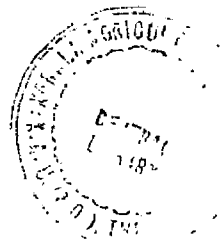
# INCORPORATION OF TOMATO LEAF CURL VIRUS (ToLCV) RESISTANCE IN BACTERIAL WILT RESISTANT TOMATO



By

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**THESIS**

Submitted in partial fulfilment of the requirement for the degree of


## Doctor of Philosophy in Horticulture

Faculty of Agriculture

KERALA AGRICULTURAL UNIVERSITY

Department of Olericulture

COLLEGE OF HORTICULTURE

VELLANIKKARA-THRISSUR-KERALA-680 656

2011

## DECLARATION

I hereby declare that the thesis entitled **"Incorporation of Tomato Leaf Curl Virus (ToLCV) resistance in bacterial wilt resistant tomato"** is a bonafied 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, associateship, fellowship or other similar title of any other University or society.

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## CERTIFICATE

Certified that this thesis entitled **"Incorporation of Tomato Leaf Curl Virus (ToLCV) resistance in bacterial wilt resistant tomato"** is a record of research work done independently by **Sri. Koteswararao Yadav, DVVR** 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 him.

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# *Acknowledgement*

To achieve a milestone is not an individual effort, but there is support, encouragement, and motivation involved from people around you. There are people who deserve my appreciation for successful completion of my Ph.D. program.

First, and foremost, I would like to acknowledge and extend my heartfelt gratitude to my major advisor, **Dr. Sadhankumar, P.G.,** Professor, Department of Olericulture for his guidance, supervision, and advice from very early stage of my research till the end. I really appreciate his professionalism, patience, experience, knowledge and noble personality. He constantly kept me challenging throughout my Ph.D. program that helped me learning by doing. He prepared me for a real world of vegetable breeding.

I hereby owe a debt of utmost gratitude and heartfelt thanks to my advisory committee soul, **Dr. T. E. George,** Professor and Head, Department of Olericulture for his guidance, untiring patience and constructive criticism throughout the investigation.

I express my sincere and heartfelt thanks to my advisory committee member, **Dr. S. Nirmala Devi,** Professor, Department of Olericulture for her guidance during the period of study.

I would like to express my heartfelt indebt ness and profound thanks to **Dr. Sally. K. Mathew,** Professor and Head, Department of Plant Pathology for her diligent encouragement and sustained interest, valuable suggestions throughout the investigation.

I express my sincere thanks to **Sri. S. Krishnan,** Associate Professor and Head, Department of Agricultural Statistics, member of advisory

committee for his valuable help and whole-hearted co-operation in the analysis and interpretation of the data and preparation of thesis.

I sincerely acknowledge the support and encouragement received from **Dr. T. Pradeepkumar,** Associate Professor, Department of Olericulture during my Ph. D.

I thankfully acknowledge the extreme co-operation and encouragement rendered by **Dr. Salikutty Joseph,** Professor, **Dr. K. V. Sureshbabu,** Professor, **Dr. Baby Lissy Markose,** Professor, **Dr. P. Indira,** Professor, **Dr. K. P. Prasanna,** Professor, **Dr. K. Krishnakumary** and **Dr. Sainamole Kurien,** Assistant Professor, during my Ph. D.

I am thankful to **Sri T. C. Sidharthan,** Farm Superintendent, **Sri. C. K. Santosh,** Farm Officer and **V. O. Joy,** Farm Officer for their co-operation and timely help during the study.

I am grateful to all staff members of the Department of Olericulture for the help rendered by them at various stages of my studies.

A special thanks to labourers of the Department of Olericulture. Especially to **Sri. K. Lekhidasan, Smt. Usha and Smt. Shobana** for their help throughout the studies.

I feel it highly privilege to express my gratefulness to my junior and senior friends **Sivaji, Manikanata, Alex, Kannan, Malu, K and Dr. Ratish.**

***"Friends are rear gifts"*** I wish to express my heartfelt thanks to my close and best friends **Capt. Viswanath Raju** (Pilot, Air India), **Subbu,** (Engineer, Tower Automotive), **Rajesh** (Business Analyst, KWE India), **Soori** (Engineer, L&T), **Jaggu** (Engineer, IBM Software) and **Dr. Basavaraj, M. Patil** for their inspiration, encouragement and support during the study and throughout my life who always stood by me in every step of my life. A special

thanks to **Sandeep, Venkat, Chiranjeevi, Raghava, Chinna Subbu, Sahithy, and Vinay.**

I feel it highly privilege to express my sincere thanks to Dr. K. Sekar, Professor, Department of Horticulture, Annamalai University who made my career foundation strong with his guidance in my post-graduation.

A bouquet of special thanks to **Siva Nageswararao,** Senior Breeder (Okra), Vibha Seeds and **Dr. Umashankar,** GM (Vegetable Research), Vibha Seeds for their encouragement and help in completing this study.

On personal note, I would like to remind other that ***"There could be no better parents and brother than mine"*** for showering mountains of love on me and need a special mention for their foundation to my successful educational career and the great source of continuous encouragement, sacrifice and inexhaustible love who always stood by me in every step of my life.

And I ardently express my indebt ness gratitude to my **Bava, Akka, Vadina** and my loving nieces **Chandani** and **Maanasa** for their love and affection.

Last but not least I would like to express my sincere heartfelt thanks to my fiancée **Shyamala yadav** for her constant prayers, support, continuous encouragement, sacrifices, love and affection, this study could not have been made possible. **A** special thanks to my sister **Sushmita yadav** for her support.

With the gratitude I also acknowledge the AVRDC, Taiwan and IIHR, Bangalore for timely sending the tomato genotypes for this study.

**KOTESWARARAO YADAV, D.**

*To my Chairman*

*Without his guidance this may not possible*

*To my Father*

*Who has given me everything That I Possess*

*To my Mother*

*For her endless prayers and strong support*

*To my BrotherVeeraiah Yadav*

*A friend, guide and inspiration to me*

*To Raju, Subbu, Rajesh*

*For their support in every stage of my life*

*And to my fiancéeShyamala Yadav*

*For her endless prayers and encouragement*

*I humbly and respectfully place this effort at your feet*

*-KOTIYADAV*

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# *Introduction*

# INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables crops grown throughout the world. In fact, it is the fifth important cultivated crop after rice, wheat, maize and potato. The fruits are consumed either as raw fruit or cooked or processed into various products like juice, ketchup, sauce, paste, puree etc. The popularity of tomato is rising among consumers, not only because of its good taste, but also because it contains high levels of vitamin A, vitamin C, potassium, phosphorus, magnesium and calcium. It also contains lycopene and beta-carotene, which are anti-oxidants that promote good health. The high demand for tomato makes it a high value crop that can generate much income to farmers. The main tomato growing countries in the world are China, U.S.A, India, Turkey, Italy, Iran, Egypt, Brazil, Spain and Mexico. FAO estimated a world production of 141.4 million tonnes of tomato from an area of 52.5 million hectares. India produces 111.49 lakh tonnes from an area of 5.99 lakh hectares and productivity of tomato is 18.6 t/ha (FAO, 2010).

In India, tomato has become a popular vegetable during last five decades because of its suitability for growing in all seasons. Hence, cultivation of tomato remains in the focus of the horticulture industry.

The area under tomato cultivation in Kerala is very meagre. The main limiting factor is the incidence of bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.* Symptoms of the disease include rapid and complete wilting of grown up plants. Pathogen is mostly confined to vascular region. Upon infection, bacterial polysaccharides mechanically block the vascular system, which check the translocation of water and other food material resulting in wilting of plants. The warm humid tropical climate and the acidic soil conditions favour the incidence of this disease in Kerala. Crop loss up to 100 per cent is reported due to bacterial wilt (Sadhankumar, 1995). This disease is wide spread in Karnataka,

Maharashtra, Orissa, Himachal Pradesh, Jharkhand and West Bengal. The pathogen is soil borne and survives at least for two years even in the absence of any host (Shekhawat *et al.*, 1979). Due to the soil borne nature of the pathogen chemical control measures have not been successful in controlling this disease. Use of resistant varieties is the obvious method to tackle this problem.

Resistance is a universal phenomenon for all kinds of phytophagous parasites (De Ponte, 1983) but understanding of genetics of resistance has been considered as a major contribution for progress in resistance breeding (Meiners, 1981). Donors of resistance are pre-requisite for the development of resistant varieties which are identified by the well-established technique like screening of germplasm and further assessment of the genetic material.

The inherent potential of a genotype to impart resistance is determined by the resistance mechanism in it. It is the genetic control exercised through gene action that decides upon the manifestation of a particular trait in a genotype. The different gene systems like polygenic, monogenic dominant, monogenic recessive and partially dominant operate in bacterial wilt resistant genotypes.

Resistance breeding taken up in Kerala Agricultural University has so far resulted in the development of three bacterial wilt resistant varieties *viz.*, Sakthi, Mukthi, Anagha and one tolerant variety Vellayani Vijay. These varieties are susceptible to another serious disease caused by Tomato leaf curl virus (ToLCV) necessitating the development of varieties resistant to this disease as well. Tomato leaf curl virus (ToLCV) disease is one of the most serious diseases of tomato in Indian sub-continent and many other tropical and subtropical Asian countries. This disease is caused by geminivirus transmitted by the whitefly *Bemisia tabaci* (Gennadius) (Anbinder *et al.*, 2009). The affected tomato plants exhibit curling,

puckering, reduction in leaflet size, severe stunting and reduction in fruit set. However, severely infected young plants almost fail to produce any fruits. This disease can cause yield losses up to 99-100% (Singh *et al.*, 2008). Chemical control measures as well as integrated pest management (IPM) strategies employed for controlling the vector have not been successful in controlling the disease. Under these circumstances breeding for resistant varieties appears to be a promising and eco-friendly approach for controlling the disease.

Development of a variety resistant to both bacterial wilt and ToLCV diseases will be a boon to tomato cultivators in Kerala and elsewhere. Keeping this as the ultimate aim, the present study was undertaken with the following objectives.

1. To find new/additional source(s) of resistance to bacterial wilt.
2. To find tomato varieties resistant to tomato leaf curl virus disease (ToLCV).
3. To incorporate resistance to ToLCV in bacterial wilt resistant tomato genotypes.
4. To study the genetics of ToLCV resistance.

# Review of Literature

# 2. REVIEW OF LITERATURE

The review of literature on evaluation of tomato genotypes for bacterial wilt resistance and Tomato leaf curl virus resistance (ToLCV), and on genetic basis of Tomato leaf curl virus (ToLCV) resistance in tomato is briefly dealt in this chapter.

## 2.1 EVALUATION OF TOMATO GENOTYPES FOR INCIDENCE OF BACTERIAL WILT

### 2.1.1 Pathogen

Bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.* has remained a major destructive plant disease in the warm humid tropics of the world. The pathogen is known to attack a wide range of host plants. It attacks more than 200 plant species belonging to 33 families. Of these family *solanaceae* has the largest number of hosts (Kelman, 1953). The disease was first reported by E. F. Smith in Florida in 1897 (Rolfs, 1898).

The first report on bacterial wilt of tomato in India was by Hedayathullah and Saha (1941).

The following *Ralstonia solanacearum* scientific classification was reported by Tahat *et al.*, (2010).

Kingdom: Bacteria

Phylum: Proteobacteria

Class: Beta Proteobacteria

Order: Burkholderiales

Family: Ralstoniaceae

Genus: *Ralstonia*

Erwin. F. Smith published the first description of *Pseudomonas solanacearum* E. F. Smith, which causes a wilt disease of solanaceous plants (Smith, 1896).

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

**Race 1 (Solanaceous strain)** – It has wide host range, distributed throughout the lowlands of tropics and subtropics. They attack tomato, tobacco and many solanaceous and other weeds.

**Race 2 (Musaceous strain)** – This is restricted to *Musa* spp. and a few perennials hosts initially limited to American tropics and spreading to Asia.

**Race 3 (Potato strain)** - This is restricted to potato and few alternate hosts in tropics and subtropics.

Two additional races affecting *Zingiber officinale* and mulberries (*Morus* spp.), respectively, were also distinguished (Buddenhagen, 1986).

**Race 4 (Ginger strain)** - Affects ginger in much of Asia and Hawaii.

**Race 5 (Mulberry Strain)** - This was described in 1983 by He *et al.* after conducting a study of 29 isolates from China. One strain (three isolates) from mulberry did not belong to the known biotypes. They produced acid from lactose, maltose, cellobiose and mannitol, but not from dulcitol and sorbitol. They were only slightly pathogenic to potato and eggplant by stem stab inoculation.

Hayward (1964) classified *Pseudomonas solanacearum* into biotypes or biochemical types namely biotype-I, biotype-II, biotype-III and biotype-IV, based on their ability to oxidise various carbon sources and on other bacteriological reactions.

1. Biotype I – Doesn't oxidise disaccharides and sugar alcohols
2. Biotype II – Oxidise only disaccharides
3. Biotype III – Oxidises both disaccharides and alcohols
4. Biotype IV – Oxidises only hexahydric alcohols

In a study of thirty tomato isolates of *Pseudomonas solanacearum* from Assam and Orissa, it was concluded that all isolates belonged to race 1 (Addy *et al.*, 1980).

Survival of *Pseudomonas solanacearum* in the rizhosphere 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.

RFLP

Cook and Sequeria (1988) used RFLP technique to study the relationship between biovar I to IV of Hayward and races 1, 2 and 3 of Buddenhagen *et al.* They divided *Pseudomonas solanacearum* 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 biovar. For example, race 3 strains produced a very distinct gel pattern which suggests that race 3 is a homogenous 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 heterogenous.

Kumar *et al.* (1993) differentiated twelve isolates of *Pseudomonas 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 sub type in biovar III. All the isolates utilised glucose, fructose, sucrose, galactose and glycerol.

Biovar III of *P. solanacearum* can be differentiated from biovar V based on its ability to utilise the sugar alcohols, sorbital and dulcitol (Hayward, 1994).

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

*R. solanacearum* passes much of their life cycle living in harmony or in an uneasy truce with their host plants (Allen, 1997).

The genetic variation among strains of *R. solanacearum* belonging to race 2 and related bacteria was investigated by polymerase chain reaction amplification with random primers. A transposon induced mutant *R. solanacearum* strain has lost pathogenicity on its natural host, banana, but is still retaining the ability to wilt tomato (Thwaites *et al.,* 1997).

Paul (1998) identified bacterial wilt affected tomato and chilli isolates as *R. solanacearum* race 1 biovar III.

Mathew *et al.* (2000) conducted studies on the isolates of *R. solanacearum* from tomato, brinjal and chilli and identified the pathogen as race 1, biovar III and biovar V.

Variability studies conducted on the isolates of *R. solanacearum* of tomato, brinjal and chilli from different locations of Kerala showed the existence of pathogen belonged to race 1, race 3 and biovar III, III A and V (James, 2001 and Mathew, 2001).

Phylogenetic analyses based on different molecular approaches including RFLP sequence analysis of the 16S–23S rRNA intergenic spacer region (ITS), polygalacturonase and endoglucanase genes, and PCR-RFLP of the hrp genes region, reported that *R. solanacearum* may be regarded as a species complex. This species involves four different phylotypes related to the geographical origin of the strains, namely Asiaticum (phylotype-I), Americanum (phylotype-II), Africanum (phylotype-III) and Indonesian (phylotype-IV) (Fegan and Prior, 2005).

1. Phylotype-I (Asian group)
2. Phylotype-II (American group)
3. Phylotype-III (African group)
4. Phylotype-IV (Indonesian group)

Tomato crops can be infected by highly diverse race 1 lowland tropical strains of *R. solanacearum,* which are distributed in all four phylotypes. The race 3 highland temperate strains belonging to phylotype II (race 3- phylotype II), while being primarily adapted to potato (brown rot disease), are also pathogenic to tomato in natural environments.

### 2.1.2 Ecology of the pathogen

The ecology of the pathogen in infested soils is poorly understood. It is inferred that the primary inoculum came from the soil but there was no

conclusive evidence that the pathogen is a ubiquitous inhabitant in the soil (Buddenhagen and Kelman, 1964). Under natural conditions, the pathogen was able to survive saprophytically in the soil for as long six years (Chester, 1950).

*Ralstonia solanacearum* does not survive in the soil for prolonged periods because it is not a strong competitor. It does not survive in the soil itself but survives on or in plant roots. The bacterium appears to survive by continually infecting the roots of susceptible or carrier plants or by colonising the rhizospheres of non-host plants (Sequeira, 1993). 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.

### 2.1.3 Symptomatology

Walker (1952) reported that the first expression of the disease is wilting of the lower leaves of the plants and it leads to the entire wilting of the plants. Dwarfing or stunting of the plants may also occur.

The entry of the pathogen is through the root system and it was believed that a wound is necessary for the entry (Walker, 1952; Kelmen, 1953; Chupp and Sherf, 1960). Hildebrant (1950) reported the entry of the bacterium through natural opening of the plant. Chupp and Sherf (1960) reported that the 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. The pathogen enters into the uninjured roots also (Libman *et al.,* 1964).

Eventually, dark brown to black areas develop due to decay of root systems and the whole plant dies off. A very distinct characteristic

indication of bacterial wilt is the appearance of bacterial ooze from the injured vascular regions (Ashrafuzzaman and Islam, 1975).

According to Hussain and Kelman (1957), breakdown of plant tissues by the pathogen is due to the cellulase and polygalacturonase enzymes produced by the pathogen. Continued tissue decay and plugging finally result in the death of the plant.

Visible symptoms of the disease occur within 2 to 8 days after the entry of the pathogen into the host plant (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, at least in part by the quantitative differences in EPS (extra 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.

Sequeira (1993) reported that 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 treachery elements, where it is exposed between the spiral thickenings.

### 2.1.4 Disease cycle and epidemiology

*Ralstonia solanacearum* is a soil borne and waterborne pathogen; which can survive and disperse for various periods of time in infested soil or

water, which can form a reservoir source of inoculum. The bacterium usually infects tomato plants through the roots (through wounds or at the points of emergence of lateral roots). Soil borne organisms, such as the root-knot nematode, can cause injury to plant roots and favour penetration of the bacterium.

Plant infection can also occur through stem injuries caused by cultural practices or insect damage. In some cases, plant-to-plant spread can occur when bacteria move from roots of infected plants to roots of nearby healthy plants, often via irrigation practices. Spread of bacteria by aerial means and subsequent plant contamination through foliage is not known to occur, thus making *R. solanacearum* a non-airborne pathogen. High temperatures (29-35°C) play a major role in pathogen growth and disease development. Several other factors that may affect pathogen survival in soil and water may also favour disease development, including soil type and structure, soil moisture content, organic matter in soil, water pH and salt content, and the presence of antagonist microorganisms.

The bacterium also has an "exterior" phase (epiphyte) in which it can reside on the outside of the plant. It is of minor importance in epidemiology of the pathogen since bacteria do not survive epiphytically for long periods of time when exposed to hot conditions or when relative humidity is below 95%.

Under favourable conditions, tomato plants infected with *R. solanacearum* may not show any disease symptoms. In this case, latently infected plants can play a major role in spread of the bacterium. Transplants are either field-grown (not common anymore) or container-grown in greenhouses. Cultural practices at either field production (high plant density, use of irrigation several times a day, multiple clipping, or plants undercutting before harvest) or greenhouse production (overhead irrigation or plant handling) may favour plant infection and spread of the pathogen

from infected tomato transplants production sites to healthy tomato growing sites.

*R. solanacearum* can survive for days to years in infected plant material in soils, infested surface irrigation water, and infected weeds. From these sources of inoculum, bacteria can spread from infested to healthy fields by soil transfer on machinery, and surface runoff water after irrigation or rainfall. *R. solanacearum* can also be propagated in infested ponds or rivers and disseminated to non-infested fields through waterways. Infected semi-aquatic weeds may also play a major role in disseminating the pathogen by releasing bacteria from roots into irrigation waters.

At low temperatures (<4°C) bacterial population densities fall rapidly but the bacteria still can survive, often in a physiological latent state. In natural habitats, *R. solanacerum* race 3 biovar 2 can survive the winter in semi-aquatic weeds, in plant debris or in the rhizophere of non-host plants that act as reservoirs for the pathogen. Bacteria were shown to be increasingly released from semi-aquatic weeds after winter when temperatures start to increase.

### 2.1.5 Diagnosis and identification

Symptom identification is the first step for early diagnosis of bacterial wilt of tomato. Accurate identification of *R. solanacearum* from either symptomatic or asymptomatic plants and from water or soil samples demands multiple microbiological and molecular methods. A battery of complementary tests that differ in their sensitivity and/or specificity should be used for field or laboratory analyses for unambiguous identification of bacteria to species and biovar.

Screening tests can facilitate early detection and identification of bacteria in potentially infected plants or contaminated soil and water samples by *R. solanacearum*. They cannot be used to identify the race or

biovar of the organism. These screening tests include stem streaming, plating on semi-selective medium (modified SMSA), immunodiagnostic assay using *R. solanacerum* specific antibodies, nucleic-acid-based identification using *R. solanacerum* specific primers, and pathogenicity assessment using susceptible hosts (e.g. tomato seedlings). Several rapid screening tests, such as immunostrips (Agdia), are available commercially for rapid and field detection of *R. solanacearum.*

A biochemical growth test is used for biovar determination of *R. solanacearum.* This test is based on the differential ability of strains of the pathogen to differentially produce acid from several carbohydrate sources, including disaccharides and sugar alcohols.

At the sub-species level, identification of strains of *R. solanacearum* can be assessed with several nucleic-acid based methods such as DNA probe hybridization and especially polymerase chain reaction (PCR) amplification with specific probes and primers.

Race determination is not generally possible because *R. solanacearum* strains usually have numerous hosts and do not have race-cultivar specificity on plant hosts.

