.2.8 Locules/fruit

Among the F_1 hybrids, Mukthi x LE 421 had maximum locules (4 locules). This showed a relative heterosis of 12.68 per cent, heterobeltiosis of 11.11 per cent and standard heterosis of 14.29 per cent.

4.3.2.9 Fruit flesh thickness

The hybrid Mukthi x LE 421 had maximum flesh thickness (4.15 mm). The relative heterosis was 46.21 per cent, heterobeltiosis 18.94 per cent and standard heterosis 23.5 per cent for this trait.

Plate: 2. LE 415 × MUKTHI

1.Resistant to bacterial wilt (Survival 97.5 Per cent)

2. Maximum number of Fruits/ Plant (48.2 Fruits)

3. High yielding (1.5 Kg fruits / Plant)

4.3.2.10 T.S.S. of fruits

T.S.S. content ranged from 4.40 to 6.45 °Brix. Maximum T.S.S. was noticed in the hybrid Sakthi x BWR-1 (6.45 °Brix). This hybrid exhibited a significant and positive relative heterosis of 30.30 per cent, heterobeltiosis of 25.24 per cent and standard heterosis of 35.79 per cent.

4.3.2.11 Ascorbic acid

Among the F_1 hybrids, LE 415 x BWR-1 contains maximum ascorbic acid (46.0 mg). This recorded a relative heterosis of 8.55 per cent, heterobeltiosis of 3.37 per cent and standard heterosis of 78.64 per cent.

4.3.2.12 Acidity

The mean acidity values of the F_1's ranged from 0.82 to 1.98 per cent. Acidity content was highest in the hybrid LE 415 x LE 421 (1.98%). This hybrid exhibited a significant relative heterosis of 25.73 per cent, heterobeltiosis of 19.35 per cent and standard heterosis of 204.62 per cent, followed by Sakthi x BWR-1.

4.3.2.13 Reducing sugars

The reducing sugar content ranged from 2.14 per cent to 3.09 per cent. The hybrid LE 415 x Mukthi had higher content of reducing sugars (3.09%). This hybrid showed a significant and positive relative heterosis of 22.38 per cent, heterobeltiosis of 17.27 per cent and standard heterosis of 19.31 per cent.

4.3.2.14 Total sugars

The total sugar content ranged from 2.76 to 3.96 per cent. Total sugar content was highest in the hybrid LE 415 x Mukthi (3.96%). This hybrid exhibited a significant relative heterosis of 48.18 per cent, heterobeltiosis of 34.24 per cent and standard heterosis of 26.11 per cent.

4.3.3 Fruit cracking

The incidence of fruit cracking was recorded (Table 7).

a) Radial cracking

The genotypes LE 415, Sakthi, Mukthi and BWR-1 and all the hybrids were resistant to radial fruit cracking. The genotype LE 421 was susceptible to radial cracking.

b) Concentric cracking

The genotypes LE 415, Mukthi and BWR-1 were resistant to concentric cracking. All the hybrids except Sakthi x LE 421 and Sakthi x BWR-1 were resistant to concentric cracking. Sakthi and LE 421 were susceptible to concentric cracking.

4.3.4 Incidence of virus diseases

Incidence of various virus diseases viz., leaf curl, mosaic and tomato spotted wilt were recorded (Table 8 & 9).

4.3.4.1 Reaction of genotypes/hybrids to leaf curl virus

Of the fifteen genotypes/hybrids evaluated against leaf curl disease, none of the genotypes/hybrids were found free of disease (Table 8). Except LE 421 x BWR-1 all others showed high per cent of incidence. Maximum disease incidence is recorded in Mukthi x LE 421 (48.6%) and LE 415 (46.6%).

Eventhough LE 415 recorded high disease incidence, it showed only 5.33 per cent severity and the coefficient of infection was only 2.48. It is also noticed that LE 415 in combination with LE 421 and Sakthi showed only mild infection. Based on the coefficient of infection LE 415 and it's hybrids were found to be highly field tolerant.