### 2.1.6 Host Range

The destructiveness of the disease is due to wide host range of the casual organism. In Kerala, bacterial wilt was first reported to cause severe damage to solanaceous vegetables in the early 1960s. The disease has since been reported from 30 plant species belonging to 15 families. Major economic hosts of the pathogen are tomato, chilli, brinjal (Devi, 1964; Rahim, 1972; Nayar, 1982), potato, groundnut, (Devi, 1978), ginger (Mathew *et al.,* 1979) and cucrbits (Mathew *et al.,* 1994; Mathew *et al.,* 2002). The other hosts include sesame, marigold, petunia, zinnia, weed hosts *Acanthospermum hispidum, Ageratum conyzoides, Blainvillea*

*rhomboidea, Euphorbia geniculata, Hyptis suaveolens, Oldenlandia corymbosa* (Devi, 1978), *Casuarina equisetifolia* (Ali *et al.*, 1991), *Coleus vettiveroides* (Estelitta *et al.*, 1992), mulberry, nutmeg (Mathew *et al.*, 1993a and 1993b), Patchouli (Mathew *et al.*, 1994), moringa (Estelitta *et al.*, 1997), cowpea, *Dolichos lablab* and *Chromolaena odorata* (Kumar and Sarma, 1999).

### 2.1.7 Characteristics of the Pathogen

*Ralstonia solanacearum* is gram negative, rod shaped, and measuring 1.5-2 x 0.5-0.7 µm in size, motile and aerobic. But under some circumstances, it grows anaerobically in media containing nitrate and an appropriate carbon source. It can be grown in agar medium, tyrosine medium or in potato and slime production on peptone beef extract agar medium (Nayar, 1982) and ginger isolate on peptone casamino acid and nutrient agar media (Samuel, 1980). On triphenyl tetrazolium chloride (TTC) medium, most of the isolates showed circular, smooth, raised, creamish white colonies with pink centre and convex with entire margin. However, some weakly virulent isolates are creamish white with reddish pink centre. Biovar V type isolates produced irregular round, rough, flat, creamish white with pink centred colonies (Mathew, 2001). Spiral pink centre colonies are observed in case of ginger isolates (Kumar and Sarma, 2004). Colony size of the isolates varied from pinpoint to big. Growth, fluidity and slimness are highly varying with isolates collected from different hosts and locations. Optimum temperature for growth of the isolates varies from 30-35°C and temperature for growth of the isolates varies from 30-35°C and temperature above 45°C is lethal to the pathogen. The pH requirement for the growth is 5.5-7.0. The bacterium lacks fluorescence and a brown diffusive pigment is produced on King's B medium supplemented with tyrosine. The pathogen loses its virulence very rapidly in culture due to transformation to avirulent mutants and the virulence is retained by preserving the culture in sterile distilled water at

room temperature (22-25°C) or under refrigerated condition (4°C) and in 20 percent glycerol at - 80°C for long term storage (Kumar and Sarma, 2004). Among the different methods of inoculation, leaf clipping (Mathew, 2001), root dipping (Paul, 1998; James, 2001) and pseudostem inoculation (Sambasivam, 2003) are the best method. For the artificial inoculation of the pathogen, fresh bacterial ooze suspension of $OD_{600nm}$ = 0.3 is the best inoculums to ensure uniform, maximum and rapid development of wilt symptoms rather than cultural suspension.

Isolates of bacterial wilt pathogen isolated from different hosts are similar to each other in terms of physiological and biochemical properties. Isolates of *R. solanacearum* did not hydrolyse starch or produce indole and utilize asparagine as a sole source of carbon and nitrogen. None of the isolates is found to liquefy gelatine. Isolates are positive for urease and tyrosinase activity and for production of the hydrogen sulphide and also show low level of salt tolerance. Among the sodium salts of organic acid, only acetate and benzoate are utilized and not citrate. Variation in reaction either acidic or alkaline in milk noticed for different isolates. Isolates also showed positive MR but negative VP tests. All the carbon compounds except cellulose are utilized by the isolates (Nayar, 1982; Jyothi, 1992). All isolates are positive for solubility in 3 percent KOH, oxidase, oxidative reaction, catalase, lipase activity and nitrate reduction. All isolates utilized carbohydrates with or without gas production and the amount of gas production varied with different isolates. The colonies on nutrient agar with 5 percent sucrose are fluidal, opaque and tend to coalesce showing negative reaction for levan production. All isolates showed negative reaction for ammonia production (Mathew *et al.*, 2000). In the intrinsic antibiotic resistance pattern studies, pathogen showed resistance to ampicillin, rifampican, tetracycline and polymyxin-B-sulpahte and sensitivity to chloromycetin, kanamycin, chloramphenicol, streptomycin sulphate and streptocycline (Rani, 1994; Akbar, 2002; Sambasivam, 2003; Kumar and

Sarma, 2004). All solanaceous isolates showed sensitivity to plant extracts of *Adhathoda vasica, Chromolaena odorata, Allium sativum, and Ocimum sanctum* at 10 per cent concentration under *in vitro* condition (Mathew, 2002).

### 2.2.1 Resistance Breeding

Bacterial wilt caused by *Ralstonia solanacearum* Yabuuchi *et al.*which is soil borne pathogen it can be survived in the soil upto two years without any host. Due to the wide range of the pathogen it is very difficult to control the pathogen by any chemical methods. Host plant resistance is the obvious method to tackle this problem and environmentally safe, with low running costs. Therefore, breeding tomato cultivars possessing inbuilt resistance is an appropriate approach for disease management.

## 2.3 SOURCES OF BACTERIAL WILT RESISTANCE

The bacterial wilt resistant gene was introduced into commercial tomato cultivars from the wild species *L. peruvianum,* using embryo rescue of an interspecific cross of the wild species with *L. esculentum* (Smith, 1944).

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). Similarly trials conducted in Sri Lanka involving several North Carolina lines indicated resistance in Masterglobe and Rahangala to bacterial wilt (Abeygunawardena and Siriwardena, 1963). They further reported that North Carolina lines 1960-8, 1960-2a, 1962-2b, 1861-57-55m to be the most resistant and these lines were superior in wilt resistance to locally cultivated varieties and out yielded the commercial varieties *viz.,* Masterglobe and Pearson.

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 the genotypes such as Venus, Saturn and Beltsville-3814 to be resistant to bacterial wilt.

The resistance in Hawaii 7998 can be traced to PI 127805A, a *L.pimpinellifolium* line (Gilbert *et al.*, 1973).

Ahuja and Waite (1974) observed more than 90 per cent survival of the seedlings in BWN-514, BWN-16, BWN-17 and BWN-7755 against the attack from the pathogen *P. solanacearum.*

Ferrer (1974) identified CRA-66 from the Caribbean area, Hawaii 7997, Hawaii 7981, PI 126408 were sources of resistance to *Pseudomonas solanacearum* these included.

Khan *et al.* (1974) reported that genotypes Saturn and Venus were moderately susceptible to potato strains of *R. solanacearum,* while tomato line 65-551-3 was resistance to all the three strains of *R. solanacearum.*

Rao *et al.* (1975) tested 23 wilt resistant cultivars and lines from USA and Philippines for their reaction to an Indian isolate of *R. solanacearum* and only one line CRA 66 selection A from Hawaii was found to be resistant, Jenkins and Nesmith (1976) evaluated the resistance of cultivars Venus and Saturn against two isolates of *R. solanacearum* from America and India. They found that both the cultivars were highly resistant

to American isolate and also reported that the Indian isolate were more pathogenic than American isolate.

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

Sonoda (1977) evaluated 121 lines for resistance to bacterial wilt pathogen and found that the cultivars Venus, Saturn and line PI-126408 as most resistant.

Mew and Ho (1977) showed the resistance to bacterial wilt in the parent, VC 9-1, but it was unstable at soil temperatures above $32^0$ C.

Augustine (1978) found that the lines PI 365950, PI 212441, and PI 263722 resistant to bacterial wilt.

Volin (1978) found tolerance to bacterial wilt in progeny from BWN-21 (an $F_1$ hybrid between Kewalo and Venus) from Hawaii.

Villareal and Lai (1979) reported that lines VC-11-7 and Kewalo derived their resistance from *Lycopersicon pimpinellifolium* PI-127085A.

Sonoda *et al.* (1979) have been identified several sources of resistance to Florida isolates of the pathogen. The best sources of resistance among them are H 7997, CRA 66 and PI 126408.

Ramachandran *et al.* (1980) evaluated 36 tomato lines for their resistance to bacterial wilt in Kerala. They observed resistance in La-Bonita and CL 32 d-0-19 GS cultivars. Similarly Celine (1981) reported field tolerance in the line CL 32 d-0-1-19 GS.

Sixteen tomato accessions were screened for resistance to *Pseudomonas solanacearum* inside a screen house. Of the 16 accessions tested, six accessions were rated resistant; three, moderately resistant; one,

moderately susceptible and six, susceptible. The resistant accessions produced locally acceptable fruits that were of medium size and red color when ripe; however, accessions 77 and 145 yielded green-shouldered fruits (Atabug *et al.*, 1981).

Wilt resistance in cultivar Venus and the line CL 32 d-0-1-19 GS 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 (Goth *et al.*, 1983). He also suggested that nematode should be considered as a factor in the development of bacterial resistant lines.

Tikko *et al.* (1983) reported the presence of two independent gene systems for wilt resistance. The resistance was governed by multiple recessive genes in CRA 66 Sel A from Hawaii and by single dominant gene in IHR 663-12-3 from Taiwan.

Scorpio is a derivative from a cross between VC 9-1 and Floradel and found to be resistant to bacterial wilt and good fruit quality attributes (Peterson *et al.*, 1983).

Bosch *et al.* (1985) reported that the back cross progeny of the cultivar Rodade showed the resistance of 72 to 100 per cent.

Moffett (1986) reported bacterial wilt 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.

BWR-1 a pure line selection with a dominant gene for bacterial wilt resistance was developed from AVRDC accession L33 (VC 8-1-2-1) (Tikko *et al.*, 1986).

More than ten years were spent in evaluating the materials and after several selections, MARDI has finally recommended six heat-tolerant and bacterial wilt resistant lines (MT 1, MT 2, MT 3, MT 5, MT 6 and MT 10) which outperform the local cultivars Banting and Local White (Melor, 1986).

Hanudin (1987) reported that tomato cultivars Intan, Ratna, CI 32-6-125-d-0, AV-22, AV-15 were found to be resistant to *P. solanacearum,* whereas, Apel Balgi, Venus, Bonset, Monresist and Goldenton were moderately resistant. On the other hand, cultivars Rostraro, Monalbo, Gondol, Hija, Moneymaker, Basket Vee and Top Set RR were susceptible and cultivars. Marvel, Swift-367, F-197, Tm-VF-2N and Lucy Tm were highly susceptible to *P. solanacearum.*

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

Jaworski *et al* (1987) evaluated 2,064 tomato accessions in the field with natural and artificial inoculation of indigenous strains of race 1 biovar 1, including 72 *S. pimpinellifolium,* 60 *S. peruvianum,* 4 *S. habrochaites,* and 6 *S. habrochaites* f. *glabratum* (previous known as *L. hirsutum* f. *glabratum*). In this study GA 1405-1-2 BWT, a selection from PI 251323 (*S. pimpinellifolium*) was the only wild accession among the four selected resistant materials. The remain three are PI263722, PI126408, PI196298 (*S. lycopersicon*)

Ho (1988) screened resistance in genotypes for bacterial wilt and observed that cultivar MT-1 was highly resistant and MT-2, MT-3, MT-5, MT-7, MT-8, MT-10, MMT-11 were moderately resistant and Banting, MT-9 were susceptible and MT-6 was highly susceptible.

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.

Toyoda *et al.* (1989) selected the leaf explants-derived callus tissues, which were resistant to toxic substances, derived from *P. solanacearum,* in the culture filtrate and they were regenerated into plants. These plants expressed resistant to *P. solanacearum* at the early infection stage by suppressing or delaying the growth of inoculated bacteria. Complete resistance was obtained in self-pollinated progeny of regenerants derived from non-selected callus tissues. He also found that these plants showed high resistance when inoculated with the virulent strain used in the experiment, and were also resistant when planted in a field infested with a different strain of the pathogen.

The most widely used bacterial wilt stocks in the breeding programme are Venus (USA), Saturn (USA), L366 (Unknown origin), VC 11-3-1-8 (Philippines), VC 48-1 (Philippines), PI 406994 (Panama) and a few more, mostly coming from the tropical Southeast Asian countries (Opena *et al.,* 1989).

Girard *et al.* (1989) Screened 121 tomato varieties for resistance to bacterial wilt, only three were found satisfactory: MST 32-1, MST-21-23 (AVRDC, Taiwan) and Caribo (INRA, France).

A bacterial wilt tolerant multiline called NTR has become popular in the highlands West Java. It has also been tested in the swampy lowland areas of South Sumatra where it performed better than Intan, Ratna, Berlian and C1-1094 (Permadi, 1989).

Advanced breeding lines, especially CL 119-1-2-0, CL 143-0-4B-1-0-0, CL8d-0-1-1-0-0-0 and CL 32d-0-1-1-p-0-0-0 from AVRDC, have formed the bulk of the materials being used in an attempt to incorporate resistance to bacterial wilt in commercial lines (Erinle, 1989).

Prior *et al.* (1990) studied the spread of the bacterium in the plants was investigated by ELISA at different stem level. Although the cultivars Hawaii, Caraibo and Carmido were tolerant in the field (respectively 5, 10 and 15% mortality), the analyses revealed that their vascular system was invaded by *P. solanacearum*.

Kapoor *et al.* (1991) screened exotic and Indian tomato lines/varieties for resistance to *R. solanacearum* during 1987-89. Of the 62 varieties screened, nine were immune, 26 resistant, five moderately resistant, four moderately susceptible and 18 were susceptible.

In filed trails at Bangladesh Agriculture University, Mymersingh, the tomato cultivars Manik and Asa-4 were highly resistant to natural infection by *R. solanacearum,* Tustic and Bikash were resistant, while Oxheart, TM 008, Ratan and TM-0003 were moderately resistant (Islam and Rahman, 1991).

Anand *et al.* (1992) reported dominant gene action in the $F_1$s of BWR-1, BWR-5, 1661, 15 SB and 1836 and incomplete dominance in the $F_1$S of 1881 and Sonali for resistance to bacterial wilt.

The lines LE-214, LE-217, LE-79, LFG, LE-79 DG and LE-79 SPF were found to be resistant (Peter *et al.,* 1992).

The most resistant germplasm in the AVRDC collection is L 285, a primitive type (*L. esculentum* var.*cerasiforme*) and CLN 65-349. (Opena *et al.,* 1992)

Scott *et al.* (1993) conducted a yield trial comparing tomato breeding lines and control varieties. The trial results indicated that one breeding line Fla. 7421 had greater bacterial wilt tolerance than susceptible 'Solar Set'.

Varieties identified to have resistance to bacterial wilt included CLN-475-BC1 F2-265-9-0, CL-6046 (AVRDC); LV-2100 and LV 2099 (Indonesia); BL-7802, FMTT-13 and BC3F2-51-0-20-5-1 5-14-1 (Philippines) (AVRDC, 1993).

High populations of *Pseudomonas solanacearum* were detected in some, but not all stems of bacterial wilt resistant ('CRA 66', 'Hawaii 7996' and 'Caraibo') and susceptible ('Floradel') tomatoes. Latent infection, i,e. spread of *P. solanacearum* into xylem vessels, was confirmed in Caraibo, Hawaii 7996 and CRA 66. None of the plants within the resistant cultivars wilted and those cultivars were characterized by tolerance of the vascular tissues to high bacterial densities. In contrast, plants of cultivar Floradel showed consistent symptoms and wilted rapidly, with higher mean bacterial density than resistant cultivars (Grimault *et al.*, 1993).

In Malaysia, a total of 24 AVRDC and three local accessions of tomato were screened in three trials. In the first trial, eight AVRDC accessions together with the resistant check L-285 and local checks MT 1 and MT 11 were found resistant, having more than 90 % survival rate. BL 355 was found to be completely resistant (100% survival rate) with high yield. In the second trial, BL 31 2, CL 591 5-223D4-2-1 -0 and CL 591 5-20GD4-2-5-0 showed very high resistance, with 100%, 99.55% and 99.51 % survival rate, respectively (AVRDC, 1993).

Three IBWDN (International bacterial wilt disease nurseries) trials of 26 AVRDC and four local accessions of tomato were carried out in the Philippines. Results of these three trials showed that local varieties TmL 46-N-12-N-early H.T., Tm L114-46-5-N-spreading and F7-80-465-10-Pink were resistant with mean survival rates of 84.87%, 83.27% and 81.57%, respectively. Local variety R3034-3-10-N-UG together with two AVRDC accessions BL 333 and BL 355 and the resistant check L 285 were rated moderately resistant (AVRDC, 1993).

In Thailand, results of IBWDN (International bacterial wilt disease nurseries) trials showed three out of 16 tomato accessions with resistant reaction to bacterial wilt. These were BL342, CL143-9-10-3-0-1-10 and CL 1 131 -0-0-43-4-1 2 (AVRDC, 1993).

Chellemi *et al.* (1994) in an effort to screen for bacterial wilt resistance of tomato, found that among 30 genotypes, Hawaii 7997, CRA 66, GA 219 and GA 1565 showed high resistance and cultivars Carvel, Neptune, Captain and Calinago were moderately susceptible.

Prior *et al.* (1994) reported that the bacterial wilt resistance in cultivated tomato originated from *L. esculentum* var. *cerasiforme* or *L. pimpinellifolium*

Chellemi *et al.* (1994) evaluated resistance of tomato bacterial wilt in nineteen tomato genotypes. Mean incidence of disease ranged from 30 per cent with North Carolina strain to 95 per cent with North Florida strain. Hawaii 7997, Hawaii 7998, and CRA 66 had the lowest incidence of disease, regardless of inoculation method. The results indicated significant pathogen diversity and using combination of resistance screening techniques could facilitate evaluation of many genotypes.

A new source of resistance was identified from *Lycopersicon esculentum* var. *cerasiforme* LA 1421 (Mohamed, 1994); the genetic nature of this new resistance from LA 1421 has, not been reported.

AVRDC recommends resistant or tolerant varieties include 'Arthaloka' in Indonesia, 'Delta' in Thailand, and 'Taichung AVRDC 4' in Taiwan (Wang and Lin, 1994).

The bacterial wilt resistant tomato varieties (KWR, T245, T146) are released by the Department of Agriculture, Sri Lanka were popular among

the farmers in the past; however, some of these varieties are now susceptible to bacterial wilt in some areas (Gunathilake *et al.*, 1994).

In an experiment on screening genotypes resistant to *R. solanacearum* biovar I 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.

A monogenic dominant resistance was reported in Hawaii 7996 (Grimault *et al.*, 1995).

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.

Gonzalez and Summers (1995) evaluated seven tomato lines which were resistance to bacterial wilt and could be used as hybrid parents namely Venus, Saturn, Rodade, Rortam 4, Hawaii 7998, UC-82B, Stevens and their 21 crosess. GCA mean squares were significant for all the strains indicating additive type of inheritance and Hawaii 7998 transmitted greater resistance that other resistant parents.

Williams and William (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 that the other resistant parents used.

Vudhivanich and Soontarasingh (1995) in an effort to screen for bacterial wilt resistance of tomato, found that among 9 genotypes, CL-5915 and 233 D4-2-1-0 showed resistance and Seedathip-2, CI-153, Mishou, Seedathip-502 and VF 134-1-2 were moderately susceptible.

Nine tomato varieties were inoculated with 1*10*[8] cfu/ml of *P. solanacearum* Nakorn Pathom isolate. Among the nine varieties Cl5915-233D4-2-1-0 shows resistance, Cl 184 and Cl 5915-206D4-2-5-0 moderately resistance and Seedathip 2, Cl 153, Mishou, Seeda, P 502 and VF 134-1-2 moderately susceptible (Sasitorn and Sug, 1995).

In Nepal, based on preliminary screening among 26 tomato cultivars tested in naturally infested fields, only BL 333 showed resistance to bacterial wilt. This variety could be a good source of resistance. And BL 323, BL 341, BL 342, and BL 355 these four lines were moderately resistant to bacterial wilt (AVRDC, 1996).

In Bangladesh, among lines tested under artificial inoculation conditions, TM 006, Manik, T-C, T-D, Doutyl 90CRS2, and TM 080 were found resistant to bacterial wilt in the 1994-95 cropping season (AVRDC, 1996).

In India, eight tomato lines showed 100 per cent survival in the field. These were BL 312, BL 410, CL 8d-0-7-1, CL 591 5-93D-4-1-0, CL 1143-0-1 0-3-0-1 -1 0, CL 591 5-206-D4-2-2-0, CL 65-349-D5-2-0, CL 675-BC1F2-285-0-21-0 (AVRDC, 1996).

In a preliminary field screening in Pakistan five tomato lines BL 350, BL 342, BL 341, BL 333, L 285 showed tolerance to bacterial wilt (AVRDC, 1996).

In areas of Sri Lanka, nine tomato lines from AVRDC (BL 312, BL 350, BL 341 , BL 342, BL 333, BL 410, BL 162, BL 311, L 285) and Eight locally available tomato lines (T 245, T 146, Vihara 1 , Vihara 2, KWR, B 17, B 15, and B 13) were resistant to bacterial wilt (AVRDC, 1996).

Bodisud *et al.* (1996) conducted a field testing of bacterial wilt-resistant tomato somaclones and they found that tomato cv. Healani

somaclones showed survival percentage ranging from 40 to 100 per cent, while the original Healani had a survival rate of 0 per cent and resistant cv. Kewalo had 30 per cent survival.

Hanson *et al.* (1996) identified L285 a bacterial wilt resistance source but it has not been extensively exploited, primarily because of the small fruit size and poor horticultural characters.

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 *R. solanacearum* and the remaining cultivars were susceptible.

Seedlings of two hundred and thirty-three accessions of the tomato and seven cultivars used as controls were evaluated for host-plant resistance to 4 virulent strains of *Pseudomonas solanacearum* representing race 1 biovars 1 and 3. Only 5 accessions, CATIE 17331, 17334, 17349, 17739, 17740, and two of the control cultivars, 'Hawaii 7998' and 'UC-82B' showed some degree of resistance. Eight CATIE accessions, 5539, 17331, 17333, 17334, 17345, 17349, 17742, and MIP-CH1, were as resistant as the resistant control 'Hawaii 7998' to 3 strains and accession 17740 was as resistant as 'Hawaii 7998' to all 4 strains (Williams and William, 1996).

Gonzalez and Summers (1996) in a research work evaluated 233 accessions of tomato collection material at the Centro Agronomic tropical de intensification Y Eusenanza, Coasta Rico, for resistance to four different virulent strains of *R. solanacearum* representing race 1 and biovar 3, found that CATIE, 17740 and Hawaii 7998 accessions to be resistance to all the four strains of the pathogen.

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 mμ) were over twice as concentrations in the xylem fluid of the resistant Hawaii 7997 (0.9 mμ). Concentrations of amino acids in the cultivar with intermediate levels of resistance were also intermediate.

Gomes *et al.* (1997) tested 45 progenies for resistance to *R. solanacearum* isolates 788 (biovar I) and ST (biovar III). The progenies P-24, P-25, P-38 and P-47 presented the lowest Bacterial Wilt Index (BWI) values in relation to isolate 788 while P-09, P-22, P-29, P-37, P-38 and P-49 showed lowest BWI values for isolate ST.

A set of 35 bacterial wilt resistant tomato lines and accessions collected from nine breeding programs worldwide, were evaluated in 11 infested fields of 10 countries. Among the entries tested, Hawaii 7996 appeared to be the most stable resistance source with the highest mean survival (96.9%) over locations. Other resistance lines with comparative stability were BF-Okitsu 101, Hawaii 7997, Hawaii 7998, CRA 66, Tml 114-48-5-N-spreading, Tml 46-N-12-N-early N.T., R-3034-3-10-N-UG, and F7-80-465-10-pink (Wang *et al.*, 1997).

Studies on the evaluation of seven bacterial wilt (*Ralstonia solanacearum*) resistant tomato lines in an infested field for three years revealed that the lines differed significantly in their reactions to the pathogen. The bacterial wilt disease was the lowest in Sakthi (10.1%) followed by LE 79-5 (28.0%) (Mathew *et al.*, 1997).

Thirty three tomato lines were evaluated during January May 1991 in a hot spot area. Selections from CL 32d-0-1-19GS like LE 79-1, LE 79-4, LE 79-3 were moderately susceptible (survival 40-60%).The variety 'Sakthi' was resistant (survival 80% and above). During July -November 1991, 25 lines were further evaluated. 'Sakthi' and LE-5 showed highly resistant reaction. Thirty lines including the previously reported resistant

lines were further evaluated during December 1991 to April, 1992. The variety 'Sakthi' and LE 790-5 showed resistant reaction. The evaluations during the three seasons confirmed high field resistance in 'Sakthi' and LE 79-5 (Peter *et al.*, 1997).

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. *Cerasiforme*. LA 1421 was different from that derived from that *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.

Bhattarai *et al.* (1998) in a varietal evaluation for bacterial wilt tolerance in tomato observed 100 per cent survival of genotypes such as FMTT 268, FMT 301, FMTT 115, 285, BL 31, Hawaii 7996, 7997, 7998, FI-80-465-10, Pink, L-285, BL-31, BL-333, BL-350, BL-355, CLN 475-$BC_1$-$F_7$-265-4-19, CRA 66, GA 219, GA 1565.

Rajan and Sadhankumar (1998) evaluated 141 tomato lines 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.

Five bacterial wilt resistant genotypes (Sakthi, LE 79-5, LE 214, LE 415 and LE 421) were crossed with five fruit crack resistant genotypes (LE 296, LE 386, LE 388, LE 393 and LE 399) in a line x tester fashion and the $F_1$S along with the parents were evaluated for bacterial wilt resistance and fruit crack resistance. All the $F_1$S were susceptible to bacterial wilt when evaluated in a wilt sick field (Sadhankumar *et al.* 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).

Berke (1999) reported that the CLN1555A and CLN1555B (Cherry tomato lines); CLN2001C, CLN2026C, CLN2026D, CLN2026E, CLN1466J, CLN1466P, CLN1466S, CLN1621E, CLN1621F and CLN1621L (Determinate tomato lines) are resistant to bacterial wilt disease and suitable for off season production also.

Protein bands PPO-1, PPO-4, PPO-7, PPO-10, PPO-11 and PPO-12 were observed 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 (Bose, 1999). He also noticed high total phenol and OD phenol content in the resistant lines.

Yui *et al.* (1999) obtained four RAPD markers, which are useful for preliminary selection of bacterial wilt resistance, introduced from a bacterial wilt resistant parent Hawaii 7998.

Yoshiko *et al.* (1999) were screened 25 tomato cultivars to bacterial wilt. The results showed that more than 50 % of the seedlings of 10 cultivars Amafuku, First Power, House Odoriko, KH-418, Merry Road, Odoriko, Oogata-Fukuju, Shifuku Tomato, Sun Road and Syofuku. No plants wilted for five cultivars Ganbaru Ne, Helper M, Momotaro 8, Super Ryoen and Hawaii 7996.

In an evaluation for bacterial wilt resistance conducted in Bangladesh out of 15 genotypes one indeterminate line L285 and two determinate tomato lines L180 and CLN1463 were found to be free from bacterial wilt. Among these, CLN1463 may be attractive to farmers because of its large fruit (AVRDC, 2000).

In an on-farm trial conducted in Bangladesh five promising lines were evaluated to bacterial wilt resistance along with a susceptible check (MH-1). CL8d-0-7-1, TD and TC these three lines are found to be resistant to bacterial wilt (AVRDC, 2000).

A preliminary yield trial (PYT) of processing tomato inbred lines was conducted at AVRDC during the dry season to identify superior entries for bacterial wilt resistance. The inbred lines CLN2413-124DC2-1-1-12, CLN2413-194DC2-1-3-13, CLN2418-161DC2-1-4-22-4, CLN2123C, CLN2123E, CLN2123F, and CLN2243B are resistant to bacterial wilt disease. In addition to bacterial wilt resistance these inbred lines also having superior processing characters (AVRDC Report, 2000).

Mohanty and Prusti (2001) evaluated eighteen genotypes of tomato which included eight from the All India Coordinated Vegetable Improvement Project, Bhubaneswar *viz.* Utkal Pallavi, Utkal Deepti, Utkal Kumari, Utkal Urvasi, BT 3, BT 12-2, BT 17 and BT18 and four from the Asian Vegetable Research and Development Centre (AVRDC) Taiwan, i.e. ET 4, ET 14, ET 27 and ET 35. All these 12 genotypes found to be tolerant to bacterial wilt.

Venkataramreddy Patil (2001) reported bacterial wilt infection ranging from 6-79 per cent in TLB 182 and Arka Vikas.

Kurian and Peter (2001) evaluated $F_1$ hybrids of bacterial wilt resistant/tolerant genotypes Sakthi, LE 214 and LE 206 with HW 208F, St 64, Ohio 8129, TH 318 and Fresh market and they found that these hybrids were completely susceptible to bacterial wilt.

A preliminary yield trial (PYT) of fresh market tomato inbred lines was conducted at the AVRDC to identify superior entries for bacterial wilt resistance. The inbred lines CLN2413C, CLN2413D, CLN2418C and CLN2418E are resistant to bacterial wilt disease (AVRDC Report, 2001).

An advanced yield trial (AYT) of fresh market tomato inbred lines was conducted at the AVRDC to identify superior entries for bacterial wilt resistance. The inbred lines CLN2413I, CLN2418C, CLN2413J, CLN2413K, CLN2413 and CLN2413M are resistant to bacterial wilt disease (AVRDC Report, 2001).

A preliminary yield trial (PYT) of processing tomato inbred lines was conducted at AVRDC during the dry season to identify superior entries for bacterial wilt resistance. The inbred line CLN2396-94-16-11-23-24-13 is highly resistant to bacterial wilt disease (AVRDC Report, 2001).

Hossain *et al.* (2001) reported that the tomato lines T-C, TM-080, CLN-2026D and CLN-2026C showed better performance against bacterial wilt and contributed higher yield. The lines SX7610, SX7611, CLN-1463, CLN-1466 and King Kong may be selected as superior lines based on the incidence of bacterial wilt and yield.

Sadashiva and Madhavi (2001) confirmed and demonstrated that two bacterial wilt resistant tomato varieties *viz;* Ratan (Bangladesh) and T-89 (Sri Lanka) were promising with respect to yield and bacterial wilt resistance. But both the varieties succumbed to wilt during summer indicating their cultivation would be restricted to cooler climate.

Sadashiva *et al.* (2001) evaluated eighteen bacterial wilt resistant tomato lines including three hybrids. Among them ten lines *viz;* L-285, BL-985, BL-986, BL-989, BL-994, BL-1009, KWR, CLN 1463-245-14-0-0, CLN 1466-65-40-15-0-12-0 and SUN 7610 were found consistently resistant to wilt with less than 10 per cent mean wilt incidence.

Girija and Roopali (2001) evaluated nineteen bacterial wilt resistant tomato lines. Among the entries evaluated L-180, L-285, CLN 1463-245-14-0-0 BL-985, BL-994, BL-986, BL-1004, BL-1009, KWR, Hawaii 7997 were found resistant to bacterial wilt recording 80-100 percent survival. The

lines L-180, L-285, CLN 1463-245-14-0-0, BL-985, BL-994 and BL-1009 have shown resistance consistently in two or three years under glass house conditions.

Timila and Shrestha (2001) evaluated bacterial wilt resistant tomato lines by both seedling evaluation and field evaluation. They found that the genotypes such as BL 1009, BL 985, SX 7611 and BL 986 were found resistant to bacterial wilt.

Two heat tolerant tomato lines TML 114 and TML 216 were developed, that are resistant to three biovars of bacterial wilt (Deanon *et al.*; 2002).

Fifty tomato genotypes were screened in the bacterial wilt disease nursery and the variety Sakthi and the genotypes LE 79-5, LE 415, LE 421, LE 582 and LE 583 were resistant and LE 576 and LE 530 were moderately resistant to wilt caused by soil-borne pathogen *R. solanacearum* (Devi *et al.*, 2002).

Kulkarni *et al.* (2002) screened 56 indigenous and exogenous tomato genotypes against *Ralstonia solanacearum* under field conditions by artificial inoculation and he found 18 genotypes to be resistant and 17 susceptible. Seven genotypes exhibited moderate resistance while 14 showed moderate susceptibility to *R. solanacearum.*

HT-01 is a derivative from a cross between Solarset and KWR and found to be with bacterial wilt resistance and good fruit quality attributes (Peiris and Kudagamage, 2002). T-245 is another variety with moderate resistance to bacterial wilt disease and good fruit quality characteristics.

Sadashiva *et al.* (2002) evaluated advanced tomato breeding lines resistant to both bacterial wilt and ToLCV. Seedlings of these lines were artificially exposed to virulent whiteflies and also artificially inoculated with

bacterial suspensions. Three entries *viz.*, CLN-2114-$DC_1F_1$-50-2-16-8-2-17-0, CLN-2116-$DC_1F_1$-180-31-9-34-4-0 and CLN-2116-$DC_1F_1$-180-31-10-25-8-0 were found to exhibit resistance both for ToLCV and bacterial wilt.

Sadashiva *et al.* (2003) screened the advanced breeding lines for bacterial wilt disease resistance along with the susceptible variety Arka Sourabh. The results indicated that the breeding lines TLBR-1, TLBR-2, TLBR-3, TLBR-4, TLBR-5, TLBR-6, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199 and IIHR-2100 had greater bacterial wilt resistance.

Forty two genotypes collected from different sources were evaluated for both heat tolerance and bacterial wilt resistance. The results of the observations on bacterial wilt incidence under field conditions revealed that 20 accessions (LE-1, Sakthi, Mukthi, LE-615, LE-560, LE-568, LE-584, LE-14, LE-4, LE-16, LE-43, CLN-2001 C, CLN-2026 C, CLN-2026 D, CLN-2026 E, CLN-1466 P, CLN-1466 S, CLN-1621 E, CLN-1621 F, CLN-1621 N) were resistant whereas, four accessions showed 100 per cent bacterial wilt. The highest yield was recorded by LE-16 followed by LE-1 and Mukthi. They were also resistant to bacterial wilt. (Celine *et al.*, 2003)

An observational trial (OYT) of indeterminate, fresh market hybrids was carried out at the AVRDC to identify promising hybrids. The results indicated that the hybrids FMTT1098 and FMTT1027 are highly resistant to bacterial wilt with survival percentage more than 90 (AVRDC Report, 2003).

Nakaho *et al.* (2004) examined bacterial multiplication in stems of 11 resistant tomato plants. Results indicated that suppressed owing to the limitation of pathogen movement from the protoxylem or the primary xylem to other xylem tissues. The limitation was most conspicuous in Hawaii 7996. Grafting experiments indicated that the percentage of wilting of Ponderosa scions was less on Hawaii 7996 rootstocks than that on the most

resistant rootstock (LS-89) used in Japan. Hawaii 7996 could be an alternative genetic source for breeding for resistance to bacterial wilt.

A preliminary yield trial (PYT) for fresh market hybrids was carried out at the AVRDC to identify promising hybrids. The results indicated that the hybrids FMTT1098, FMTT1027 and FMTT1058 are highly resistant to bacterial wilt with the survival percentage more than 90 (AVRDC Report, 2004).

A worldwide evaluation of 31 genotypes derived from at least 14 resistance sources in 11 countries identified seven genotypes that had over 90% overall survival. Three sources were from Hawaii, three were from the Philippines, and the other was apparently from North Carolina but it had a Hawaiian-like phenotype. They concluded that Hawaii 7996, the most resistant genotype in the worldwide study (Scott, *et al.*, 2005).

A primary yield trial (PYT) of fresh market tomato inbred lines was conducted at the AVRDC during October 2005–January 2006 to identify superior lines for bacterial wilt resistance. The inbred lines coded CLN2714 are lines derived from the cross [(CLN1466J x FLA456) x CLN2418A]; and CLN1466J, CLN2418A, CLN2585C (51335), CLN2585D (51336), CLN2585E (51337) and CLN2585A 51332 are bacterial wilt resistant AVRDC lines (AVRDC Report, 2005).

Prasanna Kumar *et al.* (2006) evaluated seventy-six tomato entries to bacterial wilt resistance. Out of 76 they found that ten entries viz., Sakthi, 2303, 2299, L-6, L-25, L-3, TLB-133, L-18, Arka Alok were highly resistant (HR) to wilt with disease index of zero. Whereas, another ten entries were found to be moderately resistant with disease index (DI) ranging 5.96 to 20.00 per cent.

High humidity and acidic soil conditions favours bacterial wilt this made cultivation of tomato very difficult in Tripura. Bacterial wilt resistant

varieties like Arka Abha, Arka Alok, Arka Abhijit, Arka Shreshta, RCMT-6, Udaipur local, Sikkim local, Tura local, Sakthi, CS-714 and $F_1$ hybrids like All Rounder, Gotya S-41 and Samrudh are recommended for cultivation in Tripura to overcome the bacterial wilt problem (Singh, 2006).

Peter *et al.* (2006) reported that under Kerala conditions the tomato line CL32d-0-1-9UG (LE 79) introduced in 1979 from AVRDC, Taiwan showed resistance to bacterial isolates K-60, Wr-82 and Tifft on 80-1.

Among the LA716 introgression lines, only LA3501 (IL6-2) showed a higher level of resistance than M82 and a similar level of resistance as LA716 against Pss186 in the field evaluation. The IL6-2 carried an introgression segment on chromosome 6, where the resistance gene Bwr-6 is located (Carmeille *et al.*, 2006a).

Carmeille *et al.* (2006b) Among the screened 82 accessions partial resistance to a strain of race 3 biovar2 phylotype II was detected in one accession belonging to species *Lycopersicon peruvianum*, and one *L. esculentum* var. *cerasiforme* tomato line. Five other genotypes from the species *L. esculentum*, *Lycopersicon hirsutum* and *L. peruvianum* were noteworthy. The Hawaii 7996 line represented the best source of partial resistance to race 3 with 52% of wilting.

Twenty-one AVRDC tomato lines along with Hawaii 7996 (resistance check) and L390 (susceptible check) showed 6.7% and 90% wilted plants respectively. CRA84-26-I, CLI131-0-43-8-1, CLN2545B, CL5915-93D4-1-0-3, CLN 657BCIF2-27 4-0-15-0 had more than 50% wilted plants. On the other hand, CLN2585D, CLN2498E, CLN2413D, CLNI621E, CLN698BCIF2-358-4-13 showed 10% or less wilted plants (Gao, 2006).

Subrata and Singh (2008) evaluated 12 tomato lines for identification of bacterial wilt resistant genotypes suitable to Tripura conditions. And they found that the genotypes, BT-1 and BT-10 were found most resistant to bacterial wilt, showing no mortality at all due to the disease. In addition, the genotypes CKVT-17 and Sikkim Local, showed very high degree of tolerance with percent disease infection (PI) ranging between 2.78 and 5.55. In this contrast, Manikhamna (Sel-1), a genotype selected from Manipur, was most susceptible to the disease with PI ranging between 33.33 and 55.56.

Out of the 15 genotypes evaluated, five (Anagha, Sakthi, Mukthi, Hawaii 7998 and LE-66) were observed to be resistant and the genotypes LE-20, LE-474, and LE-1-2 were observed to be moderately resistant (Karumannil *et al.,* 2008).

A total of 252 wild *Solanum* accessions and one population of 49 introgression lines of LA716 were screened for resistance to a race 1/biovar 4/phylotype I strain Pss186 of *Ralstonia solanacearum.* Most wild tomato accessions were highly susceptible. However, five accessions of *S. pennellii,* i.e. LA1943, LA716, LA1656, LA1732 and TL01845 were resistant to strain Pss186 (Hong Hai *et al.,* 2008).

30 hybrid and open-pollinated cultivars of tomato screened under laboratory and field conditions against bacterial wilt. Three accessions, 'EC 386019', 'IC 214633' and 'EC 386023', were found resistant to the disease (Aggarwal *et al.,* 2008).

Wang (2008) Screened 252 wild tomato accessions, five accessions of *S. pennellii* (LA1943, LA716, LA1656, LA1732 and TL01845) were found to be resistant to race 1/biovar4 strain Pss186. When challenged against two other more aggressive strains Pss4 and Pss190, all the five *S. pennellii* accessions were susceptible to Pss4, but displayed high to

moderate resistance to Pss190. Pss190 is an aggressive strain that made Hawaii 7996 susceptible. LA3501, which has an introgression segment of LA716 on chromosome 6, was found to be resistant to Pss186 among the screened introgression lines.

Twenty lines of tomato along with the controls Hawaii 7996 (resistant) and VF134-1-2 (susceptible) were screened for bacterial wilt. The results showed that three tomato lines, A4-7-1-1-5, THBW104, and THBW109 carried high levels of bacterial wilt resistances (20 % of wilt intensity). Four tomato lines, A2-10-3-1, A4-7-1-1-5, X12207B-5 and X12207B-4-2 are moderately resistant to bacterial wilt with 30% of wilt intensity. Therefore, A4-7-1-1-5, THBW104 and THBW109 should be considered good materials in a breeding program for bacterial wilt resistance development (Techawongstien *et al.*, 2009).

Tomato lines introduced from Tomato Genetics Resource Centre, USA (TGRC): LA2701, LA3202 and LA3526 with high resistance to bacterial wilt as used as rootstocks in grafting (Zhang *et al.*, 2010).

Pena *et al.* (2010) evaluated tomato genotypes Santa Cruz Kada, the susceptibility control; Caraíba, the resistant control; C–38; Yoshimatsu 4-11, and four $F_{13}$ and $F_{14}$ progenies from the HT-16 crossing. The data showed that advanced progenies of the HT-16 crossing are adapted for cultivation in upland and flood plain soils infested by the pathogen *Ralstonia solanacearum* and demonstrated superiority when compared to $F_7$ variety Yoshimatsu 4-11.

LE-415 was tested in various locations in AICRP (Vegetable Crops) and was identified for release in zones I, V and VIII under the name Anagha. Anagha is a bacterial wilt resistant variety which is semi determinate. It is resistant to race1, biovar 3 and 5 of *Ralstonia solanacearum* (Smith) Yabuchi *et al.* (Sadhankumar *et al.*, 2011).

## 2.4 BREEDING FOR BACTERIAL WILT RESISTANCE

Graham and Yap (1976) performed a diallel involving six cultivars Walter, CRA 66, H 7741, Venus, VC-4 and Llanos de Colce. They reported that high level of resistance was attained in a breeding procedure of repeated selfing and selection followed by intercrossing of resistant selections.

Chumvisoot and Lambeth (1983) crossed 12 accessions of tomato as female to three testers Saturn, Venus and Kewalo. Five accessions and their hybrids with Kewalo had low tolerance.

Sreelathakumari (1983) reported that no $F_1$ hybrids involving 10 lines from *Lycopersicon esculentum* as female and *L. pimpinellifolium* as male showed resistance. She also reported a complementary and hypostatic type of digenic recessive gene system for wilt resistance.

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, $F_3$s were evaluated along with the $F_2$s and non-segregating populations (Saturn x LE 79). Resistance was observed in Saturn x LE 79 $F_3$ and Saturn x LE 79 $F_2$.

In a study of seven parent diallel comprised of different genetic stocks, lines L 96 (cv. Saturn from North Carolina) and L 285 (a small fruited Taiwan collection) showed far better average bacterial wilt resistance among their hybrid progenies than other five stocks (Opena and Tschanz, 1987). These two stocks had the ability to transmit their disease resistance uniformly to their progenies. Certain stocks showed high bacterial wilt resistance in some crosses. This non additive gene action appears also to be an important feature of the genetic system conditioning bacterial wilt resistance, implying that $F_1$ hybrid breeding for the trait is a possibility.

Herrington and Saranah (1985) bred an $F_1$ hybrid Redlands Summer Taste which was resistant to bacterial wilt. This hybrid was bred using a sister line 1356 of Scorpio with a selection 1360 of Floradade.

An $F_1$ hybrid, PT 3027, was released as Tainan No.3 (TN 3) in 1986 for its resistance to bacterial wilt, its high yielding characters and its heat tolerance, tomato mosaic virus (ToMV) and nematodes (Lin *et al.* 1985)

Noda *et al.* (1986) compared ten $F_2$, $F_4$, and $F_5$ progenies of various ancestors with varieties Sao Sebastiao and Kada. Resistance was highest in the $F_4$ population HT 16-9-1 from IRAT IH 40 x UH 7976.