Table 7. Fruit cracking percentage of parents and F_1 hybrids in tomato

Accession	Concentric cracking	Radial cracking
LE-415	0	0
Sakthi	15.08	0
Mukthi	0	0
LE-421	16.89	12.67
BWR-1	0	0
LE-415 x Sakthi	0	0
LE-415 x Mukthi	0	0
LE-415 x LE-421	0	0
LE-415 x BWR-1	0	0
Sakthi x Mukthi	0	0
Sakthi x LE-421	21.88	0
Sakthi x BWR-1	15.79	0
Mukthi x LE-421	0	0
Mukthi x BWR-1	0	0
LE-421 x BWR-1	0	0

Table 8. Reaction of tomato genotypes/hybrids to leaf curl virus disease

Genotypes	Disease incidence (%)	Disease severity (%)	CODEX
LE-415	*46.6 (0.740) [ab]	*5.33 (0.224) [ab]	2.48 (4.73) [a]
Sakthi	40.0 (0.685) [ab]	32.8 (0.596) [a]	13.12 (4.27) [ab]
Mukthi	23.1 (0.503) [ab]	31.3 (0.589) [a]	7.23 (3.63) [abc]
LE-421	23.3 (0.503) [ab]	12.0 (0.352) [ab]	2.80 (3.26) [abc]
BWR-1	30.0 (0.355) [b]	32.0 (0.601) [a]	9.60 (3.24) [abc]
LE-415 x Sakthi	23.3 (0.503) [ab]	9.0 (0.298) [ab]	2.10 (2.89) [abc]
LE-415 x Mukthi	26.0 (0.332) [b]	19.3 (0.450) [ab]	5.03 (2.74) [abc]
LE-415 x LE-421	23.3 (0.419) [ab]	8.7 (0.298) [ab]	2.03 (2.69) [abc]
LE-415 x BWR-1	41.2 (0.785) [ab]	22.7 (0.487) [ab]	9.35 (2.28) [bc]
Sakthi x Mukthi	33.3 (0.615) [ab]	24.0 (0.513) [ab]	8.00 (2.28) [bc]
Sakthi x LE-421	30.0 (0.574) [ab]	17.3 (0.427) [ab]	5.20 (1.18) [c]
Sakthi x BWR-1	36.3 (0.643) [ab]	14.6 (0.378) [ab]	5.30 (1.56) [c]
Mukthi x LE-421	48.6 (0.842) [a]	34.6 (0.621) [a]	16.80 (1.53) [c]
Mukthi x BWR-1	28.0 (0.548) [ab]	35.8 (0.619) [a]	10.02 (1.42) [c]
LE-421 x BWR-1	13.3 (0.354) [b]	10.0 (0.320) [ab]	1.33 (1.39) [c]

*Mean of 2 replications

Figures in parantheses are transformed values

Table 9. Reaction of tomato genotypes / hybrids to mosaic, tomato spotted wilt virus and combined infection of mosaic and leaf curl

Genotypes	Mosaic	Tomato spotted wilt virus	Combined infection of mosaic and leaf curl
	Disease incidence (%)	Disease incidence (%)	Disease incidence (%)
LE-415	*9.0 (0.212)^{b}	*19.05 (0.458)^{ab}	*46.6 (0.414)^{bc}
Sakthi	21.5 (0.335)^{ab}	1.3 (0.122)^{b}	60.5 (0.900)^{a}
Mukthi	6.6 (0.195)^{b}	21.0 (0.474)^{a}	28.6 (0.557)^{abc}
LE-421	16.6 (0.419)^{ab}	13.4 (0.252)^{ab}	13.3 (0.373)^{bc}
BWR-1	2.0 (0.136)^{b}	15.0 (0.398)^{ab}	36.5 (0.649)^{abc}
LE-415 x Sakthi	13.3 (0.363)^{ab}	20.0 (0.297)^{ab}	16.6 (0.418)^{bc}
LE-415 x Mukthi	3.9 (0.188)^{b}	2.5 (0.144)^{ab}	12.5 (0.361)^{bc}
LE-415 x LE-421	6.6 (0.262)^{b}	20.5 (0.464)^{ab}	9.9 (0.318)^{c}
LE-415 x BWR-1	6.6 (0.195)^{b}	18.6 (0.445)^{ab}	26.6 (0.529)^{abc}
Sakthi x Mukthi	6.3 (0.195)^{b}	16.6 (0.401)^{ab}	49.8 (0.785)^{ab}
Sakthi x LE-421	13.3 (0.363)^{ab}	13.3 (0.251)^{ab}	13.5 (0.362)^{bc}
Sakthi x BWR-1	13.3 (0.251)^{b}	18.6 (0.454)^{ab}	24.6 (0.324)^{c}
Mukthi x LE-421	14.0 (0.372)^{ab}	20.0 (0.297)^{ab}	30.0 (0.574)^{abc}
Mukthi x BWR-1	9.4 (0.221)^{b}	24.0 (0.486)^{a}	30.4 (0.590)^{abc}
LE-421 x BWR-1	29.6 (0.559)^{a}	2.6 (0.146)^{ab}	33.3 (0.608)^{abc}