Tikko *et al.* (1987) attempted development of $F_1$ hybrids resistant to bacterial wilt. Two resistant sources CRA 66 Sel A and IHR 663-12-3 were crossed with susceptible varieties like Pusa Ruby, HS 101 and Sel 24. Large fruited selections were recovered only in crosses with IHR 663-12-3. None of the CRA 66 derivatives showed absolute resistance but their survival beyond 80 days after inoculation in the field resulted acceptable yields. Resistance in selections from Taiwanese line was very high. Pedigree selection in the crosses between IHR 663-12-3 and firm fruited wilt susceptible lines Arka Saurabh and Florida 1011 resulted in medium fruited selections in the range of 80 to 125 g and yield of 1 kg to 3 kg/plant.

Tikoo (1987) reported that 13 $F_1$ hybrids evolved using IHR 663-12-3 (BWR 1) as female and wilt susceptible lines as male exhibited 100 per cent survival even up to 120 days after planting, confirming the dominance of bacterial wilt resistance in BWR 1. Out of the 14 hybrids, only one (BWR 1 x KH det) proved to have significantly higher yield of 2.24 kg/plant as against 1.4 kg/plant in the wilt resistant parent BWR 1. The only other promising hybrid was BWR 1 x 674 (a processing line) as the fruits were uniformly ripening, square round shape and good for processing. Since

BWR 1 had soft fruits, the $F_1$s even with firm fruited lines was soft or medium firm.

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.

In a study on the economic characters of certain tomato genotypes and $F_1$s in a bacterial wilt sick field by Devi and Tikoo (1992). They found that $F_1$s namely, BWR-1 x Rossol, BWR-12-2 x 998, 83BWR 120 x Patriot, MITA 668 x 83-BWR 120 were found to be the best hybrids resistant to *R. solanacearum.*

Hanson *et al.* (1998) crossed five bacterial wilt-resistant tomato lines (CL5915, L285, CRA84, H7997, and GA219), with susceptible processing tomato line (UC204A) in diallel fashion without reciprocals. Parents, $F_1$ progenies, and $F_2$ progenies were evaluated in greenhouses at three locations (Taiwan, Philippines, and Indonesia). Percent survival means over locations were 17.4 to 83.0 for parents and $F_1$ progeny and 16.2 to 75.0 for parents and $F_2$ progeny.

Rani (2000) reported that the $F_1$ hybrids LE 415 x Mukthi, LE 415 x Sakthi, LE 415, LE 415 x BWR-1 and Sakthi x Mukthi are resistant to bacterial wilt.

Prasanna *et al.* (2002) developed 65 $F_1$ hybrids by crossing 13 bacterial wilt resistant lines with 5 ripening mutants to develop bacterial wilt resistant tomato $F_1$ hybrids with extended shelf life. They found that the hybrids IIHR 2199 x IIHR 2052, BWR IF x nor-1, IIHR 2199 x IIHR 1136 were high yielding and resistant to bacterial wilt.

Katoch (2002) reported that the $F_1$ hybrids BT-18 x EC 191536 and Hawaii 7998 x BT-18 are resistant to bacterial wilt and having considerable marketable yield also.

Rattan (2006) screened 11 bacterial wilt resistant tomato genotypes in two locations. Out of 11 genotypes BT-18, Rodade, Hawaii-7998 and EC-392698 are resistant at Palampur and at Bajaura BL-333-6-1, CLN-2123-A-1, EC-392698 and EC-191536 are resistant BT-18 and BL-333-6-1 are resistant to bacterial wilt at both the locations. The cross combinations BT-18 x Hawaii-7998, Rodade x EC-392698 and CLN-2026-D-1 x PTOM-9802-3 at Palampur, BL-333-6-1 x EC-191536, BL-333-6-1 x EC-392698 and CLN-2123-A-1 x EC-191536 at Bajaura and BT-18 x Hawaii-7998, Rodade x EC-392698 and BL-333-6-1 x EC-191536 are resistant to bacterial wilt disease at both locations.

Dharmatti *et al.*,(2009) study the bacterial wilt resistance and yield of tomato hybrids in a bacterial wilt sick field out of thirteen hybrids only 6 hybrids Arka Alok x SP-2-2, Arka Alok x L-101, Sonali x SP-2-2, Arka Alok x W-9430, Sakthi x L-50 and Sakthi x Arka Vikas were found to be the best hybrids resistant to *R. solanacearum* and also superior in yield.

Yin *et al.* (2010) developed a new indeterminate and mid-late maturity tomato hybrid 'Yukang-10' with average fruit weight of 140 g. It is highly resistant to bacterial wilt.

## 2.5 EVALUATION OF TOMATO GENOTYPES FOR THE INCIDENCE OF TOMATO LEAF CURL VIRUS (ToLCV)

Tomato leaf curl virus diseases (ToLCV) are caused by geminivirus vectored by the whitefly (*Bemisia tabaci*) belonging to family geminiviridae and genus begmovirus (Anbinder *et al.*, 2009). The disease incidence is correlated with the size of the *B. tabaci* population and attributed to the failure of the crop. Several weed species occurring in nature are known to

be hosts for both virus and the vector and reported to be major contributors of ToLCV inoculum for the disease outbreak (Gameel, 1977).

### 2.4.1 Taxonomy

Geminiviruses are plant viruses that belong to the family Geminiviridae, first described by Goodman in 1977 (Goodman, 1977a, 1977b). Geminiviruses are characterized by the unique Gemini shape of a fused icosahedral viral particle. The geminate virions consists a circular single-stranded DNA (ssDNA) genome. The family Geminiviridae is comprised of three genera, all of which share similarities in genome organization, insect transmission, and host range.

**The genus Mastrevirus**

Consists of geminiviruses with a monopartite genome, and the Mastreviruses are transmitted by leafhoppers, in most cases by a single species in a persistent, circulative, non-propagative manner.

**The genus Curtovirus**

Includes viruses with monopartite genomes, transmitted by leafhoppers or treehoppers in a persistent, circulative, non-propagative manner. Curtoviruses have very wide host ranges.

**The genus Begomovirus**

Consists viruses with monopartite and bipartite genomes. Begomoviruses are transmitted by whiteflies in a persistent, circulative, non-propagative manner, and infect dicotyledonous plants. Bean golden mosaic virus (BGMV) is the type species.

### 2.4.2 Geminivirus Genome Organization

The geminivirus genome is organized in one (monopartite) or two (bipartite) covalently closed, circular, ssDNA molecules of about 2.5 - 2.9 Kb (Lazarowitz, 1992).

The genes in monopartite and bipartite geminiviruses are arranged in two divergent clusters 280 to 350 nucleotides each separated by the intergenic region (IR) each. The single genomic component of monopartite geminiviruses (mastreviruses and curtoviruses) contains all the information necessary for virus replication and infectivity (Lazarowitz, 1992; Hanley-Bowdoin *et al.,* 1996). Bipartite begomoviruses have seven genes distributed in the two genomic components designated A and B. The A component contains genes involved in virus replication and encapsidation, and the B component contains the genes involved in virus movement (Lazarowitz, 1992). The A and B components each have a common region, which consists of a block of approximately 200bp within the IR (Sunter and Bisaro, 1991; Lazarowitz, 1992). The common regions are virtually identical in sequence in a given bipartite begomovirus, but are completely different in sequence among the other geminiviruses, with the exception of a 30 nucleotide conserved region (stem loop) that has been identified as the origin of replication (Sunter and Bisaro, 1991). The common region also contains two divergent promoters which differentially regulate the temporal expression of the viral genes (Lazarowitz, 1992).

### 2.4.3 Historical background and spread of the disease

A Tomato Yellow Leaf Curl Virus(TYLCV) like disease was first reported in Israel in 1939-1940 associated with outbreaks of *Bemisia tabaci.* Twenty years later, in 1959, the entire tomato crop was destroyed by a disease with TYLCV-like symptoms in the Jordan Valley (Cohen and Antignus, 1994). Cohen and Harpaz (1964) published the first description of this new disease transmitted by the whitefly *Bemisia tabaci.* It has since become an economically important disease in many countries of the Middle

East, Southern Asia, Eastern and Western Africa, and the Mediterranean Basin.

Before virus isolation, the detection and diagnosis of TYLCV relied on symptom expression, transmission mode, and host range. This situation led to some confusion, since the variety of symptoms associated with TYLCV disease makes it difficult to identify. In this sense, tomato leaf curl disease caused by the Tomato leaf curl virus (TLCV), reported from Sudan, India, or Australia has been considered caused by the same viral agent, TYLCV. However, more studies consider both diseases caused by different viral agents (Muniyappa *et al.*, 1991; Dry *et al.*, 1993).

Electron microscopic observations of geminate viral particles and ultra-structural modifications in the cell nucleus of infected plants provided evidence of the viral nature of the disease (Russo *et al.*, 1980). In a study, the causal agent of the tomato yellow leaf curl disease was isolated from diseased tomato and *Datura stramonium* plants. Reproduction of the disease using the isolated virus proved the association of viral particles with TYLCV symptoms. Data of particle morphology, mode of transmission, and properties of TYLCV genome confirm this whitefly-transmitted geminivirus as the causal agent of this tomato disease (Czosnek *et al.*, 1988).

The first report of tomato yellow leaf curl disease in America came from the region of Sonora in Mexico, where a new TYLCV-like tomato disease, transmitted by *Bemisia tabaci, was* observed in 1986. The lack of accurate diagnostic methods hampered the correct virus identification. TYLCV isolates have been reported from North America and its presence has been confirmed in Mexico and India (McGlashan *et al.*, 1994).

### 2.4.4 Tomato Leaf Curl Virus (ToLCV) disease

Tomato is affected by 30 different viruses belonging to 16 different taxonomic groups. Among them, gemini virus group, which causes Tomato

Leaf Curl Virus disease which is one of the most devastating disease. Serious nature of leaf curl disease on tomato was first reported by Hussain (1932). In India occurrence of leaf curl virus disease was first observed in the northern plains by Pal and Tandon (1937) and later by Pruthi and Samuel (1939) and after by Vasudeva and Sam Raj (1948) in northern India, Delhi (Vasudeva, 1959), Maharashtra (Varma, 1959), Coimbatore (Ramakrishnan *et al.,* 1964), Karnataka (Govindu, 1964), Kanpur (Singh and Lal, 1964), Kerala (Nair and Wilson, 1969), Punjab (Butter and Rataul, 1973), Lucknow (Srivastava *et al.,* 1975), Hissar (Varma and Poonam, 1977), and Pantnagar, U.P. (Saklani and Mathai, 1978).

Besides India, tomato leaf curl virus has also been reported from Sudan (Cowland, 1932), Israel (Cohen and Harpaz, 1964), Sri Lanka (Shivanathan, 1983), Egypt (Nour-Eldir *et al.,* 1969), Philippines (Retuerma *et al.,* 1971), Somalia (Castellani *et al.,* 1981), Thailand (Thanapase *et al.,* 1983) and from Taiwan (Green *et al.,* 1987).

### 2.4.5 Importance of Tomato Leaf Curl Virus (ToLCV) disease

ToLCV was reported to be a serious disease on tomato throughout India. Each year this disease causes millions of dollars damage to tomato crops all over the world.

Sastry and Singh (1973) reported that ToLCV infested plants produced very few fruits when infested within 20 days after transplanting and resulted upto 92.30 per cent yield loss, whereas plants infected at 35 and 50 days after transplanting resulted in 74 and 22.9 percent yield loss respectively.

Banerjee and Kalloo (1987b) reported that the major constraint in the cultivation of tomato was the outbreak of ToLCV during summer in south India and autumn in north India.

Sadashiva *et al.* (2006) reported that incidence of the disease results in yield loss between 70 and 100 percent.

### 2.4.6 Symptomatology

In tomato symptoms vary depending on the growth stage at the time of initial infection, environmental conditions and the variety of tomato plant and include severe stunting, marked reduction in leaf size, deformation of leaflets, upward cupping, puckering of leaflets, chlorosis of leaf margins, mottling, flower abscission and partial or complete sterility if infection occurs at an early stage of plant development (Sastry and Singh, 1973; Saikia and Muniyappa, 1989).

Yassin and Nour (1965a) described tomato leaf curl symptoms viz., leaf curling, stunting of the plants, thickening, greening of the veins of the leaves as similar to those described by Vasudeva and Sam Raj (1948).

Gevorkyan *et al.* (1976) reported that the growth and development of tomato plants infected by leaf curl virus were considerably delayed. The disease accompanied by decreased content of green and yello pigments and increased total nitrogen and accumulations of hexose and sucrose.

### 2.4.7 Host Range of ToLCV

In nature, the virus mainly infects tomato. The experimental host range of ToLCV is narrow, mainly infecting some species of the Solanaceae, Composite, and Caprifoliaceae. Vasudeva and Sam Raj (1948) reported that ToLCV exhibits leaf curl symptoms on *Nicotiana tabaccum L.* cvs. White Burley, Samsum and Harrison special, *Solanum tuberosum L.* Cv. Craig defiance, *Datura stramonium L, N. Sylvestris Spegaz and N.glutinosa L,* when inoculated by grafting. Varma (1959) transmitted ToLCV by *B. tabaci* to *N. Rustica L., Zinnia elegans* Jacq., *Datura*

*stramonium L, Salvia splendens* Selle, *Althea rosea* Cav, *Petunia hybridia* Vilm, *Euphorbia geniculata* Orteg and *Cassia tora L.*

Ramakrishnan *et al.* (1964) transmitted ToLCV to *Althea rosea, Carica papaya L., Petunia hybridia, Sesame oriantale L., N. Tabaccum* and *Zinnia elegans* through *B. tabaci.* Nariani (1968) also transmitted ToLCV by *B. tabaci* to ToLCV by *B. Tabaci* to tobacco *D. Stromonium* and *Capsicum annum.*

Sastry *et al.* (1978) listed three different categories viz., weeds, ornamental and cultivated plants as host plants which had been harbouring ToLCV as well as vector, *B.tabaci.* Out of the 32 different plant species listed, some of them were perennials (*Gossypium arborium L.* and *Hibiscus rosa sinensis L.*) which acted as reservoir not only for virus but also for the whitefly throughout year.

Seetharama Reddy (1978) transmitted the ToLCV to *Ageratum conyzoides L., Centratherum anthelminticum L., Zinnia elegans, Althea rosea, C. annum, D. Stramonium L., Soalnum seaforthianum L., N. tabaccum L.,* cv. White Burley, *N. gluctinosa* and *N. rustica.*

Natural infection of ToLCV up to 31 percent amongst weed population at the Gezira Agricultural Research Station locality was observed. Weed hosts *Solanum dubium* Frasn and *Withania somnifera* Dun., occurring in continuous cycles were found perpetually infective throughout the year, whereas, short duration annuals such as *Acalypha indica L.* and *Helitropium sundanicum* Andr. Seem to occurduring the limited growing season of tomato in the locality (Yassin and Dafalla, 1980).

Saikia and Muniyappa (1989) transmitted ToLCV by *B.tabaci* to *Acanthosperum hispidum, Ageratum conyzoides, Bidens biternata* (Lour.) Sheriff, *Centratherum anthelminticum* (L.) Kuntze, *Conyza stricta, Galinsoga parviflora, Sonchus brachyotis, Syndrella nodiflora* Gaertn.,

*Zinnia elegans, Euphorbia geniculata, Althea rosea, Oxalis acetosella L., Capsicum annum, Datura stramonium, Lycopersicon esculentum L. gladulosum* Mull., *L. hirsutum* Humb, and Bonpl., *L. peruvianum* (L.) Mill., *N. Benthamiana Domin., N. Glutinosa, N.tabaccum, Physalis minima* and *Solanum nigrum. Galinsoga parviflora,*

Sastry (1984) reported that, weed hosts such as *Acanthospermum hispidum, Ageratum conyzoides, Parthenium hysterophorus, Datura stramonium, Euphorbia geniculata and Gynandropsis pentaphylla* were source of inoculum for tomato. ToLCV was transmitted to *Acanthosperum hispidum, Ageratum conyzoides, Conyza stricta, Datura stramonium, Euphorbia geniculata,G. Parviflora, Oxalis corniculata, Parthenium hysterophorus, S. Nigrum, Sonchus brachyotis, Stachyterpicta indica, Syndrella nodiflora, Nicotiana benthamiana by B.tabaci* inoculation (Ramappa, 1993).

Saikia and Muniyappa (1989) reported that tomato plants were susceptible to infection by ToLCV at all stages of their growth. The incidence of ToLCV in some tomato growing areas of Karnataka, India, ranged from 17-53 per cent in July-November to 100 per cent in crops grown in February-May (summer). In sequential sowings, 90-100 per cent of plants were infected in plots sown between the end of January and end of May. Infection in plots sown later was progressively less. 50 to 70 per cent yield loss was observed in tomato cv. Pusa Ruby in February – May. A strong correlation was obtained between the percentage incidence of ToLCV and *B.tabaci* number ($r = +0.970$, $P = 0.01$)

In addition to tomato, the following plants have been reported as hosts of tomato yellow leaf curl viruses:

Family Solanaceae*:* *Capsicum annuum, C. frutescens, Datura stramonium, D.bernhardii, Lycopersicon peruvianum, L. hirsutum, L.*

*pimpinellifolium, Nicotiana sylvestris, N. benthamiana, N. glutinosa,* and *Nicotiana tabacum vars Samsun* and *Havana 423, and Solanum nigrum*

Family Malvaceae*: Malva arvensis, Malva nicaensis, M. parviflora, Corchorus tinctorius, Hibiscus syriacus,* and *Gossypium hirsutum*

Family Fabaceae*: Arachis hypogaea, Lens esculenta, and Phaseolus vulgaris*

Family Pedaliaceae: *Sesamum indicum.*

Family Asteraceae*: Sonchus oleraceus*

Family Euphorbiaceae*: Euphorbia heterophylla*

Family Acanthaceae*: Achyranthes aspera*

### 2.4.8 Virus Transmission

The whitefly, *Bemisia tabaci* (Gennadius), is the only known vector of ToLCV (Vasudeva & Sam Raj, 1948; Saikia and Muniyappa, 1989). In laboratory experiments, ToLCV was shown to be transmitted in a persistent manner and single *B.tabaci* adults could transmit the virus (Butter and Rataul, 1977; Seetharama Reddy and Yaraguntaiah, 1981; Ramappa, 1993).

The virus is transmitted in nature by the whitefly *B.tabaci* in a semi persistent (circulative) manner. Minimum acquisition and inoculation feeding periods are 15-30 minutes. The latent period in the vector is more than 20 hours. The virus is retained by the vector for up to 20 days but not throughout the life span insect, but is not transmitted to the progeny. Whiteflies can carry a finite number of virions, in the range of 600 millions, indicating that their acquisition (Zeidan and Czosnek,, 1991). TYLCV DNA replicates in the insect shortly after virus acquisition (Zeidan and Czosnek,, 1994). A single whitefly is able to transmit the virus and the rate of

transmission increases with increased population density of the vector (Mansour and Al Musa, 1992).

The virus–vector relationship was studied by testing the transmission efficiency of TYLCV by whiteflies. Following 48 h of acquisition access feeding on infected tomato, only 5% of the male whiteflies transmitted the virus by transmission feeding of a single insect per test plant. However, female whiteflies were able to transmit the virus with 32% efficiency, six fold better than their male counterparts. Transmission feeding with 1, 3, 5, 10, and 15 viruliferous female whiteflies per plant yielded transmission rates of 32%, 83%, 84%, 86%, and 100%, respectively (Cohen and Nitzany, 1966).

Although symptoms usually appear at about 15 days post-whitefly inoculation, viral DNA can be detected 7 days earlier. TYLCV-DNA concentration peaks at 4 days before symptom appearance. The highest concentrations of TYLCV-DNA were found in rapidly growing tissues such as shoot apices, young leaves, and roots. Young leaves and apices are best for inoculation by whiteflies (Ber *et al.*, 1990).

Mechanical transmission has not been possible and there are no reported cases of transmission through seed.

### 2.4.9 Whitefly

Gennadius (1889) first identified the holotype specimen of whitefly on tobacco from Greece. The sweet potato whitefly was first recorded as early as 1984 in Florida (Russell, 1975) and 1920 in California (Natwick and Zalom, 1984).

*Bemisia tabaci* (Gennadius) is widely polyphagous, feeding on over 500 species of plants in 74 families. *B.tabaci* occupies tropical and sub-tropical habitats and is multivoltine producing 11 to 15 generations per year under

conducive condition (Hussain and Trehan, 1933). *Bemisia tabaci* has been identified based on molecular data and are placed in the Genus *Begomovirus* in the Family *Geminiviridae*. Its hosts include vegetable, field and ornamental crops. *Bemisia tabaci* is a major pest of tomato, peppers, squash, cucumber, beans, brinjal, watermelon and cabbage in vegetables. The whitefly, *Bemisia tabaci* (Gennadius), transmits ToLCV in a persistent, circulative manner (Cohen and Nitzany, 1966), single *Bemisia tabaci* adults could transmit the virus (Butter and Rataul, 1977) and whitefly is the only known vector to transmit ToLCV (Vasudeva and Sam Raj, 1948). There are no reports of seed transmission and mechanical transmission does not occur in nature (Morionces *et al.,* 2000). *Bemisia tabaci* (Gennadius) is highly fecund and has the ability to adapt to new host crops. ToLCV has been found to be the causal agent of a novel disease of common bean (*Phaseolus vulgaris* L.) Sanchez-Campos *et al,* (1999) and also occurs in peppers (*Capsicum annuum*) Reina *et al,* (1999). ToLCV isolates are monopartite and consist of geminate, quasi- isometric particles which have been measured at 20 nm in diameter and 30nm in length, Brunt *et al,* (1990).

About 1,300 whitefly species (family Aleyrodidae) in over 120 genera have been described, but relatively few transmit plant viruses (Byrne and Bellows, 1991). Presently only three whitefly species *Bemisia tabaci, Trialeurodes vaporariorum,* and *Trialeurodes abutilonia,* are known vectors of plant viruses. Of the three virus transmitting whiteflies, *Bemisia tabaci* is the most important, demonstrated to be the vector of over 100 different viral diseases in the tropics and subtropics (Jones, 2003).

Populations of *Bemisia tabaci* fluctuate significantly during the year in south India. The *B. tabaci* population is highest during the hot season of February to May when temperatures are high and rainfall is low. From September to October, this is also the period of low temperatures and high rainfall, numbers fall to approximately a tenth of their summer levels (Saikia and Muniyappa, 1989).

### 2.4.10 Host range of *B. tabaci*

The occurrence of *B.tabaci* on different plants was reviewed by various workers. Its presence has been recorded on 41 different plant species from 19 families (Misra and Lamba, 1929; Thomas, 1932), on 30 different plant species from 9 families (Hussain and Trehan, 1933) on 101 different plant species from 24 families (Pruthi and Samuel, 1942), on 74 different plant species belonging to 17 families (Nene, 1972; Naresh and Nene, 1980), on 36 different weed species from 13 families (Gameel, 1977) on 99 different host plants belonging to 20 different families (Pimpale and Summanwar, 1983) and on 41 species from 10 plant families (Saikia and Muniyappa, 1989).

### 2.4.11 Epidemiology

Pruthi and Samuel (1942) studied the population of whitefly on tobacco crop in northern India at different months of the year, where the population of whiteflies were highest in autumn up to middle of November, decreases in winter and again increased in March. Further, the incidence of tobacco leaf curl disease was found to be dependent on vector population.

Varma (1959) reported that the incidence of tomato leaf curl virus on tomato was directly related to the population density of the vector *B.tabaci.* The vector population developed during January when incidence of the disease also began to increase.

Yassin and Nour (1965b) reported that during March-September, 304 out of 577 (52 %) tomato seedlings, which were exposed to virus carrying whiteflies developed leaf curl symptoms. Similarly in the cooler months of December to February, 132 out of 367 (35.90%) exposed seedlings became infected.

Cohen *et al.* (1974) reported that tomato yellow leaf curl virus (TYLCV) spread was significantly correlated with population size of its vector, *B.tabaci.* An increase in the *B.tabaci* population and in TYLCV infection was found in tomato plots surrounded by windbreaks.

Nitzany (1975) reported that in Israel TYLCV outbreaks always followed in months with a mean relative humidity less tha 60 per cent and mean maximum temperature of $30^0$C, However, Lebanon TYLCV outbreaks were only reported in the coastal region with a mean relative humidity more than 60.00 per cent (Makkouk *et al.,* 1979).

Yassin (1975) reported the negative correlation between ToLCV incidence and wind direction during five growing seasons in Sudan and the highest rate of natural spread of ToLCV in the early stages of growth, usually within 7 to 10 weeks after planting.

Saklani and Mathai (1977) reported that October to mid December was the most effective time for planting of tomato followed by January to 1st March in Pantnagar (U.P.). The tomato leaf curl virus disease appeared very early (24 to 45 days), when the crop was planted between 16th March to16th September and there was delayed appearance (132 to 162 days) of the disease between October to mid-December.

Mazyad *et al.* (1979) reported that in tomato growing areas of Saudi Arabia TYLCV caused severe epidemics in summer and early autumn owing to optimum conditions and an abundance of the vector, *B.tabaci.* Winter planting showed only low infection with mild symptoms. Tomato cultivars varied in their susceptibility to the virus infection.

Ohnesorge (1981) studied the population dynamics of *B.tabaci* in the winter months, when the density of the pest was lowest. Of the immature stages, eggs and young larvae were most abundant during this period. A high mortality rate resulted from the asynchrony of the development of the

insect and aging of plant leaves. When the temperature was low, a large part of the pest population was unable to complete life cycle before aging and deterioration of the food plants. On early transplanted tomatoes some of the whiteflies developed to the adult stage, while on late transplanted tomatoes very few completed their development.

Shanab and Awad-Allah (1982) studied the seasonal population fluctuations in *B.tabaci* on tomato in relation to temperature and relative humidity in Egypt. Whitefly population first appeared in May, were lowest from July to October when the daily mean temperature was 20.86 to 27.58$^0$C and the relative humidity 58.90 to 66.66 percent and reached peak number in September. The effect of daily mean temperature on population in summer was insignificantly negative in first year and significantly positive in second year, while autumn it was highly significantly positive during both the years. The effect of daily mean relative humidity in summer was highly significantly positive during both the years, while in autumn it was insignificantly negative during both years.

Shaheen (1983) found *B.tabaci* attacking tomato in April to November with infestation peak in August to October. Early sown tomato in February was seldom infested, but crop sown in April became severely infected throughout the flowering and fruiting stage resulting in 40.00 percent crop loss. Severe infestation at the seedling stage resulted in complete yield loss on autumn crops sown in August.

Ioannou (1987) reported that incidence of TYLCV was high in nursery beds situated near infected tomato crops whereas nursery near inland areas where tomato crop was not taken previously found free from TYLCV infection.

Populations of *B. tabaci* fluctuate significantly during the year in South India. The *B. tabaci* population is highest during the hot season of

February to May when temperatures are high and rainfall is low. From September to October, this is also the period of low temperatures and high rainfall, numbers fall to approximately a tenth of their summer levels (Saikia and Muniyappa, 1989).

Tomato leaf curl virus disease (ToLCVD) incidence in South India is highly correlated with the size of the *B. tabaci* population. For unsprayed, susceptible tomato planted in March, ToLCVD symptoms can appear as early as 2 wk after planting (WAP). ToLCVD incidence then increases rapidly to 100 percent by 11 WAP, usually leading to complete crop failure (Saikia and Muniyappa, 1989).

Shankarappa (2002) conducted a survey to assess the incidence of ToLCV on open pollinated tomato varieties where the incidence of ToLCV varied from 11.00 to 100 percent. The incidence and spread was more rapid in February to May planted crop than June planted crop.

## 2.5 SOURCES OF TOMATO LEAF CURL VIRUS RESISTANCE

An effective screening procedure, at large scale makes the ToLCV breeding programme more efficient. Many successful screening programmes for ToLCV resistance were carried out in the field, relying upon natural virus infection. However, it becomes reliable only when artificial method of virus inoculation is used.

Pilowsky and Cohen (1974) have conducted artificial inoculation using viruliferous white flies maintained on *Datura stamonium* plants for testing resistance to ToLCV. Hayati (1978) suggested individual plant inoculation in which white flies were reared on immune eggplant inoculation in which were starved for one hour before transferring to ToLCV infected tomato

plants. After 48 hours of acquisition feeding, they were gently removed and allowed to feed on healthy tomato plants to be tested for their resistance to ToLCV at three to four true leaf stages.

*Bemisia tabaci* is a thermophilic insect (Avidov, 1978), the fecundity of which is known to be influenced by higher temperature (Pruthi and Samuel, 1942). Butter and Rataul (1978) reported that, transmission of ToLCV was 100% at 33-39$^0$C, while it was 30 percent at 44$^0$C or only 10 percent at 10$^0$C.

Vasudev and Sam Raj (1948) screened more than sixty varieties of tomato and reported all of them to be susceptible to ToLCV.

Nariani and Vasudeva (1963) tested 98 varieties of tomato and *Lycopersicon spp.* including lines of *L. pimpinellifolium, L. hirsutum* and *L. peruvianum* but did not find resistant genotypes.

Mayee *et al.* (1974) reported that HS-110, HS-102, Nematex, T-1 and Nova are some of the ToLCV tolerant varieties developed by conventional breeding methods.

Two lines of *L. pimpinellifolium,* XXXII-354-A Silestra and P13-2247 are reported to show mild reactions to ToLCV (Som and Choudhury, 1976).

In an experiment conducted at Jordan, over 100 tomato cultivars were tested under greenhouse conditions for resistance to *Meloidogyne incognita, M. javanica* and tomato leaf curl virus (ToLCV). Fourteen cultivars exhibited a good level of resistance to both species of root-knot nematode (Abu-Gharbieh and Makkouk, 1978).

Varma *et al.* (1980) reported the resistance in accession of *L. esculentum* EC 104395.

Joshi and Choudhury, (1981) reported the resistance in accession of *L. chilense* viz., 414-2 x 414-1 SIB, LA 267, 55 L-Antogagster to ToLCV.

Hassan *et al.* (1984) tested 118 tomato cultivars and breeding lines and 25 accessions of four wild *Lycopersicon* species against ToLCV. All the cultivars breeding lines were highly susceptible, but all the accessions of *L. cheesnmanii, L. hirsutum f. glabratum, L. peruvianum*, and *L. peruvianum f. humifusum* were higly resistant. Accession *L. pimpinellifolium* varied in their reaction to ToLCV.

Hassan *et al.* (1985) tested 46 tomato cultivars and breeding lines against tomato yellow leaf curl virus and found none of them were resistant.

One hundred and ninteen tomato cvs and breeding lines and 26 accessions of 4 wild Lycopersicon species are evaluated for TYLCV resistance. All tested commercial tomato cvs and breeding lines were highly susceptible. All tested accessions of *L. cheesmani, L. hirsutum* f. *glabratum, L. peruvianum, and L. peruvianum* f. *humifusum* were highly resistant (Hassan *et al.*, 1986).

Banerjee and Kalloo (1987b) screened 122 varieties, lines and wild accessions of *Lycopersicon* and recorded that *L. hirsutum f. typicum* (A 1904), *L. peruvianum* possessed resistance to ToLCV and observed no disease symptoms in *L. pimpinellifolium* (A 1921) till 90 days of age.

Kasrawi *et al.* (1988) screened sixteen accessions of three wild species and fifty five fresh market *L. esculentum* cultivars were also included for resistance to ToLCV. All six *L. peruvianum* accessions, *L. peruvianum f. humifusum* and *L. hirsutum* showed zero incidence to ToLCV. The three *L. pimpinellifolium* accessions showed moderate to low severity.

Banerjee and Kalloo (1989) observed that two lines *viz.*, A-1921 (*L. pimpinellifolium*) and B-6013 (*L. hirsutum f. glabratum*) were resistance for ToLCV.

Kalloo and Banerjee (1990) developed five breeding lines *viz.*, LCP-22, LCP-2, LCP-3, LCP-9 and LCP-15 through introgression of tolerance from *L. pimpinellifolium* LA 1921 to *L. esculentum* cultivars HS 102 and Punjab Chhuhara. These lines exhibited 28.3, 30.3, 30.2, 33.3 and 35.0 per cent disease incidence respectively compared with 91.7 per cent for cv. HS 101 and 100 per cent for HS 102 and Punjab Chhuhara. The Co-efficient of variation ranged from 2.6 to 4.6 in resistant lines and 55.5 to 96.2 in susceptible varieties.

In 1986, the first commercial TYLCV-resistant tomato hybrid TY20 was released (Pilowsky and Cohen, 1990).

Moustafa and Nakhla (1990) reported that 6 lines of *L. cheesnmanii, L. peruvianum* and *L. pimpinellifolium* showed resistance to ToLCV.

Bisht *et al.* (1990) evaluated a total of 88 germplasm collections for resistance to various diseases such as ToLCV, Fusarium wilt, fruit rot and early blight. *L. hirsutum* and *L. peruvianum* showed high degree of resistance to ToLCV.

Kandeel (1991) reported that the cross between Clivia x Aurgia was recorded ToLCV resistance.

Several TYLCV-tolerant cultivars have been released by the private sector. The first one available was the $F_1$ hybrid TY-20 which was released in 1988 in Israel (Hazera Seed Co.) for open field cultivation. *L. peruvinnium* PI 126935 was the source of TYLCV tolerance to develop TY-20 hybrid which was polygenic and recessive (Zamir *et al.* 1991).

Muniyappa *et al.* (1991) observed that two lines of *L.hirsutum* (PI 390658 and PI 390659) and two lines of *L. peruvianum* (PI 127830 and PI 127831) were resistant to ToLCV infection.

Zakay *et al.* (1991) screened 23 accessions for resistance to ToLCV. Plants were grown in natural infested condition and the genotypes were examined for presence of viral DNA and symptom development at two weeks interval. An accession of *L. chilense* showed highest level of resistance.

Among *L. esculentum* accessions LE-812 and LE-376 and AVRDC lines were carrying filed resistance to ToLCV (Shoba and Armugam, 1991).

A very high level of resistance was found in one accession of *L.hirsutum* (LA 1777) (Moustafa, 1990).

Accessions from several species were screened for resistance and the best resistance came from accessions of *Lycopersicon chilense* Dunal (Scott and Schuster, 1991).

Davino *et al.* (1992) studied the reaction of tomato $F_1$ hybrids Turguesa, Samar, Arlette, Rita and Mereto and varieties M46, M47, M48 and RS9020 to ToLCV in green house. Cherry type tomato variety RS9020 had the lowest disease incidence.

Ioannou (1992) screened over 52 cultivars and 10 tomato lines for ToLCV. Only *L. peruvianum* CMV Sel. INRA and *L. pimpinellifolium* Hirsutae accessions found most promising in breeding programmes.

Moustafa and Hassan (1993) screened 17 true breeding cultivars, four tolerant hybrids and the local control Castlerock for ToLCV resistance. The four hybrids Typhoon, TY 20, BB234, and BB235 and true breeding cultivar T22 showed better virus resistance.

Two ToLCV resistant varieties (Hisar Anmol and Hisar Gaurov) derived from a backcross pedigree of *L. hirsutum f. glabratum x L. esculentuan* have been identified by the variety evaluation committee of Haryana Agricultural University, Hissar (Kalloo and Banerjee 1993).

Accessions of wild tomato species *L. chilense* (LA 1969) and *L. hirsutum* (LA 1777) were found resistant to ToLCV in field tests and *B.tabaci* mediated transmissions tests. Further the resistance was broken down by field inoculation of ToLCV (Kheyr *et al.*, 1994).

The intermediate TYLCV resistance gene *Tyl*, introgressed from S. *chilense* LA1969 (Michelson *et al.*, 1994)

Several *Lycopersicon species* have been discovered and reported to be TYLCV resistant, including *L. peruvianum, L. pimpinellifolium, L. hirsutum* and *L. cheesnmanii* (Scott *et al.*, 1995).

Kasrawi and Mansour (1995) developed $F_7$ lines (T27, T37 and T62) from the crosses between *L. peruvianum, L. pimpinellifolium* and *L. hirsutum* with susceptible cv. Special Black. These lines remained symptom less for two years in the field trials and are seen source of stable resistance.

Under the Sri Lankan conditions, tomato cultivars BL 982, Fiona, Jackal, LA 1777, RS 8990 and TY King were reported as highly resistant as no plant could be infected by graft inoculation (Zoysa, 1996). Three of these cultivars (BL 982, Jackal and LA 1777) were, however, found susceptible under South Indian conditions (Singh, 1996) and four (cv. B 1982, Fiona, Jackal and RS 8990) were susceptible in Pakistan (Hameed, 1996).

Twelve accessions were selected for introgression based on their lack of virus symptoms and larger leaf size; LA 1932, LA 1938, LA 1959, LA 1960, LA 1961, LA 1963, LA 1968, LA 1969, LA 2747, LA 2762, LA 2774, and LA 2779 (Scott *et al.*, 1996).

Raghupathi *et al.* (1997) screened one hundred and sixty germplasm entries of tomato against ToLCV. Under natural conditions only two wild species namely *L. hirsutum* (LA 1353) and *L. hirsutum f. glabratum* (LA 1223) were free from ToLCV infection.

The effect of tomato yellow leaf curl virus (TYLCV) on total yield and yield components of various resistant $F_1$ tomato cultivars and new breeding lines was evaluated in the field. Seeds of the $F_1$ hybrids 8484, 3761, Fiona, and Tyking and the new breeding lines TY172 and TY197 were sown in an insect-proof greenhouse. Plants of TY172 and TY197 suffered the least relative yield loss and contained the lowest level of viral DNA. Therefore, these two lines exhibited the highest level of resistance (Lapidot *et al.*, 1997).

Barg *et al.*, (1997) reported that the TYLCV-tolerant breeding line MP-1, which has been is highly amenable to transformation compared with the commonly utilized tomato cultivars. The tomato line MP-1 excels the cultivars commonly used for transformation with regard to the speed of regeneration, percentage of transformation and frequency of phenotypically normal transgenic plants. These characteristics, together with its tolerance to Tomato Yellow Leaf Curl Virus, make line MP-1 very suitable for large scale generation of transgenic tomatoes.

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.

The highly resistant line 902 is derived from a cross between two *L. hirsutum* accessions resistant to TYLCV, followed by crossing *L. esculentum* and selfing resistant symptomless individuals. In addition, an advanced breeding line ($F_8$ generation) derived from *L. pimpenellifolium* "Hirsute" and a line derived from *L. chilense* that underwent four

backcrosses to *L. esculentum* exhibit strong resistance as evidenced by symptom less scores (Vidavsky *et al.*, 1998).

The resistant line 902 developed from accessions LA1777 and LA386 of the wild tomato species *L. hirsutum* was used to develop the new resistant lines referred to as "Favi". Line 902 was a stable line that is resistant to TYLCV from Israel, had *L. esculentum* plant morphologies, and was self-compatible. Subsequent crosses between Line 902 and a very prolific and large size tomato line but susceptible to TYLCV resulted in the hybrid Favi-9. Favi-9 was resistant to TYLCV-Is. Six resistant tomato lines, Favi -21, Favi -22, Favi -23, Favi -24, Favi -25 and Favi -27 were derived from the hybrid Favi -9. All the Favi lines and were found to be resistant to TYLCV in Israel (Vidavsky and Czosnek, 1998).

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).

Pico *et al.* (1999) developed six advanced breeding lines (UPV Ty 1, 3, 6, 9, 17 and 53), exhibiting a high level of resistance to TYLCV-Sr, were obtained from two highly resistant $F_1$ hybrids derived from *L .chilense* (LA 1932 and LA 1938).

Thirteen tomato varieties of different geographic origin were screened for resistance to tomato yellow leaf curl virus (TYLCV). BL937, BL938, FLA582-17, and TY-King did not show any TYLCV symptoms, while Hirseptyle was severely infected. Avinash#2, FLA438-17, and CLN 2117dcl-26-19-15 had both TYLCV resistance and favorable horticultural characteristics (Li, 1999).

Ten determinate tomato inbred lines were evaluated in the field for tomato yellow leaf curl (TYLCV). Entries with high TYLCV severity, except for CLN 1466S, CLN 1466P, CLN 2026E, showed low incidence from 1 to 3 (Sin, 1999).

Thirty-one accessions representing four tomato species (*L. esculenium, L. peruvianum, L. pimpinellifolium, L. chilense*) were screened for resistance to geminivirus with bipartite from Brasilia-DF. Resistant genotypes were found in *L. peruvianum* (CNPH-784, CNPH-786 and CNPH 787), *L. chilense* (LA 1967), *L. pimpinellifolium* (LA 1342) and *L. esculenium* (TY-52; Multichiltyle 95; Chiltyle 93-3). Most of the resistant genotypes harbored the virus without showing symptoms. On the other hand, LA 1967 showed no disease symptom and the presence of viral DNA was detected in only one out of 10 inoculated plants, suggesting a different mechanism of resistance (Giordano *et al.*, 1999)

Kalloo and Banerjee (2000) reported the performance of H-24 with respect to yield and reaction to ToLCV under field and artificial inoculation. They found that mean PDI values of H-24, Sel-7 and Punjab Chhuhara were 18.83%, 50.23% and 67.57% respectively.

Plants of 25 wild *Lycopersicon* accessions were screened in the greenhouse for resistance to the whitefly-borne tomato yellow leaf curl virus (TYLCV). High levels of resistance were detected in 7 of 9 accessions of *L. peruvianum* and in all 5 accessions of *L. chilense* tested. In contrast, plants of 7 accessions of *L. hirsutum* and 3 of 4 accessions of *L. pimpinellifolium* were highly susceptible. Plants of accession CIAS 27 (*L. pimpinellifolium*) showed moderate resistance to TYLCV (Pilowsky and Cohen, 2000).

Six of the most promising tomato yellow leaf curl virus (TYLCV) resistant hybrids (HA3017A, HA3017B, HA3044, HA3048, Pxl50420 and Psl50535) were evaluated along with, two grower standard cultivars, 'Sanibel' (Petoseed) and 'FL47' (Asgrow) in trials. Of these HA3017A, HA3044 and Pxl50420 are resistant to TYLCV compare to standard cultivars (Gilreath *et al.*, 2000).

Twenty-five tomato lines and varieties from America, Middle East, India and Taiwan with reported resistance to tomato yellow leaf curl virus (TYLCV) were evaluated for resistance to TYLCV at ARC-AVRDC, Nakhon Pathom, Thailand. TLCV (271/1x26)-1 and two wild accessions, LA 1392 (*L. chilense*) and LA 1177 (*L. hirsutum*) did not show any TYLCV symptoms (Lieu, 2000).

Partial resistance to the virus along with resistance to the vector were found in *L. hirsutum* LA 1777 and *L. pimpinellifolium* Hirsute INRA. The highest levels of virus resistance were observed in three *L. chilense* accessions (LA 1969, LA 1938, LA 1932). Resistance derived from LA 1932 remained after its introgression into cultivated tomato, giving breeding lines that were highly resistant to TYLCV (Pico *et al.*, 2001).

New and old accessions of *Lycopersicon chilense* (LA 1932, LA 1938 and LA 1963), *L. peruvianum* (PI-143679 and PI-126944), and *L. hirsutum* (UPV-16910) reported as resistant to TYLCV (Pico *et al.*, 2002).

Rattan and Bindal (2002) screened two hundred fourteen genotypes of tomato against Tomato leaf Curl Virus (ToLCV). Seven lines viz., 620, 646, 672, 742, 761, 765 and 776 were highly resistant (0.5 % infection) where as seven lines were resistant (6-20% infection).

Muniyappa *et al.* (2002) developed three open-pollinated (OP) tomato varieties (Sankranthi, Nandi and Vybhav, previously referred to as TLB-111, TLB-130 and TLB-182, respectively) that are resistant to South Indian ToLCVs. These varieties derived virus resistance from the variety H-24, which in turn derived its resistance originally from the wild species *Solanum habrochaites* (previously *Lycopersicon hirsutum* f. *glabratum*).

Ganesh Naik *et al.* (2002) reported that three lines of *L. esculentum* (TLB-122, TLB-134, and TLB-146) were found to be resistant to ToLCV under field conditions.

Sadashiva *et al.* (2002) evaluated advanced tomato breeding lines resistant to both bacterial wilt and ToLCV. Seedlings of these lines were artificially exposed to virulent whiteflies and also artificially inoculated with bacterial suspensions. Three entries *viz.*, CLN-2114-$DC_1F_1$-50-2-16-8-2-17-0, CLN-2116-$DC_1F_1$-180-31-9-34-4-0 and CLN-2116-$DC_1F_1$-180-31-10-25-8-0 were found to exhibit resistance both for ToLCV and bacterial wilt.