*Mean of 2 replications
Figures in parantheses are transformed values

4.3.4.2 Reaction of genotypes/hybrids to mosaic diseases

Out of fifteen genotypes/hybrids screened against mosaic disease all were found susceptible to the disease (Table 9). However, degrees of resistance varied with genotypes and hybrids. Among the genotypes, lowest incidence (2%) was noticed in BWR-1 and the maximum (21.5%) was noticed in Sakthi. However, Sakthi with other genotypes showed a decrease in disease incidence.

Among the hybrids, LE 415 x Mukthi showed least incidence (3.91%). It is also observed that it's parents otherwise also showed only 9 per cent and 6.6 per cent incidence respectively. Maximum incidence (29.6%) was scored in LE 421 x BWR-1.

As far as the mosaic infection is considered, genotype LE 415 and it's combination with other genotypes recorded maximum field tolerance to the disease.

4.3.4.3 Reaction of genotypes/hybrids to tomato spotted wilt virus

From the Table 9 it was observed that tomato spotted wilt incidence was low as compared to mosaic and leaf curl. Among the fifteen genotypes/hybrids tested, Sakthi, LE 415 x Mukthi and LE 421 x BWR-1 showed lowest incidence of 1.3 per cent, 2.5 per cent and 2.6 per cent respectively. All others were found susceptible to this virus.

4.3.4.4 Reaction of genotypes/hybrids to combined infection of leaf curl and mosaic

All fifteen genotypes/hybrids tested were found affected with both mosaic and leaf curl disease (Table 9). However, per cent incidence differed with the genotypes/hybrids. Maximum incidence was noticed in Sakthi (60.5%) and the hybrid Sakthi x Mukthi (49.8%). Combination of LE 415 x LE 421 recorded the lowest incidence of 9.9 per cent.

DISCUSSION

5. DISCUSSION

Tomato (*Lycopersicon esculentum* Mill.) is an important commercial vegetable crop. It is grown throughout the world in farm gardens, small home gardens and by market gardeners for fresh fruits as well as for processing. Bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.* is the major production constraint in the tropics and sub-tropics. This is more prevalent in Kerala where the acidic soil conditions favour the incidence of this disease. The chemical control measures are not effective as the pathogen is soil borne. The only way out is the development of resistant varieties. But the resistant varieties are generally low yielding with small fruits.

Heterosis has been reported in tomato as early as in 1908 by Hedrick and Booth. The success of a hybridisation programme depends on the choice of parents which require information on the general combining ability of the parents and specific combining ability exhibited in the hybrids. The present study was therefore, taken up with a view to generate information on combining ability of selected parents in tomato and also to identify F_1 hybrids which are resistant to bacterial wilt and exhibit heterosis for economic characters.

Studies on genetics of bacterial wilt resistance by kurian (1990) and Sadhankumar (1995) have shown that the genes for resistance to bacterial wilt in tomato are recessive in nature. Eventhough Tikoo (1987) has reported dominant source of resistance to bacterial wilt, this source itself is susceptible to bacterial wilt under Vellanikkara conditions (Sadhankumar, 1995). Singh (1996) was successful in developing F_1 hybrids in brinjal by crossing resistant parents. So an attempt was made to develop a heterotic F_1 hybrid in tomato by crossing resistant genotypes. The major findings are discussed hereunder.

5.1 Evaluation of tomato genotypes and F_1 hybrids for resistance to bacterial wilt

The F_1 hybrid LE 415 x Mukthi was found resistant to bacterial wilt with survival percentage of 97.5 per cent. This was followed by LE 415 x Sakthi (95%), LE 415 x BWR-1 (90%) and Sakthi x Mukthi (82.5%). The genes responsible for resistance in the parental lines (LE 415, Sakthi, Mukthi, LE 421 and BWR-1) were recessive in nature as reported by Sadhankumar (1995). By crossing resistant parents like LE 415, Mukthi and Sakthi; resistant hybrids are obtained whereas the hybrids involving other parents were not found to be resistant. When dominant source for resistance are not available, the only way out for producing F_1 hybrid resistant to bacterial wilt is crossing two resistant parents. Singh (1996) has also got resistant F_1 hybrids in brinjal by crossing two resistant parents.