A total of 90 genotypes of *Lycopersicon* species were tested for resistance to the *Tomato leaf curl geminivirus* (ToLCV) by agroinoculation and the vector whitefly (*Bemisia tabaci* Genn.). Of the 38 cultivars and 11 breeding lines of *L. esculentum* tested, none was highly resistant. On the other hand, among the 38 commercial cultivars screened, 16 (42.1%) were highly susceptible in vector inoculations and 31 (81.6%) in agroinoculation. Among the exotic collection (EC) accessions six were highly resistant, eleven resistant to whitefly inoculation and none was highly susceptible in either of the two tests. While only one accession of *L. cheesmanii* was tested, it could not be infected by either of the two methods. *L. pimpinellifolium* genotype EC 251580 was similarly resistant. In *L. peruvianum*, five EC accessions could not be infected by whitefly inoculation, with three of these being resistant and two moderately resistant in agroinoculation (Savarni and Varma, 2002).

The tomato lines tested in Bangalore include wild *Lycopersicon* species, advanced breeding lines and commercial hybrids. Of the 34 ToLCV resistant/tolerant tomato genotypes field screened for ToLCV-[Ban4] resistance, none was found to be resistant, 11 showed mild and/or moderate infections and the rest were susceptible showing moderate to severe infections (Maruthi *et al.*, 2003a).

The wild species *Lycopersicon peruvianum* INRA sel. and *L. chilense* LA 1969 were resistant to ToLCBV-[Ban4] but highly susceptible to whiteflies, whereas *L. hirsutum* LA 1777 was resistant to both the virus

and the vector. Among the *L. esculentum* genotypes, H-24, FL 744-6-9, FL 699 and FL 699 SP+ were tolerant to ToLCBV-[Ban4], but were susceptible to whiteflies (Maruthi *et al.*, 2003b).

Evaluations of tomato resistance were done under field (natural infections) and screen house conditions (natural and controlled infections) using genotypes of diverse origins, comprising cultivars, hybrids, breeding lines, populations and wild tomato species. Out of these resistance found in the *L. peruvianum* access LA 444-1, in the IAC 14-2 series, in the $F_4$ line TySw5, and in the hybrids 'Franco' and BX 1653088 ('Densus'), with ratings close to absence of symptoms (Matos *et al.*, 2003).

Five commercial tomato cultivars (Amoretto, Birloque, Royesta, Tovigreen and Ulises) naturally infected by TYLC viruses. The analyses showed that Ulises, Birloque and Tovigreen exhibited a moderate resistance, and Ulises was also highly tolerant (Rubio *et al.*, 2003).

Sadashiva *et al.* (2003) screened the advanced breeding lines for ToLCV disease resistance along with the susceptible variety Arka Sourabh. The results indicated that the breeding lines TLBR-1, TLBR-2, TLBR-3, TLBR-4, TLBR-5, TLBR-6, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199 and IIHR-2100 had greater tomato leaf curl virus resistance.

Kashina *et al.* (2004) evaluated eight advanced breeding lines along with three locally popular (Moneymaker, Tengeru 97 and Cal-J) varieties. The susceptible cultivar Moneymaker had the most severe symptoms of TYLCTZV of all the cultivars tested, while no symptoms were observed on the resistant tomato line TY172. The line TY172 consistently performed better than the rest of the tomato genotypes, followed by Tengeru 97.

Four tomato lines introgressed from *Lycopersicon chilense* were compared with the commercial $F_1$ hybrids 'ARO 8479' and 'HA 3108',

which are tolerant to Tomato yellow leaf curl virus, and the cv. 'Campbell 28' as a susceptible control. Resistance was evaluated by the use of grafted diseased scions as well as in a field trial where plants infected by viruliferous whiteflies and disease-free plants were transplanted in paired rows. The new lines LD 3, LD 4, LD 5 and LD 6 showed no disease symptoms after grafting or in the field trial (Gomez *et al.*, 2004).

In order to obtain breeding materials, four TYLCV resistant varieties were screened. Those four varieties showed resistance to TYLCV. Aichi line and were proved to grow normally in spite of infection TYLCV by field resistance. It is considered that 'Athyla' is an elite line for breeding material causing of field resistance test (Masashi *et al.*, 2005).

Four tomato cultivars (TLB111, TLB130, TLB133, and TLB182) resistant/tolerant to South Indian ToLCV were screened against the Bangladesh ToLCVs in 2003–04. Although challenged by diverse viruses and potentially mixed infections, disease incidence remained low (6 to 45%) in the resistant cultivars compared with local cultivars (68 to 100%) (Maruthi *et al.*, 2005).

Germplasm with *S. chilense* resistance genes were evaluated only in Lebanon, Jordan, and Israel and they were found to be resistant to tomato leaf curl virus (Agrama and Scott, 2006).

Thirty-two hybrids were produced and evaluated along with ToLCV tolerant commercial hybrids (Mruithyunjaya-2, Sasya 9449 and Laxmi) during summer 2005. Of the 32 hybrids tested, 16 hybrids showed resistant reaction to ToLCV. Four hybrids *viz.*, Sankranthi x PKM-1, Sankranthi x Arka Meghali, LCR-9 x Vybhav and Vybhav x PKM-1 were found more promising with respective to resistance, yield and other horticultural characters (Shankarappa *et al.*, 2006).

Tomato germplasm accessions; FLA456-4, FLA591-15, H24, CLN2443A, CLN2443B, CLN2443C, TLB111, TLB182-1, TLB111-F6-4-1, TLB130-F6-3-1 and TLB134-F6-8-1 from the Asian Vegetable Research Development Center (AVRDC), Taiwan, were screened for resistance to the *Tomato Yellow Leaf Curl Virus*, Thailand isolate (TYLCTHV-[2]). AVRDC tomato lines: H-24, FLA591-15 and FLA456-4 expressed mild or no symptoms after one month inoculation (Chomdej *et al.*, 2007).

Boiteux *et al.* (2007) reported that the *Ty-1* locus, introgressed from *Lycopersicon chilense*, controls tolerance to species of the monopartite *Tomato yellow leaf curl virus* (TYLCV) complex in Europe and the Middle East.

Anjali (2007) found that Hawaii 7998, H-24, H-86, LE-474, LE-640, and LE-658 were completely free from ToLCV incidence.

A total of 25 lines were screened for tolerance to high temperature and ToLCV. Of which, sixteen lines *viz*; IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2199, IIHR-2000, IIHR-2201, IIHR-2202 IIHR-2223, IIHR-2230, IIHR-2231, IIHR-2234, IIHR-2239, IIHR-2243, IIHR-2248, IIHR-2249 and IIHR-2251 were found to be tolerant to high temperature and resistant to ToLCV and all the lines had high per cent fruit set under field conditions (Singh and Sadashiva, 2007).

Sadashiva *et al.* (2007) screened the reported sources of resistance to ToLCV against Tomato Leaf Curl Bangalore Virus (ToLCBV) which is most prevalent in South India. Eight tomato lines *viz;* IIHR-2101 (*Lycopersicon hirsutum* LA-1777), IIHR-2195, IIHR-2205, IIHR-2406, IIHR-2413, IIHR-2611 and two *L. peruvianum* accessions (IIHR-1943 & IIHR-1970) were found to be resistant to ToLCBV.

García *et al.* (2008) concluded with their studies performed with the line '468-1-1-12' indicated that the resistance was also effective against

three other virus species associated with TYLCD, indicating wide spectrum resistance of this source.

Pérez de Castro *et al.* (2008) reported partial resistance to TYLCD in line L102, derived from *Solanum pimpinellifolium* UPV16991. Resistance in this line is monogenic, with partial recessiveness and incomplete penetrance.

Azizi *et al.* (2008) screened 134 accessions of *Solanum lycopersicum* and six accessions of *Solanum peruvianum* for resistance to an Iranian isolate of TYLCV. Plants were inoculated using whiteflies (*Bemisia tabaci*). All accessions of *S. lycopersicum* had demonstrated various degrees of disease symptoms. However, all six accessions of *S. peruvianum* were resistant and remained symptomless.

Shankarappa *et al.* (2008) developed hybrids by crossing three varieties Sankranthi, Nandi and Vybhav (which are resistant to ToLCV) with 12 tomato genotypes with superior agronomic characteristics. From those selected 20 hybrids (named BLRH-1 to BLRH-20, *Bangalore leaf curl virus-resistant hybrid*) which are and evaluated for their resistance to ToLCV. Of the 20 hybrids evaluated, 11 were found resistant to ToLCV in the field, but only three (BLRH-3, BLRH-9 and BLRH-16) remained resistant when challenged with high virus inoculum pressure in the glasshouse through whitefly-mediated inoculations.

Three tomato (*Solanum lycopersicum*) lines and a variety reported to be resistant to tomato yellow leaf curl virus (TYLCV) in Cuba were tested against a TYLCV isolate from the Reunion Island (TYLCV-Mld [RE]) as well as an Israeli resistant line TY-172 and TYLCV-susceptible lines R-13 (Israel), 13–8–2 (Cuba) and cv. 'Farmer.' Resistance was evaluated by using viruliferous whiteflies and virus-infected scions. The TYLCV-resistant lines: 13–8–1, LD 5, LD 6, TY-172 and cv. 'Vyta' did not show viral

disease incidence and symptoms in the plants. On the contrary, the TYLCV-susceptible lines R-13, 13–8–2 and cv. 'Farmer' showed TYLCV-Mld [RE]-like strong symptoms after vector inoculation and grafting (Piñón, 2009).

Resistance to begomoviruses, including bipartite tomato mottle virus (ToMoV) and monopartite tomato yellow leaf curl virus (TYLCV), has been introgressed to cultivated tomato (*Solanum lycopersicum*) from *Solanum chilense* accessions LA1932 and LA2779 (Yuanfu *et al.*, 2009).

Resistance to begomoviruses, including bipartite tomato mottle virus (ToMoV) and monopartite tomato yellow leaf curl virus (TYLCV), has been introgressed to cultivated tomato (*Solanum lycopersicum*) from *Solanum chilense* accessions LA1932 and LA2779 (Ji *et al.*, 2009).

The breeding line TY172, originating from *Solanum peruvianum*, is highly resistant to TYLCV (Anbinder *et al.* 2009).

Pereira *et al.* (2010) screened seventy-one Solanum (section *Lycopersicon*) accessions were whitefly inoculated with the bipartite Begomovirus sp. Tomato rugose mosaic virus (ToRMV) and simultaneously infested with a mixture of *Meloidogyne incognita* and *M. javanica* under greenhouse conditions in Brazil. Out of those five *S. peruvianum* accessions (PI- 306811, PI-365951, LA-1609, LA-2553, and CNPH-1194) displayed nematode and broad-spectrum resistance to all Begomovirus spp.

Singh *et al.* (2010) screened 22 genotypes under artificial conditions to tomato leaf curl virus out of 22 genotypes, only H-88-78-1 is highly resistant, H-88-87 and H-88-78-2 are moderately resistant remaining 4 are moderately susceptible, 13 susceptible and two (Punjab Chhuhara and Sel 7) highly susceptible.

Olson *et al.* (2010) reported that Security-28, HA-3073, Tygress varieties are resistant to tomato leaf curl virus and recommended for commercial cultivation in Florida.

## 2.6 GENETICS OF THE DISEASE

Crosses between *L. esculentum* and *L. pimpinellifolium* (currant tomato/accession LA 121) and genetic analyses of $F_{1-3}$ and backcross generations indicated the existence of incomplete dominance of resistance over susceptibility, suggesting a monogenic control of resistance (Pilowski and Cohen, 1974). They also studied the tolerance of ToLCV derived from the wild tomato *L. peruvianum* in 1990. Tolerance was found to be governed by five recessive factors.

Som and Choudhary (1977) reported incompletely dominant polygenes to govern the ToLCV resistant trait.

Resistance to tomato leaf curl virus in *L. hirsutum* was dominant and controlled by more than one gene (Mazyad *et al.*, 1982).

The cross *L. esculentum* cv DC 82 x *L. hirsutum* (LA 386) was studied by Hassan *et al.*, (1984). Inoculation was carried out prior to transplanting and evaluated later. Reactions of parents, $F_2$ and $F_3$ plants and backcrosses of resistant plants to DC 82 indicated that resistance derived from *L. hirsutum* is dominant and controlled by more than one gene.

Yassin (1985) reported that *L. pimpinellifolium* (LA 1582) carried a dominant gene for ToLCV resistance.

Resistance in *L. pimpinellifolium* (A1921) was found to be monogenic and incompletely dominant (Banerjeeand Kalloo 1987a) and resistance in *L. hirsutum f. glabratum* (B 6013) was governed by two epistatic genes (Banerjee and Kalloo 1987b). Two independent genes for

resistance seem to be involved in these two wild species with that of *L. hirsutum f. glabratum* dominant over the other (Banerjee and Kalloo 1990).

Kasrawi (1989) reported the inheritance of resistance is governed by single dominant gene in *L. pimpinellifolium* to TYLCV in progenies derived from crosses between the resistant parents *L. pimpinellifolium* Hirsutae-INRA and LA1478 and the susceptible parent *L. esculentum* cv. Special Back.

Fraser (1990) tabulated the information available on the genetics of resistance for 87 viruses to gain an overall insight on the relative frequency of different types of genetic controls operating for virus resistance. Among the examples considered, he noted that 38 showed single dominant gene control, 13 incomplete/partial dominance which is gene-dosage dependent, 18 exhibited control by apparently recessive genes and 5 oligogenic control. The remaining 13 in addition to monogenic control exhibited possible presence of modifiers having mostly direct or nonspecific influence such as an effect through growth rates.

Pilowsky and 'Cohen (1990) developed a TYLCV tolerant tomato variety (TY 20) with the tolerance derived from *L. peruvianum.* The ToLCV resistant lines – H-2, H-11, H-17, H-24 and H-36 were developed through the controlled introgression of *L. hirsutum* f. *glabaratum* into *L. esculentum* (Kalloo and Banerjee, 1990).

Shoba and Arumugam (1991) studied the association of leaf curl virus resistance in tomato. They observed that the simple correlation co-efficient between disease incidence and some important characters were not significant indicating the independent nature of resistance of leaf curl virus with other traits.

Jalikop (1992) reported complimentary gene action (9 susceptible: 7 resistant) in four crosses of *L. esculentum* x *L. hirsutum* for days to ToLCV

symptom expression and ToLCV score showed predominance of the additive effect in the crosses involving *L. pimpinellifolium.*

Interespecific hybrids obtained from crosses between *L. pimpinellifolium, L. peruvianum,* and *L. hirsutum*, show transgressive segregation for their reaction to TYLCV, suggesting that different but complementary genes condition resistance (Kasrawi and Mansour, 1994).

Nagaraja (1995) reported additive gene action for days to ToLCV symptom expression. For symptom severity, both additive and additive x additive effects were predominant.

Tolerance to ToLCV obtained in *L. chilense* (LA 1969) was reported to be controlled by partial dominant gene (Zamir *et al.,* 1994).

Dharmatti (1995) observed complementary type of gene action (9 susceptible: 7 resistant) involving two pairs of genes for ToLCV resistance in $F_2$ generation of the cross 20/5 Alcobasa x N 2298 $MF_6$.

The genetics of resistance to TYLCV has been studied for a number of the resistant breeding lines mentioned above. In most cases, the sources of resistant to TYLCV appear to be controlled by multiple genes (Pico *et al.,* 1996).

Inheritance of resistance to TYLCV was studied in segregant progenies derived from a cross between susceptible *L. esculentum* and resistant *L. chilense* accession LA 1969. Analysis of segregation in the progenies revealed that resistance in *L. chilense* was controlled by a dominant gene (Gomez and Laterrot, 1997).

Friedmann *et al.* (1998) developed a breeding line, TY 172 which was resistant to ToLCV. When TY 172 was crossed with susceptible cultivar, the hybrids exhibited milder symptoms than susceptible parent, but higher

than TY 172, suggesting a partial dominance for the resistance. $F_2$ population segregation suggested that at least three genes may account for resistance.

*L. hirsutum* has been reported to be symptomless to TYLCV infection. This resistance is apparently controlled by one dominant major gene in wild species accessions LA1777 and LA 368 (Vidavsky and Czosnek, 1998).

The resistance in *L. hirsutum* appears to be controlled by two to three additive recessive genes and that of *L. pimpinellifolium* by one major gene (Vidavsky *et al.*, 1998).

Bhattacharjee (1999) reported ToLCV resistance to be governed by two completely dominant genes under inhibitory gene action with a segregation ratio 13 resistant: 3 susceptible plants.

Hassan and Abdel (1999) studied the inheritance of ToLCV in crosses between *L. esculentum* as a female parent and *L. pimpinellifolium* PI 407543, PI 407544, PI 407555 and *L. pennelli* LA 716 as male parents. Evaluation of parental, $F_1$, $F_2$ and backcross populations revealed complete dominance in crosses involving PI 407543 and PI 407544, partial dominance in cross with PI 407555 and recessiveness in cross with LA 716. Gene action was additive with PI 407543 and LA 716, while additive, dominance and non-allelic interaction were involved in crosses with PI 407544 and PI 407555.

Bhushana (2000) evaluated $F_2$ generation material of four different crosses of tomato under filed conditions and reported that in three of the four crosses ToLCV resistance was governed by two incompletely dominant genes in a inhibitory gene action (13 resistant: 3 susceptible in $F_2$, 3 resistant: 1 susceptible in $B_1$ and 3 resistant: 0 susceptible in $B_2$).

Resistance to ToLCV was mapped in H-24 to the short arm of chromosome 11, between the markers TG393 and TG36, and was found to be dominant (Hanson *et al.*, 2000).

The genetic basis of the resistance to ToLCV, which depends on the species, ranges from a single incompletely dominant gene to a polygenic recessive pattern (Lapidot and Friedmann, 2000).

Chandrashekara (2000) assessed the genetics of ToLCV resistance in two crosses of tomato using triple test crosses analysis and reported that the magnitude of dominance variance was higher for ToLCV symptom expression.

Nainar and Pappaih (2002) assessed inheritance of resistance to ToLCV under filed conditions in eight crosses of tomato cultivars PKM 1, CO 2, CO 3 and Pusa Ruby and resistant wild parents *L. hirsutum* and *L. pimpinellifolium*. The individual plants of six generations *viz.*, $P_1$, $P_2$, $F_1$, $F_2$, $B_1$, and $B_2$ were scored for disease incidence. The resistant to ToLCV in *L. hirsutum* was reported to be controlled by three recessive genes and a single incompletely dominant gene in *L. pimpinellifolium*.

Frimpongu and Kantaka (2002) studied the genetics of ToLCV resistance in interspecific crosses involving the wild tomato variety, Cherry. It was observed that the ToLCV is controlled by duplicate dominant epistatic genes ($F_2$ ratio of healthy: diseased plants were 15:1). The hybrids especially $F_1$, $B_1$, $B_2$ and $F_2$ were observed to be close to wild cherry in most of the characters.

The genetic basis of resistance to one *Begomovirus* isolate was investigated using populations from the cross between 'TX 468-RG' (P1) and the susceptible line 'Ohio 8245' ($P_2$). Parental lines ($P_1$ and $P_2$), $F_1$, backcross (BC) to $P_1$ ($BC_1$) and BC to $P_2$ ($BC_2$) and $F_2$ generations Assessed for symptom expression upon visual analysis. The ratio of resistant to

susceptible plants closely fit to a single recessive gene (locus) model (Giordano *et al.*, 2005).

More recently, the partially dominant *Ty-3* resistance gene (which confers resistance to TYLCV as well as tolerance to bipartite *Begomovirus* spp. infecting tomato) was introgressed from crosses derived from *S. chilense* LA-2779 (Ji *et al.*, 2007).

Tomato germplasm accessions; FLA456-4, FLA591-15, H24, CLN2443A, CLN2443B, CLN2443C, TLB111, TLB182-1, TLB111-F6-4-1, TLB130-F6-3-1 and TLB134-F6-8-1 from the Asian Vegetable Research Development Center (AVRDC), Taiwan, were screened for resistance to the *Tomato Yellow Leaf Curl Virus*, Thailand isolate (TYLCTHV-[2]). The accessions expressing the resistant genotype were then crossed to the TYLCV-susceptible female parent, Seedathip3 (SD3), to produce $F_1$ hybrids. Tomato parents and their $F_1$ progenies were inoculated with TYLCTHV-[2] at 3 weeks of seedling age using viruliferous whitefly (*Bemisia tabaci*) as the inoculation vector. Progeny of crosses between the AVRDC donor parental lines and susceptible Thai cultivars showed intermediate tolerance to TYLCTHV-[2] infection. This indicated that resistance was incompletely dominant (Chomdej *et al.*, 2007).

Crosses between four breeding lines susceptible to TYLCD and L102 were also performed to study the dominance of the resistance in *S. lycopersicon* genetic backgrounds. Response to TYLCV infection of $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ generations fitted, for this line, a monogenic control with partial recessiveness and incomplete penetrance (Pérez de Castro *et al.*, 2007)

Five crosses derived from crossing between TYLCV-susceptible female, (Edkawy, Castle Rock, Strain-B, Peto-86 and Marmmande) and TYLCV-resistant male (Favi-9) were performed. Field and laboratory

evaluation was done to six population of each cross for finding out TYLCV resistance. Conclusion pointed out that effective gene for TYLCV resistance could be one to two pairs of genes (Mazyad *et al.*, 2007).

Ornubol *et al.* (2008) concluded from their study, a donor parent line, *S. habrochaites* accession 'L06112' from the AVRDC showed complete resistance while their $F_1$ and $BC_1F_1$ expressed different levels of resistance to TYLCTHV-[2]. This indicated that this *S. habrochaites* accession was a heterozygous plant and its resistance to TYLCV is probably controlled by more than one gene.

Singh *et al.* (2008) in their investigation they screened $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ generations of H-24 and H-88-78-4 for TYLCV disease which are crossed with a highly susceptible variety Punjab Chhuhara. The $F_2$ progenies segregated and also distributed in three classes-resistant, intermediate and susceptible in the ratio of 1:2:1 respectively. Thus the $F_2$ data supports the hypothesis the inheritance of H-24 and H-88-78-4 to a local strain of TYLCV is controlled by a single completely dominant gene.

Quantitative genetics analyses suggested that a major recessive locus with epistatic interactions is controlling the resistance to TYLCD in '468-1-1-12', which could facilitate introgression of this trait into elite tomato lines (García *et al.*, 2008).