Among the genotypes, LE 415, Sakthi and Mukthi were resistant to bacterial wilt with survival percentage of 90 per cent, 90 per cent and 80 per cent respectively, where as LE 421 was moderately resistant (75% survival) and BWR-1 was found susceptible (25% survival). All the hybrids involving the resistant parents (survival percentage more than 80%) were also resistant to bacterial wilt.

All the Pusa Ruby seedlings used for spot planting succumbed to bacterial wilt within 10 days of planting. This confirmed the presence of virulent bacterium (*Ralstonia solanacearum*) in the field.

5.2 Combining ability

5.2.1 Plant height

Sakthi with maximum positive gca effect (1.81) is a good general combiner for increased plant height. Mukthi had maximum negative gca effect (-3.19). So Mukthi can be used as a general combiner for producing dwarf hybrids.

Maximum positive sca effect (5.33) was for the hybrid LE 415 x Mukthi. Maximum negative sca effect was for Mukthi x BWR-1 (-8.88).

5.2.2 Days to flowering

LE 415 was a good general combiner for early flowering as suggested by it's high and negative gca effect (-0.46). Precosity is a desirable character in F_1 hybrids and for achieving this target LE 415 which has a high and negative gca effect can be used in heterosis breeding programme especially in bacterial wilt resistant varieties. All hybrids involving LE 415 except LE 415 x BWR-1 had high and negative sca effect.

5.2.3 Days to first harvest

LE 415 is a good general combiner for days to harvest also. This is evident from the fact that it had maximum and negative gca effect for days to harvest among the different parents. This can be expected because LE 415 was having maximum and negative gca effect for days to flowering also. The hybrid LE 415 x Mukthi had a negative sca effect for days to harvest.

5.2.4 Fruits/plant

LE 415 and Sakthi with high positive gca effects (4.16 and 3.71 respectively) were good general combiners for increased fruits/plant. LE 415 x Mukthi had maximum positive sca effect (17.86). This hybrid ranked first in *per se* performance also. High x low gca effects of the parents give rise to high sca effects in hybrids due to additive x dominance gene action.

5.2.5 Fruit yield/plant

LE 415 and Mukthi had maximum positive gca effects (188.90 and 81.84 respectively). They are good general combiners for increased fruit yield. Mukthi as a good general combiner for fruit yield/plant has been reported earlier by Sadhankumar (1995). This fact is further evidenced by maximum sca effect

shown by the cross LE 415 x Mukthi which can be attributed to additive x additive gene interaction. BWR-1 and LE 421 were not good parents for increased fruit yield/plant. This is also convinced by the per se performance of the hybrids involving these parents.

5.2.6 Average fruit weight

One drawback with respect to bacterial wilt resistant varieties is that their fruit size is small. So this factor is of prime importance in breeding programme involving bacterial wilt resistance. BWR-1 and Mukthi were found to be good general combiners for this character as evidenced by the high gca effect for this character in these genotypes. The cross LE 415 x Mukthi is a combination of medium x medium gca combiners which has resulted in the highest *per se* and sca effect as well for average fruit weight. This suggests a non-additive gene action of complementary nature.

5.2.7 Fruit shape index

Fruit shape is a character related to consumer preference. Fruit shape index gives an indication towards the fruit shape. When it is one the fruits will be round in shape, when it is more than one it will be more or less pear shape.

5.2.8 Locules/fruit

BWR-1 was a good general combiner for increased locules/fruit. Among the hybrids Mukthi x LE 421 had maximum sca effect for locule number.

5.2.9 Fruit flesh thickness

Mukthi is a good general combiner for fruit flesh thickness. The F_1 hybrid Mukthi x LE 421 had maximum positive sca effect for this trait.

5.2.10 T.S.S. of fruits

The genotype Mukthi is a good general combiner for T.S.S. Among the hybrids Sakthi x BWR-1 had maximum sca effect (1.17).

5.2.11 Acidity

For acidity, BWR-1 is a good general combiner. The F_1 hybrid Sakthi x BWR-1 had maximum sca effect for acidity.

5.2.12 Ascorbic acid

BWR-1 is a good general combiner for ascorbic acid as evidenced by high positive gca effect. The hybrid LE 415 x BWR-1 had maximum positive sca effect for ascorbic acid.

5.2.13 Reducing sugars

Mukthi is a good general combiner for reducing sugars. Among the F_1 hybrids, LE 415 x Mukthi had maximum sca effect.

5.2.14 Total sugars

For total sugars also, Mukthi is a good general combiner. The F_1 hybrid LE 415 x Mukthi had maximum positive sca effect.

5.3 Heterosis

The relative heterosis, heterobeltiosis and standard heterosis for 15 characters including yield were estimated. The number of heterotic hybrids for each character was recorded (Table 10).

5.3.1 Plant height

Mukthi x BWR-1 was the dwarfest hybrid (54.5 cm). It was dwarfer than it's parents. There were three relatively heterotic hybrids, four heterobeltiotic hybrids and four standard heterotic hybrids.

Table 10. Performance of promising F_1 hybrids

Character	Hybrids	Perse-performance	sca effect	RH (%)	HB (%)	SH (%)
Plant height						
(Tallest)	Sakthi x BWR-1	71.0 cm	2.62	-1.05	-1.39	-13.89
(Dwarfest)	Mukthi x BWR-1	54.5 cm	-8.88	-19.85	-23.78	-24.31
Earliest to flowering	LE 415 x LE 421	56 days	-1.10	-2.18	-2.61	-2.61
Earliest to harvest	Mukthi x BWR-1	98.5 days	-1.57	-0.25	-1.99	1.03
Fruit/plant	LE 415 x Mukthi	48.2	17.86	71.12	67.65	21.14
Fruit yield/plant	LE 415 x Mukthi	1499.5 g	735.93	190.39	156.04	142.66
Average fruit weight	LE 415 x Mukthi	43.15 g	5.51	25.42	21.48	37.29
Fruit shape index	Sakthi x LE 421	1.22	0.13	12.44	7.96	7.96
Locules/fruit	Mukthi x LE 421	4.0	0.30	12.68	11.11	14.29
Fruit flesh thickness	Mukthi x LE 421	4.15	0.96	46.21	18.94	23.50
T.S.S. of fruits	Sakthi x BWR-1	6.45°B	1.17	30.30	25.24	35.79
Acidity	Sakthi x BWR-1	1.94%	0.55	94.00	43.17	198.46
Ascorbic acid	LE 415 x BWR-1	46 mg	7.45	8.55	3.37	78.64
Reducing sugars	LE 415 x Mukthi	3.09%	0.45	22.38	17.27	19.31
Total sugars	LE 415 x Mukthi	3.96%	0.85	48.18	34.24	26.11

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5.3.2 Days to flowering

The F_1 hybrid LE 415 x LE 421 was the earliest to flower (56 days). There were no relatively heterotic, heterobeltiotic and standard heterotic hybrids for days to flowering.

5.3.3 Days to first harvest

Among the hybrids, Mukthi x BWR-1 was the earliest to harvest (98.5 days) followed by LE 415 x Mukthi (99 days). There were three relative heterotic, one heterobeltiotic and six standard heterotic hybrids.

5.3.4 Fruits/plant

The maximum and significant relative heterosis (71.12%) and heterobeltiosis (67.65%) for total fruits per plant was recorded in LE 415 x Mukthi. The sca effect for this combination also was found to be high. There were two relatively heterotic hybrids, three heterobeltiotic and seven standard heterotic hybrids. Hegazi *et al.* (1995) reported positive heterosis for number of fruits/plant in tomato. Sadhankumar (1995) reported heterosis in the hybrid CAV-5 x LE 296 for fruits/plant.

5.3.5 Fruit yield/plant

For fruit yield per plant, the heterosis was positive and significant for LE 415 x Mukthi. This is due to the high and significant gca effects of the parental lines LE 415 and Mukthi. This hybrid had a high sca effect also. Several workers like Sidhu and Surjan Singh (1993), Dev *et al.* (1994), Dod *et al.* (1995), Sadhankumar (1995), Vidyasagar *et al.* (1997) and Chaurasia and Kalloo (1998) have reported significant heterosis in several parental combinations for fruit yield/plant in tomato.

5.3.6 Average fruit weight

There was only one relatively heterotic hybrid, two heterobeltiotic and one standard heterotic hybrid for increased fruit weight. Among the F_1 hybrids, LE 415 x Mukthi produced bigger sized fruits. The highest positive heterosis was observed in this combination. Suresh *et al.* (1995), Sadhankumar (1995) and Dhaliwal *et al.* (1998) have reported significant positive heterosis for fruit weight in F_1's in tomato.