Lebanese tomato landraces were crossed with four parents: Lines Ih 902 and GF 13 (*S. habrochaites*) which carry dominant monogenic resistances to TYLCV, Line GS 16 (*S. chilense*), which carries a major gene of resistance to TYLCV with partial dominance; Line 197 (*S. peruvianum*) which is believed to carry a few recessive genes that impart resistance to TYLCV (Atamian *et al.*, 2009).

## 2.7 HETEROSIS IN TOMATO

Heterosis in tomato was first observed by Hedrick and Booth (1908) for higher yield and more fruits. Since then, heterosis for yield, its components and other quality traits were extensively studied. Heterosis has been reported for many characters in tomato, a brief review on the topic is made below.

### 2.7.1 Plant height

For outdoor scale production, determinate types with negative heterosis or no heterosis would be appreciated. Heterosis for plant height in tomato was reported by Anbu *et al.* (1981), Sidhu *et al.* (1981), Patil (1984), Ahmed *et al.*(1988), Rama Mohan (1988), Kanthaswamy and Balakrishnan (1989), Prabhushankar (1990), Dundi (1991), Naidu (1993), Tendulkar (1994), Dharmatti (1995) and Nagaraja (1995), Bhushana (2000) and Patil (2001).

### 2.7.2 Number of branches per plant

Sidhu *et al.* (1981), Patil (1984), Kanthaswamy and Balakrishnan (1989), Prabhushankar (1990), Dundi (1991), Dharmatti (1995) and Nagaraja (1995) and Bhushana (2000) observed positive heterosis for this trait. Significant negative heterosis for this trait was reported by Ashwathappa in 1980.

### 2.7.3 Days to flowering

Negative heterosis over better parent is a desirable attribute for days to flowering and was an established manifestation of heterosis among the tomato hybrids as it has been reported by several authors like Sekar (2001), Dhaliwal *et al.* (2003), Gaikwad *et al.* (2002) and Naidu (1993). However, Pujari and Kale (1994) indicated positive heterosis for early flowering.

### 2.7.4 Days to first harvest

Negative heterosis over better parent is a desirable attribute for days to first fruit maturity and it has been reported by several authors like Sharma *et al.* (1999), Viredelwala *et al.* (1981) and Thakur *et al.* (2004).

### 2.7.5 Number of fruits per plant

The number of fruits per plant is considered as an important component of fruit yield. Manifestation of heterosis for fruits per plant has been reported by Dixit *et al.* (1980), Anbu *et al.* (1981), Sidhu *et al.* (1981), Sonone *et al.* (1981), Govindarasu *et al.* (1982), Valicek and Obeidat (1987), Ahmed *et al.* (1988), Rama Mohan (1988), Kanthaswamy and Balakrishnan (1989), Yadav *et al.* (1989), Prabhushankar (1990), Dundi (1991), Naidu (1993), Tendulkar (1994), Dharmatti (1995), Nagaraja (1995), Bhushana (2000) and Patil (2001).

### 2.7.6 Average fruit weight

Dixit *et al.* (1980), Anbu *et al.* (1981), Ahmed *et al.* (1988), Yadav *et al.* (1989), Prabhushankar (1990), Dundi (1991), Naidu (1993), Tendulkar (1994), Dharmatti (1995) and Bhushana (2000) have reported significant positive heterosis for this trait, while Patil (2001) reports significant positive and negative heterosis.

### 2.7.7 Fruit yield per plant

A wide range is observed for midparental, better parental and standard heterosis. Dixit *et al.* (1980), Ahmed *et al.* (1988), Yadav *et al.* (1989), Prabhushankar (1990), Dundi (1991), Mandal *et al.* (1992), Naidu (1993), Tendulkar (1994), Dharmatti (1995) and Bhushana (2000) and Patil (2001) reported significant positive heterosis.

### 2.7.8 Fruit shape index

Ashwathappa (1980), Patil (1984), Dundi (1991), Reddy and Reddy (1994), Tendulkar (1994), Kulkarni (1999) have reported significant positive heterosis for this trait.

### 2.7.9 Number of locules per fruit

Number of locules per fruit showed mid parental values as reported by Tesi *et al.* (1970) and Nandapuri and Tyagi (1974), Anbu *et al.* (1981), Dundi (1991) and Rai *et al.* (1996) reported increases number of locules per fruit in the $F_1$ hybrid. Significant negative heterosis was reported by Gowda (1979), Sidhu *et al.* (1981), Tendulkar (1994) and Bhushana (2000).

### 2.7.10 Ascorbic Acid

Significant positive heterosis was observed by Nagaraja (1995) and Sharon (2002).

### 2.7.11 Acidity

It is generally accepted fact that higher acidity is an undesirable character in tomato. The reduction in the acidity in hybrids was reported by Rai *et al.* (1996). Bhushana (2000) and Patil (2001) observed significant negative heterosis.

### 2.7.12 Total Soluble Solids (T.S.S)

Processing industry requires high T.S.S. in the fruits. Significant positive heterosis was observed by Sonone *et al.* (1987), Patil and Patil (1988), Dundi (1991), Naidu (1993), Tendulkar (1994), Nagaraja (1995) and Patil (2001). Significant negative heterosis for T.S.S. was reported by Ashwathappa (1980), Kanthaswamy and Balakrishnan (1989), Prabhushankar (1990). Bhushana (2000) reported both negative and positive heterosis for this trait.

# *Materials and Methods*

# MATERIALS AND METHODS

The project consisted of the following experiments.

1. Screening of tomato genotypes for resistance to Tomato Leaf Curl Virus disease (ToLCV).
2. Screening of tomato genotypes for resistance to bacterial wilt.
3. Transfer of resistance to ToLCV in bacterial wilt resistant tomato genotypes.
4. Genetics of ToLCV resistance.

## 3.1 Screening of tomato genotypes for Tomato Leaf Curl Virus (ToLCV) resistance

### 3.1.1 Experimental materials

The experimental material comprised of 80 genetically diverse tomato genotypes (Table-1) collected from India and abroad. These 80 tomato genotypes were screened for ToLCV resistance under natural conditions during February-May, 2009 in the Department of Olericulture, College of Horticulture, Kerala Agricultural University, Thrissur. Thirty day old seedlings were transplanted in pots filled with sterilised potting mixture. Formaldehyde was used for the sterilization. The cultural and agronomic practices were followed as per the Packages of practices Recommendations: Crops (KAU, 2007). No plant protection measures were taken up in order to build up the vector population for facilitating the spread of the disease. Reaction genotypes to the disease was assessed by adopting a score chart of 0-4 scale as suggested by Banerjee and Kalloo, 1987.

| | | |
|---|---|---|
| 0 | : | Symptoms absent |
| 1 | : | Very mild curling (Up to 25% leaves) |
| 2 | : | Curling, puckering of 26-50% leaves |
| 3 | : | Curling, puckering of 51-75% leaves |

Table-1 Genotypes screened for resistance to ToLCV

| S.No | Genotypes | Source |
|---|---|---|
| 1 | Anagha | Department of Olericulture, Kerala Agricultural University, Vellanikkara. |
| 2 | Sakthi | " |
| 3 | Mukthi | " |
| 4 | LE-1-2 | " |
| 5 | LE-66 | " |
| 6 | LE-474 | AVRDC, Taiwan |
| 7 | LE-633 | " |
| 8 | LE-635 | " |
| 9 | LE-636 | " |
| 10 | LE-638 | " |
| 11 | LE-640 | " |
| 12 | LE-641 | " |
| 13 | LE-649 | " |
| 14 | LE-650 | " |
| 15 | LE-651 | " |
| 16 | LE-653 | " |
| 17 | LE-654 | " |
| 18 | LE-655 | " |
| 19 | LE-656 | " |
| 20 | LE-658 | " |
| 21 | LE-666 | " |
| 22 | LE-667 | " |
| 23 | LE-668 | " |
| 24 | LE-669 | " |
| 25 | LE-670 | " |
| 26 | GA-1565 | " |
| 27 | Arka Abha | IIHR, Bangalore |
| 28 | Arka Alok | " |
| 29 | Arka Ananya | " |

| S.No | Genotypes | Source |
|---|---|---|
| 30 | IIHR-2195 | IIHR, Bangalore |
| 31 | IIHR-2196 | " |
| 32 | IIHR-2197 | " |
| 33 | IIHR-2198 | " |
| 34 | IIHR-2199 | " |
| 35 | IIHR-2202 | " |
| 36 | IIHR-2747 | " |
| 37 | TLBRH-1 | " |
| 38 | TLBRH-6 | " |
| 39 | TLBRH-9 | " |
| 40 | TLCVR-1 | " |
| 41 | Arka Vikas | " |
| 42 | BT-218 | OUAT, Bhubaneswar |
| 43 | DVRT-1 | IIVR, Varanasi |
| 44 | H-24 | " |
| 45 | H-86 | " |
| 46 | TV-55 | " |
| 47 | Hawaii-7998 | HPKV, Palampur |
| 48 | Palam Pink | " |
| 49 | Palam Pride | " |
| 50 | Pusa Ruby | IARI, New Delhi |
| 51 | Swarna Naveen | HARP, Ranchi |
| 52 | BL-333-3-1 | " |
| 53 | Jhali | Ranchi (Local variety) |
| 54 | Rani | Ranchi (Local variety) |
| 55 | LE-682 | Hyderabad, Andhra Pradesh |
| 56 | LE-683 | " |
| 57 | LE-684 | " |
| 58 | LE-685 | " |
| 59 | LE-686 | " |
| 60 | LE-687 | " |
| 61 | LE-688 | " |

| S.No | Genotypes | Source |
|---|---|---|
| 62 | LE-689 | Hyderabad, Andhra Pradesh |
| 63 | LE-690 | " |
| 64 | LE-691 | " |
| 65 | LE-692 | " |
| 66 | LE-693 | " |
| 67 | LE-694 | " |
| 68 | LE-695 | " |
| 69 | LE-696 | " |
| 70 | LE-697 | " |
| 71 | LE-698 | " |
| 72 | LE-699 | " |
| 73 | LE-700 | " |
| 74 | LE-701 | " |
| 75 | LE-702 | " |
| 76 | LE-703 | " |
| 77 | LE-704 | " |
| 78 | LE-705 | " |
| 79 | LE-711 | " |
| 80 | Cherry Tomato | " |

4 : Severe curling, puckering of >75% leaves

Based on the disease score, Per cent disease severity (PDS) was calculated using the formula.

$$PDS = \frac{\text{Sum of numerical rating}}{\text{Total number of plants observed x Max disease grade}} \times 100$$

Per cent disease incidence (PDI) was calculated using the formula.

$$PDI = \frac{\text{Number of plants infected}}{\text{Total number of plants observed}} \times 100$$

Based on the per cent disease severity (PDS) and per cent disease incidence (PDI) the Coefficient of Infection (CI) was calculated using the formula.

$$\text{Coefficient of Infection} = \frac{\text{Per cent disease severity x Per cent disease incidence}}{100}$$

Based on the coefficient of infection, the genotypes were categorized into six groups (PDVR, 1997).

| | |
|---|---|
| 0 – 4 | : Highly Resistant (HR) |
| 4.1 – 9 | : Resistant (R) |
| 9.1 – 19 | : Moderately Resistant (MR) |
| 19.1 – 39 | : Moderately Susceptible (MS) |
| 39.1 – 69 | : Susceptible (S) |
| 69.1 – 100 | : Highly Susceptible (HS) |

Genotypes resistant to leaf curl virus under natural conditions were subjected to artificial inoculation by cleft graft transmission (Hill, 1984) and whitefly transmission (Pilowsky and Cohen, 1990).

### 3.1.2 Graft Transmission

Artificial inoculation was done by cleft graft transmission in 26 genotypes found highly resistant to ToLCV under natural conditions. Grafting was done in five plants per genotype. The root stocks comprised of 30 day old seedlings of resistant genotypes. Scions were taken from the susceptible variety Pusa Ruby showing severe symptoms of ToLCV. The grafted plants were kept in polyhouse for symptom expression in the newly emerged leaves in the root stock (Plate 1a-1d).

### 3.1.3 Whitefly Transmission

Twenty genotypes found resistant to ToLCV in graft transmission were selected for this study along with susceptible variety Pusa Ruby. Whitefly (*Bemisia tabaci*), the vector of ToLCV was used for artificial inoculation. Whiteflies were collected from field and reared on healthy tomato plants in insect proof cages and these non-viruliferous whiteflies were used for the transmission studies. Whiteflies were subjected to pre-acquisition fasting for half an hour and then for acquisition access for 24 hours on ToLCV infected plants followed by, 24 hours inoculation access on 30 day old seedlings of 20 test plants. After the required inoculation access period, the plants were sprayed with the insecticide (Dimethoate 0.05 %) to kill the whiteflies. Inoculated seedlings were kept under net house conditions for symptom expressions (Plate 2a-2d). Healthy plants without inoculation served as control.

## 3.2 Evaluation of tomato genotypes for reaction to bacterial wilt

The experimental material comprised of 76 tomato genotypes collected from India and abroad (Table-2).

They were screened for bacterial wilt resistance in a bacterial wilt sick plot (Plate-3 and 4) during August-November, 2009 in Department of


PUSA RUBY
SCION

Table-2 Genotypes screened for resistance to bacterial wilt.

| S.No | Genotypes | Source |
|---|---|---|
| 1 | Anagha | Department of Olericulture, Kerala Agricultural University, Vellanikkara. |
| 2 | Sakthi | " |
| 3 | Mukthi | " |
| 4 | LE-1-2 | " |
| 5 | LE-66 | " |
| 6 | LE-626 | " |
| 7 | LE-649 | AVRDC, Taiwan |
| 8 | LE-474 | " |
| 9 | LE-628 | " |
| 10 | LE-634 | " |
| 11 | LE-635 | " |
| 12 | LE-636 | " |
| 13 | LE-638 | " |
| 14 | LE-640 | " |
| 15 | LE-641 | " |
| 16 | LE-650 | " |
| 17 | LE-651 | " |
| 18 | LE-653 | " |
| 19 | LE-654 | " |
| 20 | LE-655 | " |
| 21 | LE-656 | " |
| 22 | LE-658 | " |
| 23 | LE-671 | " |
| 24 | LE-672 | " |
| 25 | LE-673 | " |
| 26 | LE-675 | " |
| 27 | LE-676 | " |

| S.No | Genotypes | Source |
|---|---|---|
| 28 | LE-677 | " |
| 29 | LE-678 | " |
| 30 | LE-679 | " |
| 31 | LE-680 | " |
| 32 | GA-1565 | " |
| 33 | DVRT-1 | IIVR, Varanasi. |
| 34 | H-24 | " |
| 35 | H-86 | " |
| 36 | LE-709 | " |
| 37 | Pusa Ruby | IARI, New Delhi. |
| 38 | BT-218 | OUAT, Bhubaneswar |
| 39 | Swarna Naveen | HARP, Ranchi |
| 40 | Swarna Lalima | " |
| 41 | BL-333-3-1 | " |
| 42 | IIHR-2202 | IIHR, Bangalore |
| 43 | Arka Alok | " |
| 44 | Arka Abha | " |
| 45 | Arka Vikas | " |
| 46 | Arka Sourabh | " |
| 47 | TVLCVR-1 | " |
| 48 | TLBRH-1 | " |
| 49 | TLBRH-6 | " |
| 50 | TLBRH-9 | " |
| 51 | IIHR-2195 | " |
| 52 | IIHR-2196 | " |
| 53 | Palam Pride | HPKV, Palampur |
| 54 | Palam Pink | " |
| 55 | Hawaii-7998 | " |
| 56 | Rani | Ranchi (Local variety) |
| 57 | Jhali | Ranchi (Local variety) |

| S.No | Genotypes | Source |
|---|---|---|
| 58 | LE-710 | Hyderabad, Andhra Pradesh |
| 59 | LE-703 | " |
| 60 | LE-704 | " |
| 61 | LE-705 | " |
| 62 | LE-682 | " |
| 63 | LE-683 | " |
| 64 | LE-684 | " |
| 65 | LE-685 | " |
| 66 | LE-712 | " |
| 67 | LE-686 | " |
| 68 | LE-687 | " |
| 69 | LE-688 | " |
| 70 | LE-692 | " |
| 71 | LE-694 | " |
| 72 | LE-695 | " |
| 73 | LE-696 | " |
| 74 | LE-700 | " |
| 75 | LE-701 | " |
| 76 | Cherry Tomato | " |


KERALA AGRICULTURAL UNIVERSITY
COLLEGE OF HORTICULTURE
DEPARTMENT OF OLERICULTURE
INCORPORATION OF TOMATO LEAF CURL VIRUS (ToLCV)
RESISTANCE IN BACTERIAL WILT RESISTANT TOMATO
YEAR OF START: 2009
TECHNICAL PROGRAMME:
1.SCREENING FOR RESISTANCE TO BACTERIAL WILT
2.SCREENING FOR RESISTANCE TO ToLCV
3.GENETICS OF ToLCV RESISTANCE
4.INCORPORATION OF ToLCV RESISTANCE IN BACTERIAL WILTRESISTANT GENOTYPES
5.EVALUATION OF F2 FOR COMBINED RESISTANCE (BW & ToLCV)
MAJOR ADVISOR:
Dr. SADHAN KUMAR, P.G.
PROFESSOR & PI (AICVIP)
STUDENT:
KOTESWARA RAO YADAV.B
Ph. D. SCHOLAR


2010/11/02

Olericulture, College of Horticulture, Kerala Agricultural University, Thrissur. Seedlings were transplanted in a bacterial wilt sick plot 30 day after sowing. Spot planting (Plate-5a and 5b) with the known suscept Pusa Ruby was done to confirm the presence of virulent pathogen in the field. Bacterial wilt incidence was confirmed by ooze test (Plate-6). Management practices were followed as per Package of practices Recommendations: Crops (KAU, 2007). Bacterial wilt incidence was recorded as and when wilt was observed and per cent wilt incidence was calculated by the following formula.

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

Based on the Percent disease incidence (PDI) the genotypes were categorized in to four groups as suggested by Mew and Ho (1976).

| PDI | Disease reaction |
|---|---|
| 0 – 20 | Resistant |
| 20 – 40 | Moderately Resistant |
| 40 – 60 | Moderately Susceptible |
| 60 – 100 | Susceptible |

## 3.3 Transfer of resistance to ToLCV to a bacterial wilt resistant genetic background

### 3.3.1 Combining ability and Heterosis

#### 3.3.1.1 Experimental materials

Five bacterial wilt resistant genotypes *viz.*, Anagha, Sakthi, Mukthi, LE-1-2, and LE-626 were selected (Plate-7 to 11). Seven Tomato Leaf Curl Virus (ToLCV) resistant genotypes *viz.*, IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640 (Plate-12 to 20) were selected which


ANAGHA


SAKTHI

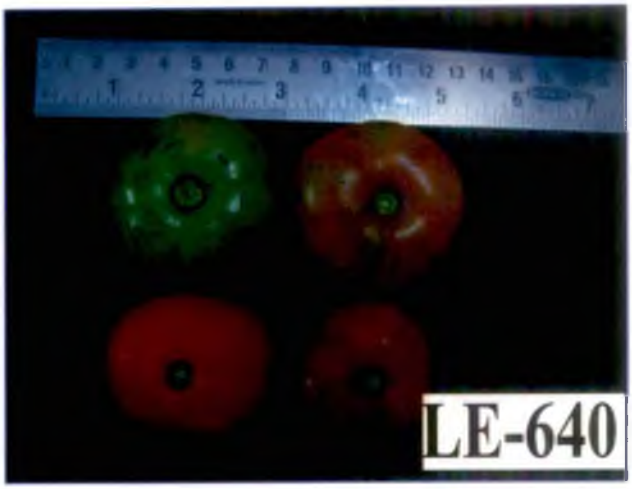

Mukthi
2011/12/02


LE-1-2


LE-626


LE-474


LE-640


LE-640


IIHR-2195


H-24


H-86


Hawaii-7998
2010/12/03

formed testers. The bacterial wilt resistant genotypes were crossed in a line x tester fashion with the seven ToLCV resistant genotypes. The thirty five $F_1$ hybrids along with their parents were grown in a wilt sick field to study their reaction to both bacterial wilt and ToLCV during August-November, 2010.

The following observations were taken.

1. Bacterial wilt incidence (%)
2. ToLCV incidence & severity
3. Plant height (cm)
4. Days to flowering
5. Days to harvest
6. Number of branches per plant
7. Number of fruits per plant
8. Yield per plant (g)
9. Average fruit weight (g)
10. Fruit shape index
11. Number of locules per fruit
12. Fruit cracking (%)
13. Total soluble solids (%)
14. Ascorbic acid (mg/100g)
15. Acidity (%)
16. Total sugars (%)
17. Reducing sugars (%)
18. Shelf life (days)

**1. Bacterial wilt incidence (%)**

Incidence of bacterial wilt was recorded as and when wilt was observed and final count was computed. The genotypes were classified into four groups as suggested by Mew and Ho, 1976.

**2. ToLCV incidence**

Based on the per cent of disease severity (PDS) and per cent of disease incidence (PDI), the Coefficient of Infection (CI) was calculated. Based on coefficient infection, the genotypes were categorized into six groups.

**3. Plant height (cm)**

The plant height was measured from ground level to tip of the plant expressed in centimetres and mean was computed.

**4. Days to first flowering**

The number of days from sowing to the appearance of first flower was recorded.

**5. Days to first harvest**

The days taken from sowing to the first harvest of ripe tomatoes was recorded.

**6. Number of branches per plant**

Number of branches arising from the main stem above the ground was recorded.

**7. Number of fruits per plant**

Fruits harvested periodically from each plant were added to obtain the total number of fruits per plant.

**8. Fruit yield per plant (g)**

The weight of fruits from each picking was recorded from the plants of each experimental plot. Total yield per plant was worked out by adding yield of all harvests and was expressed in grams (g) per plant.

**9. Average fruit weight (g)**

The best five fruits were weighed and the average fruit weight was worked out and expressed in grams (g).

**10. Fruit shape index**

Fruit shape index was derived by dividing polar diameter by equatorial diameter.

**11. Number of locules per fruit**

The fruits were halved transversely and the locule numbers were counted from the five fruits. The average was worked out.

**12. Fruit cracking (%)**

The number of fruits showed cracking out of the total number of fruits harvested from a plant was noted and expresses as per cent.