5.3.7 Fruit shape index

The hybrid Sakthi x LE 421 was having high fruit shape index as compared to others (1.22). This hybrid exhibited highest positive heterosis for this trait.

5.3.8 Locules/fruit

Among the hybrids, Mukthi x LE 421 contains more number of locules. There was no heterobeltiotic, relatively heterotic or standard heterotic hybrid. The highest positive heterosis was exhibited by the hybrid Mukthi x LE 421. Dod *et al.* (1992), Amaral *et al.* (1996) and Kujur *et al.* (1998) have also reported heterosis for locule number per fruit in the hybrid combinations in tomato.

5.3.9 Fruit flesh thickness

The hybrid Mukthi x LE 421 was having more thick flesh. This cross exhibited significant positive relative heterosis also.

5.3.10 T.S.S. of fruits

Sakthi x BWR-1 exhibited significant and positive relative heterosis, heterobeltiosis and standard heterosis for this trait. Patil and Patil (1988), Dod and

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Kale (1992), Shrivastava (1998) and Kujur *et al.* (1998) have reported significant heterosis in the parental combinations for total soluble solids in tomato.

5.3.11 Acidity

The hybrid Sakthi x BWR-1 had significantly higher acidity than others. This cross showed highest and significant positive heterosis. There were six relatively heterotic hybrids, four heterobeltiotic and eight standard heterotic hybrids. Shrivastava (1998) observed highest heterosis in the cross Marglobe x Hisar Arun for acidity.

5.3.12 Ascorbic acid

LE 415 x BWR-1 had high ascorbic acid content (46.0 mg). This hybrid also showed maximum and significant standard heterosis (78.64%). There were three relatively heterotic, five heterobeltiotic and ten standard heterotic hybrids. Dod and Kale (1992) observed highest value of heterosis in the cross Punjab chuuhara x S_{12} for ascorbic acid.

5.3.13 Reducing sugars

Among the hybrids, LE 415 x Mukthi showed highest positive and significant heterosis for reducing sugar content. There were nine relatively heterotic, eight heterobeltiotic and four standard heterotic hybrids. Kujur *et al.* (1998) reported heterosis in the hybrids Reshmi and Karnataka for sugar content.

5.3.14 Total sugars

The hybrid LE 415 x Mukthi recorded maximum and significant heterosis. There were six relatively heterotic, five heterobeltiotic and three standard heterotic hybrids.

5.4 Incidence of fruit cracking

All the F_1 hybrids were resistant to radial cracking, which shows that the genes responsible for radial cracking is dominant. Sakthi was susceptible to concentric cracking. The susceptibility of Sakthi to concentric cracking has already been reported by Sadhankumar (1995). All the hybrids involving Sakthi also showed susceptibility to concentric cracking. The genotypes LE-415, Mukthi and BWR-1 were resistant to both concentric and radial cracking. The resistance of LE 415 to both radial and concentric cracking was also reported earlier (Sadhankumar, 1995). He has also reported a dominant gene action for resistance to fruit cracking in LE 415.

5.5 Incidence of virus diseases

An attempt was made to evaluate the tomato genotypes/hybrids against the important virus diseases like leaf curl, mosaic and tomato spotted wilt. Among the 15 genotypes/hybrids tested, none was found immune to these diseases. However, field tolerant reaction, to these diseases, was noticed among some of the genotypes and hybrids.

As far as leaf curl infection is considered, maximum per cent infection was recorded in the hybrid Mukthi x LE 421, whereas LE 421 x BWR-1 showed the lowest leaf curl infection. In addition to this hybrid, LE 415 and it's combination with Sakthi, Mukthi and LE 421 also showed mild infection in which coefficient of infection varied from 2.03 to 5.03 only and these are categorised as highly field tolerant ones. Mishra *et al.* (1998) has reported resistance to leaf curl virus in the tomato crosses of Anand T-1 x BT-12 and H-24 x BT-12. Resistance to tomato leaf curl virus was also reported in tomato genotypes viz. H-11, H-22, H-106 and H-107 (Banerjee and Kalloo, 1998).

Regarding mosaic infection, the genotype LE 415 and it's crosses showed maximum field tolerance to the disease. Rajan and Sadhankumar (1998) reported tolerance to TMV in the lines LE 470, LE 474 and LE 471.

As compared to leaf curl and mosaic, spotted wilt infection was low among the genotypes/hybrids. The genotype Sakthi and the hybrids LE 415 x Mukthi and LE 421 x BWR-1 were found field tolerant to this disease. Highest incidence was noticed in the hybrid Mukthi x BWR-1. Resistance to tomato spotted wilt virus was reported earlier, in the cultivars Red Cheri Small and Italian Red pear by Joi and Summanwar (1986).

All genotypes/hybrids were found affected with both leaf curl and mosaic diseases. Maximum combined infection of leaf curl and mosaic was noticed in Sakthi and whereas the hybrid LE 415 x LE 421 recorded the minimum incidence.

SUMMARY

6. SUMMARY

The investigations on "Heterosis in bacterial wilt resistant tomato" was carried out during June, 1999 to March, 2000 at the College of Horticulture, Vellanikkara. The major objectives of the study were development of bacterial wilt resistant F_1 hybrids in tomato and estimation of heterosis in the wilt resistant F_1 hybrids.

Five bacterial wilt resistant parents viz. LE 415, Sakthi, Mukthi, LE 421 and BWR-1 were crossed in a diallel fashion (without reciprocals) to produce ten F_1 hybrids. These F_1 hybrids along with the parents were grown in a bacterial wilt sick plot to evaluate their reaction to bacterial wilt.

The hybrids LE 415 x Mukthi, LE 415 x Sakthi, LE 415 x BWR-1 and Sakthi x Mukthi were found resistant with survival percentages of 97.5 per cent, 95 per cent and 90 per cent and 82.5 per cent, respectively.

Good general combiners for different characters were identified. The parental lines LE 415 and Sakthi were good general combiners for maximum number of fruits/plant. LE 415 and Mukthi were good general combiners for fruit yield/plant and BWR-1 and Mukthi were good general combiners for average fruit weight. The best combination for fruit yield/plant, fruits/plant, average fruit weight and precocity was LE 415 x Mukthi.

The relative heterosis, heterobeltiosis and standard heterosis for forteen biometric characters were estimated. LE 415 x Mukthi was the best F_1 hybrid with maximum positive relative heterosis, heterobeltiosis and standard heterosis for fruits/plant, fruit yield/plant and average fruit weight. The hybrid Mukthi x BWR-1 had negative heterosis for plant height indicating it's dwarf character.

The biochemical constituents like T.S.S., acidity, ascorbic acid, reducing and non reducing sugars of the F_1 hybrids and the parents were estimated. The F_1 hybrid Sakthi x BWR-1 had a significantly higher content of total soluble solids and acidity. Similarly the hybrid LE 415 x Mukthi had a high content of reducing and non reducing sugars. This hybrid exhibited positive and significant heterosis for this character. The combination LE 415 x BWR-1 had maximum ascorbic acid content. This exhibited high positive standard heterosis for ascorbic acid.

The F1 hybrid which had the highest per se performance was LE 415 x Mukthi for fruits/plant (48.20 fruits/plant), fruit yield/plant (1499.5 g) and average fruit weight (43.15 g). It also had high reducing sugar content (3.09%) and total sugars (3.96%). The other promising F_1 hybrids were LE 415 x LE 421 (56 days) for earliness to flowering, LE 415 x BWR-1 (46 mg) for ascorbic acid content and Sakthi x BWR-1 (6.45°B) for T.S.S.

Genotypes/hybrids were also evaluated for fruit cracking. It was found that all the F_1 hybrids were resistant to radial fruit cracking, whereas all the hybrids except Sakthi x LE 421 and Sakthi x BWR-1 and the genotypes Sakthi and LE 421 were found to be resistant to concentric cracking.

Reaction of genotypes/hybrids to various virus diseases was also studied and none was found to be immune to these diseases. However, the hybrid LE 421 x BWR-1 and the genotype LE 415 and it's combination with Sakthi, Mukthi and LE 421 were found to be field tolerant to leaf curl virus disease. Similarly, the genotype LE 415 and it's combination with other genotypes showed maximum field tolerance to mosaic infection. Also, the genotype Sakthi and the hybrids LE 415 x Mukthi and LE 421 x BWR-1 were found field tolerant to the tomato spotted wilt virus disease.

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* Original not seen

Appendix-I. General analysis of variance for 15 characters in five genotypes of tomato and their 10 F_1 hybrids

Source of variation	df	Plant height	Days to flowering	Days to first harvest	Fruits/plant	Fruit yield/plant	Average fruit weight
Replication	1	5.63	0.30	16.13	46.00	1188.42	49.83
Genotype	14	57.60*	1.18	6.98	160.96**	192995.63**	64.43*
Error	14	22.35	0.73	3.20	40.16	12858.38	19.13

Appendix-I. Continued

Fruit shape index	Locules/fruit	Fruit flesh thickness	T.S.S. of fruits	Ascorbic acid	Acidity	Reducing sugars	Total sugars
0.003	0.0012	0.012	0.36	2.55	0.00012	0.014	0.035
0.012	0.198	0.46	0.64*	94.59**	0.29**	0.098**	0.34**
0.0073	0.147	0.22	0.19	3.96	0.015	0.0053	0.010

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

Appendix-II. Analysis of variance for combining ability in a 5 x 5 diallel in tomato

Source of variation	df	Plant height	Days to flowering	Days to first harvest	Fruits/plant	Fruit yield/plant	Average fruit weight
gca	4	28.92	0.51	2.08	121.55**	145175.9**	69.49**
sca	10	28.75*	0.62	4.06	64.05*	77026.53**	17.30
Error	14	11.17	0.36	1.60	20.08	6429.19	9.57

Appendix-II. Continued

Fruit shape index	Locules/fruit	Fruit flesh thickness	T.S.S. of fruits	Ascorbic acid	Acidity	Reducing sugars	Total sugars
0.0078	0.213	0.176	0.338**	104.90**	0.153**	0.028**	0.139**
0.0053	0.054	0.258	0.311*	24.25**	0.148**	0.057**	0.183**
0.0036	0.074	0.111	0.098	1.98	0.007	0.0027	0.0053

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

Appendix-III. Analysis of variance for diallel analysis for yield and it's components in tomato

Source of variation	df	Plant height	Days to flowering	Days to first harvest	Fruits/plant	Fruit yield/plant	Average fruit weight
Replication	1	5.63	0.30	16.13	46.01	176.19	49.82
Parents	4	20.25	0.25	5.35	40.17	48298.30*	136.05**
Hybrids	9	53.49	1.69	5.67	133.67	275231.53**	38.93
Parents Vs hybrids	1	244.02**	0.27	25.35*	32.91	31660.98	7.48
Error	14	22.35	0.73	3.20	40.17	12858.55	19.13

Appendix-III. Continued

Fruit shape index	Locules/fruit	Fruit flesh thickness	T.S.S. of fruits	Ascorbic acid	Acidity	Reducing sugars	Total sugars
0.003	0.0013	0.012	0.36	2.55	0.0001	0.01	0.03
0.006	0.45	0.55	0.86*	226.83**	0.14**	0.02*	0.52**
0.02	0.11	0.41	0.57*	34.56**	0.31**	0.14**	0.20**
0.000003	0.02	0.67	0.37	106.00**	0.86**	0.006	0.87**
0.0073	0.15	0.22	0.20	3.96	0.02	0.005	0.01

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

HETEROSIS IN BACTERIAL WILT RESISTANT TOMATO

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The investigation on "Heterosis in bacterial wilt resistant tomato" was undertaken in the Department of Olericulture, College of Horticulture, Vellanikkara during the period from June, 1999 to March 2000. The findings are mentioned below.

Five bacterial wilt resistant genotypes viz., LE 415, Sakthi, Mukthi, LE 421 and BWR-1 were crossed in a diallel fashion (without reciprocals) to produce ten F_1 hybrids. These F_1 hybrids along with the parents were evaluated for resistance to bacterial wilt in a wilt sick plot. The F_1 hybrids LE 415 x Mukthi, LE 415 x Sakthi, LE 415 x BWR-1 and Sakthi x Mukthi were found to be resistant.

The general combining ability of the parents and the specific combining ability of the crosses were estimated. The good general combiner for fruits/plant was LE 415 x Mukthi (48.2 fruits/plant). This hybrid was the best general combiner for fruit yield/plant (1.5 kg/plant).

The relative heterosis, standard heterosis and heterobeltiosis for different biometric characters were estimated. LE 415 x Mukthi was the best F_1 hybrid for fruits/plant (48.2 fruits/plant), fruit yield/plant (1.5 kg/plant) and average fruit weight (43.15 g). This hybrid was resistant to both radial and concentric fruit cracking. It was also tolerant to mosaic disease and tomato spotted wilt virus.