**13. Total soluble solids percentage**

Total soluble solids was determined by using a hand refractometer and expressed as percentage.

**14. Ascorbic acid (mg/100g)**

The ascorbic acid content in fruit was estimated by 2, 6-dichlorophenol indophenol visual titration method and values were expressed in mg per 100 g of fruits (Sadasivam and Manickam, 1991).

**15. Acidity of fruits (%)**

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

**16. Reducing sugars (%)**

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

**17. Total Sugars (%)**

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

**18. Shelf life (days)**

Fruits at turning stage were selected at random from each genotype. They were kept in open under ambient conditions in paper trays. The shelf life was calculated as the number of days from harvest till the commencement of spoilage.

### 3.3.1.2 Statistical analysis

**(i) Combining ability and gene action**

General combining ability (gca) effects of the parents and the specific combining ability (sca) effects of the hybrids were estimated using line x tester analysis as suggested by Kempthrone (1957).

**(ii) Estimation of heterosis**

The performance of parents and their $F_1$ hybrid was considered for estimation of heterosis. Heterosis over better parent (heterobeltiosis), mid parent (relative heterosis) and standard variety, Mukthi (standard heterosis) were calculated (Briggle, 1963; Hayes *et al.*, 1965).

The formulae used were

$$\text{Heterobeltiosis} = \frac{\text{F1-BP}}{\text{BP}} \times 100$$

$$\text{Relative heterosis} = \frac{F_1\text{-MP}}{\text{MP}} \times 100$$

$$\text{Standard heterosis} = \frac{\text{F1-SV}}{\text{SV}} \times 100$$

Where, $F_1$, BP, MP and SV were the mean performance of $F_1$ hybrid over better parent, mid parent and standard variety respectively. Significance of heterosis was using student 't' test.

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

To test the significance over the mid parent

$$CD = t \text{ value} \times SE$$

$$CD_{(0.05)} = t_{e\,(0.05)} \times \sqrt{\frac{3MSE}{2r}}$$

$t_e$- 't' value at error degree of freedom

To test the significance over better and standard parent

$$CD_{(0.05)} = t_{e\,(0.05)} \times \sqrt{\frac{2MSE}{2r}}$$

### 3.3.2 Evaluation of $F_2$'s for combined resistance to bacterial wilt and tomato leaf curl virus disease

The $F_2$'s of thirty five crosses were grown in bacterial wilt sick field to screen for bacterial wilt and ToLCV resistance during February-May, 2011. Hundred plants were maintained in each $F_2$ population. No plant protection measures were taken in order to build up the vector population for facilitating the spread of the ToLCV disease.

## 3.4 Genetics of ToLCV resistance

IIHR-2195 was identified as resistant parent. This was crossed with the susceptible parent Pusa Ruby to develop $F_1$ population during September-December, 2009. The $F_1$s were raised in the pots filled with sterilised media during Feb-2010. $F_1$s were selfed to develop $F_2$.

$F_1$s were backcrossed to susceptible parent to develop $B_1$. $F_1$s were backcrossed to resistant parent to develop $B_2$.

To study the genetics of Tomato Leaf Curl Virus (ToLCV) disease, parents, $F_1$s, $F_2$s, $B_1$ and $B_2$s were raised in pots filled with sterilized medium. No plant protection measures were undertaken. These were screened for ToLCV using a 0-4 scale score chart as suggested by Banerjee and Kalloo, 1987.

### 3.4.1 Chi-square test

The plants were classified into 2 categories namely, resistant to virus and susceptible to virus. Plants with numerical rating of disease score with value 0 and 1 were classified as resistant and those with score 2, 3 and 4 were classified as susceptible. The gene action of virus resistance was

determined by subjecting the $F_2$ and back cross ratios to chi-square test (Fisher, 1950).

# Results

# RESULTS

The results of the investigation are presented under the following heads.

1. Screening of tomato genotypes for resistance to Tomato Leaf Curl Virus (ToLCV).
2. Screening of tomato genotypes for resistance to bacterial wilt.
3. Transfer of resistance to ToLCV to bacterial wilt resistant tomato.
4. Genetics of ToLCV resistance.

## 4.1 Screening of tomato genotypes for resistance to Tomato Leaf Curl Virus (ToLCV)

### 4.1.1 Screening under natural conditions

Eighty tomato genotypes were screened for ToLCV resistance during February-May, 2009. The genotypes were classified into six groups based on their reaction to tomato leaf curl disease (Table 3). Of these, 26 were highly resistant, two were resistant, one was moderately resistant and nine genotypes were moderately susceptible to ToLCV. The remaining genotypes were categorized to susceptible and highly susceptible groups. The biometric characters of highly resistant, resistant and moderately resistant genotypes are given in Appendix-I.

### 4.1.2 Screening by graft transmission

Twenty six genotypes which were highly resistant under natural conditions (LE-474, LE-635, LE-640, LE-641, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998, Rani, LE-683, LE-688, LE-691 and LE-697) were artificially inoculated by cleft graft transmission. Their reaction to ToLCV is given in Table-4. Only 20 genotypes (LE-474, LE-635, LE-640, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198,

Table-3 Reaction of tomato genotypes to tomato leaf curl virus (ToLCV) under natural conditions

| S.No | Genotypes | PDI (%) | PDS (%) | C.I | Category |
|---|---|---|---|---|---|
| 1 | Anagha | 100.0 | 66.7 | 66.7 | Highly Susceptible |
| 2 | Sakthi | 100.0 | 94.4 | 94.4 | Highly Susceptible |
| 3 | Mukthi | 100.0 | 75.0 | 75.0 | Highly Susceptible |
| 4 | LE-1-2 | 100.0 | 50.0 | 50.0 | Susceptible |
| 5 | LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 6 | LE-633 | 83.3 | 25.0 | 20.8 | Moderately Susceptible |
| 7 | LE-635 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 8 | LE-636 | 100.0 | 22.5 | 22.5 | Moderately Susceptible |
| 9 | LE-638 | 88.9 | 33.3 | 29.6 | Moderately Susceptible |
| 10 | LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 11 | LE-641 | 28.6 | 7.1 | 2.0 | Highly Resistant |
| 12 | LE-649 | 100.0 | 69.4 | 69.4 | Highly Susceptible |
| 13 | LE-650 | 87.5 | 25.0 | 21.9 | Moderately Susceptible |
| 14 | LE-651 | 100.0 | 84.4 | 84.4 | Highly Susceptible |
| 15 | LE-653 | 100.0 | 37.5 | 37.5 | Moderately Susceptible |
| 16 | LE-654 | 100.0 | 35.7 | 35.7 | Moderately Susceptible |
| 17 | LE-655 | 100.0 | 82.1 | 82.1 | Highly Susceptible |
| 18 | LE-656 | 100.0 | 62.5 | 62.5 | Susceptible |
| 19 | LE-658 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 20 | LE-66 | 37.5 | 18.8 | 7.0 | Resistant |
| 21 | LE-666 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 22 | LE-667 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 23 | LE-668 | 100.0 | 63.9 | 63.9 | Susceptible |
| 24 | LE-669 | 100.0 | 72.2 | 72.2 | Highly Susceptible |
| 25 | LE-670 | 100.0 | 75.0 | 75.0 | Highly Susceptible |
| 26 | Arka Abha | 100.0 | 90.6 | 90.6 | Highly Susceptible |
| 27 | Arka Alok | 100.0 | 71.9 | 71.9 | Highly Susceptible |
| 28 | Arka Ananya | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 29 | Arka Vikas | 100.0 | 100.0 | 100.0 | Highly Susceptible |

(Table-3 Continued)

| S.No | Genotypes | PDI (%) | PDS (%) | C.I | Category |
|---|---|---|---|---|---|
| 30 | IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 31 | IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 32 | IIHR-2197 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 33 | IIHR-2198 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 34 | IIHR-2199 | 18.2 | 4.5 | 0.8 | Highly Resistant |
| 35 | IIHR-2202 | 25.0 | 6.3 | 1.6 | Highly Resistant |
| 36 | IIHR-2747 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 37 | TLBRH-1 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 38 | TLBRH-6 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 39 | TLBRH-9 | 30.0 | 17.5 | 5.3 | Resistant |
| 40 | TLCVR-1 | 100.0 | 50.0 | 50.0 | Susceptible |
| 41 | BL-333-3-1 | 100.0 | 78.1 | 78.1 | Highly Susceptible |
| 42 | BT-218 | 100.0 | 81.3 | 81.3 | Highly Susceptible |
| 43 | Cherry Tomato | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 44 | DVRT-1 | 85.7 | 39.3 | 33.7 | Moderately Susceptible |
| 45 | H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 46 | H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 47 | TV-55 | 55.6 | 19.4 | 10.8 | Moderately Resistant |
| 48 | GA-1565 | 100.0 | 82.1 | 82.1 | Highly Susceptible |
| 49 | Hawaii-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 50 | Jhali | 100.0 | 83.3 | 83.3 | Highly Susceptible |
| 51 | Rani | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 52 | Palam Pink | 100.0 | 91.7 | 91.7 | Highly Susceptible |
| 53 | Palam Pride | 100.0 | 87.5 | 87.5 | Highly Susceptible |
| 54 | Pusa Ruby | 100.0 | 92.9 | 92.9 | Highly Susceptible |
| 55 | Swarna Naveen | 100.0 | 65.6 | 65.6 | Susceptible |
| 56 | LE-711 | 100.0 | 58.3 | 58.3 | Susceptible |
| 57 | LE-682 | 100.0 | 83.3 | 83.3 | Highly Susceptible |
| 58 | LE-683 | 12.5 | 3.1 | 0.4 | Highly Resistant |

(Table-3 Continued)

| S.No | Genotypes | PDI (%) | PDS (%) | C.I | Category |
|---|---|---|---|---|---|
| 59 | LE-684 | 100.0 | 53.1 | 53.1 | Susceptible |
| 60 | LE-685 | 100.0 | 55.6 | 55.6 | Susceptible |
| 61 | LE-686 | 100.0 | 53.1 | 53.1 | Susceptible |
| 62 | LE-687 | 100.0 | 70.0 | 70.0 | Highly Susceptible |
| 63 | LE-688 | 11.1 | 2.8 | 0.3 | Highly Resistant |
| 64 | LE-689 | 100.0 | 66.7 | 66.7 | Susceptible |
| 65 | LE-690 | 100.0 | 88.9 | 88.9 | Highly Susceptible |
| 66 | LE-691 | 20.0 | 10.0 | 2.0 | Highly Resistant |
| 67 | LE-692 | 60.0 | 45.0 | 27.0 | Moderately Susceptible |
| 68 | LE-693 | 100.0 | 66.7 | 66.7 | Highly Susceptible |
| 69 | LE-694 | 100.0 | 59.4 | 59.4 | Susceptible |
| 70 | LE-695 | 100.0 | 50.0 | 50.0 | Susceptible |
| 71 | LE-696 | 100.0 | 50.0 | 50.0 | Susceptible |
| 72 | LE-697 | 25.0 | 6.3 | 1.6 | Highly Resistant |
| 73 | LE-698 | 100.0 | 70.0 | 70.0 | Highly Susceptible |
| 74 | LE-699 | 60.0 | 35.0 | 21.0 | Moderately Susceptible |
| 75 | LE-700 | 100.0 | 54.2 | 54.2 | Susceptible |
| 76 | LE-701 | 100.0 | 88.9 | 88.9 | Highly Susceptible |
| 77 | LE-702 | 100.0 | 42.9 | 42.9 | Susceptible |
| 78 | LE-703 | 100.0 | 57.1 | 57.1 | Susceptible |
| 79 | LE-704 | 100.0 | 56.8 | 56.8 | Susceptible |
| 80 | LE-705 | 100.0 | 58.3 | 58.3 | Susceptible |

Table-4 Reaction of tomato genotypes to ToLCV under graft inoculation

| S.No | Genotypes | PDI (%) | PDS (%) | C.I | Category |
|---|---|---|---|---|---|
| 1 | LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 2 | LE-635 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 3 | LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 4 | LE-658 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 5 | H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 6 | H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 7 | Hawaii-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 8 | IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 9 | IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 10 | IIHR-2197 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 11 | IIHR-2198 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 12 | IIHR-2202 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 13 | IIHR-2747 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 14 | Arka Ananya | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 15 | TLBRH-1 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 16 | TLBRH-6 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 17 | LE-666 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 18 | LE-667 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 19 | Rani | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 20 | Cherry Tomato | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 21 | LE-641 | 100.0 | 70.0 | 70.0 | Highly Susceptible |
| 22 | IIHR-2199 | 55.6 | 19.4 | 10.8 | Moderately Resistant |
| 23 | LE-683 | 100.0 | 55.6 | 55.6 | Susceptible |
| 24 | LE-688 | 100.0 | 59.4 | 59.4 | Susceptible |
| 25 | LE-691 | 100.0 | 70.0 | 70.0 | Highly Susceptible |
| 26 | LE-697 | 100.0 | 66.7 | 66.7 | Susceptible |

IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998 and Rani) remained highly resistant in graft transmission and the other six genotypes (LE-641, IIHR-2199, LE-683, LE-688, LE-691 and LE-697) showed symptoms of tomato leaf curl virus. Among these, IIHR-2199 was moderately resistant to ToLCV with a coefficient of infection of 10.8 and LE-683, LE-688 and LE-697were susceptible with CI values of 55.6, 59.4 and 66.7 respectively. LE-641 and LE-691 were highly susceptible as they recorded CI value of 70.0.

### 4.1.3 Screening by whitefly transmission

Twenty genotypes which were highly resistant to ToLCV in graft transmission (LE-474, LE-635, LE-640, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998 and Rani) were artificially screened for resistance to ToLCV by whitefly transmission. Their reaction to ToLCV is given in Table-5. All 20 genotypes (LE-474, LE-635, LE-640, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998 and Rani) remained resistant after the whitefly transmission and Pusa Ruby showed typical symptoms of tomato leaf curl virus disease (Plate-2c).

## 4.2 Screening of tomato genotypes for resistance to bacterial wilt

Seventy six tomato genotypes were screened for bacterial wilt resistance in a wilt sick plot during August-November-2009. Cent per cent disease incidence was noticed in spot planted Pusa Ruby, confirming the presence of adequate virulent bacterial inoculum in the field.

The genotypes were classified into four groups based on their reaction to bacterial wilt (Table-6).

Table 5 Reaction of tomato genotypes to whitefly transmission

| S.No | Genotypes | PDI (%) | PDS (%) | C.I | Category |
|---|---|---|---|---|---|
| 1 | LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 2 | LE-635 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 3 | LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 4 | LE-658 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 5 | H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 6 | H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 7 | Hawaii-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 8 | IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 9 | IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 10 | IIHR-2197 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 11 | IIHR-2198 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 12 | IIHR-2202 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 13 | IIHR-2747 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 14 | Arka Ananya | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 15 | TLBRH-1 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 16 | TLBRH-6 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 17 | LE-666 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 18 | LE-667 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 19 | Rani | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 20 | Cherry Tomato | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 21 | Pusa Ruby | 100.0 | 100.0 | 100.0 | Highly Susceptible |

Table 6 Reaction tomato genotypes to bacterial wilt resistance

| S.No | Genotype | PDI (%) | Disease Reaction |
|---|---|---|---|
| 1 | Anagha | 10.0 | Resistant |
| 2 | Sakthi | 16.7 | Resistant |
| 3 | Mukthi | 19.0 | Resistant |
| 4 | LE-1-2 | 13.3 | Resistant |
| 5 | LE-626 | 16.7 | Resistant |
| 6 | LE-649 | 20.0 | Resistant |
| 7 | LE-66 | 23.3 | Moderately Resistant |
| 8 | LE-474 | 13.3 | Resistant |
| 9 | LE-628 | 13.3 | Resistant |
| 10 | LE-634 | 90.0 | Susceptible |
| 11 | LE-650 | 70.0 | Susceptible |
| 12 | LE-651 | 61.0 | Susceptible |
| 13 | LE-635 | 62.0 | Susceptible |
| 14 | LE-636 | 100.0 | Susceptible |
| 15 | LE-638 | 83.3 | Susceptible |
| 16 | LE-640 | 16.7 | Resistant |
| 17 | LE-641 | 76.7 | Susceptible |
| 18 | LE-653 | 70.0 | Susceptible |
| 19 | LE-654 | 56.7 | Moderately Susceptible |
| 20 | LE-655 | 66.7 | Susceptible |
| 21 | LE-656 | 36.7 | Moderately Resistant |
| 22 | LE-658 | 53.3 | Moderately Susceptible |
| 23 | Pusa Ruby | 100.0 | Susceptible |
| 24 | GA-1565 | 26.7 | Moderately Resistant |
| 25 | DVRT-1 | 86.7 | Susceptible |
| 26 | BT-218 | 63.3 | Susceptible |
| 27 | H-24 | 90.0 | Susceptible |
| 28 | H-86 | 62.0 | Susceptible |

Table 6 Cont.

| S.No | Genotype | PDI (%) | Disease Reaction |
|---|---|---|---|
| 29 | IIHR-2195 | 80.0 | Susceptible |
| 30 | IIHR-2196 | 90.0 | Susceptible |
| 31 | Swarna Naveen | 36.7 | Moderately Resistant |
| 32 | Swarna Lalima | 30.0 | Moderately Resistant |
| 33 | BL-333-3-1 | 53.3 | Moderately Susceptible |
| 34 | Hawaii-7998 | 36.7 | Moderately Resistant |
| 35 | IIHR-2202 | 90.0 | Susceptible |
| 36 | Arka Alok | 66.7 | Susceptible |
| 37 | Arka Abha | 90.0 | Susceptible |
| 38 | Arka Vikas | 76.7 | Susceptible |
| 39 | Arka Sourabh | 86.7 | Susceptible |
| 40 | TLCVR-1 | 90.0 | Susceptible |
| 41 | TLBRH-1 | 96.7 | Susceptible |
| 42 | TLBRH-6 | 36.7 | Moderately Resistant |
| 43 | TLBRH-9 | 50.0 | Moderately Susceptible |
| 44 | LE-671 | 50.0 | Moderately Susceptible |
| 45 | LE-672 | 83.3 | Susceptible |
| 46 | LE-673 | 80.0 | Susceptible |
| 47 | LE-675 | 86.7 | Susceptible |
| 48 | LE-676 | 90.0 | Susceptible |
| 49 | LE-677 | 66.7 | Susceptible |
| 50 | LE-678 | 50.0 | Moderately Susceptible |
| 51 | LE-680 | 56.7 | Moderately Susceptible |
| 52 | LE-679 | 43.3 | Moderately Susceptible |
| 53 | Palam Pride | 50.0 | Moderately Susceptible |
| 54 | Palam Pink | 60.0 | Susceptible |
| 55 | Rani | 63.3 | Susceptible |
| 56 | Jhali | 43.0 | Moderately Susceptible |
| 57 | Cherry Tomato | 100.0 | Susceptible |

Table 6 Continued

| S.No | Genotype | PDI (%) | Disease Reaction |
|---|---|---|---|
| 58 | LE-710 | 60.0 | Susceptible |
| 59 | LE-703 | 76.7 | Susceptible |
| 60 | LE-704 | 66.7 | Susceptible |
| 61 | LE-705 | 50.0 | Moderately Susceptible |
| 62 | LE-682 | 90.0 | Susceptible |
| 63 | LE-683 | 70.0 | Susceptible |
| 64 | LE-684 | 50.0 | Moderately Susceptible |
| 65 | LE-685 | 43.3 | Moderately Susceptible |
| 66 | LE-712 | 60.0 | Susceptible |
| 67 | LE-686 | 56.7 | Moderately Susceptible |
| 68 | LE-687 | 53.3 | Moderately Susceptible |
| 69 | LE-688 | 30.0 | Moderately Resistant |
| 70 | LE-692 | 40.0 | Moderately Resistant |
| 71 | LE-694 | 50.0 | Moderately Susceptible |
| 72 | LE-695 | 50.0 | Moderately Susceptible |
| 73 | LE-696 | 80.0 | Susceptible |
| 74 | LE-700 | 80.0 | Susceptible |
| 75 | LE-701 | 46.7 | Moderately Susceptible |
| 76 | LE-709 | 30.0 | Moderately Resistant |

Anagha, LE-1-2, LE-474, LE-628, Sakthi, LE-626, LE-640, Mukthi and LE-649 were resistant to bacterial wilt recorded PDI of 10.0, 13.3, 13.3, 13.3, 16.7, 16.7, 16.7, 19.0 and 20.0 respectively. There were 10 moderately resistant genotypes, 18 moderately susceptible genotypes and 39 susceptible genotypes. The biometric characters of resistant and moderately resistant genotypes are given in Appendix-II.

### 4.3 Transfer of resistance to ToLCV to bacterial wilt resistant tomato

Five bacterial wilt resistant genotypes (Anagha, Sakthi, Mukthi, LE-1-2 and LE-626) (Plates-7-11) were crossed with seven ToLCV resistant genotypes (IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640) (Plates-12-20) in a line x tester fashion and the progenies along with the parents were screened for ToLCV resistance and bacterial wilt resistance.

#### 4.3.1 Evaluation of $F_1$ hybrids for ToLCV resistance

Thirty five hybrids along with 12 parents were screened for ToLCV resistance during August-November, 2010. The genotypes were classified into six groups based on their reaction to ToLCV (Table-7).

Among the parents, Anagha, Sakthi, LE-1-2 and LE-626 were moderately susceptible with coefficient of infection of 33.7, 27.0, 20.3 and 29.6 respectively. Mukthi was moderately resistant with CI value 10.8. The remaining parents IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640 were highly resistant.

Among the hybrids, thirty hybrids were resistant to ToLCV disease. LE-626 x H-86 showed mild symptoms of ToLCV and this hybrid recorded a coefficient of infection of 2.6. LE-626 x H-24 was resistant with a CI of 5.1. Sakthi x LE-474 was moderately resistant with a CI of 14.8. Sakthi x IIHR-

Table-7 Reaction of $F_1$ hybrids and parents to ToLCV

| S.No | Hybrids/Parents | PDI | PDS | CI | Disease Reaction |
|---|---|---|---|---|---|
| LINES | | | | | |
| 1 | Anagha | 85.7 | 39.3 | 33.7 | Moderately Susceptible |
| 2 | Sakthi | 60.0 | 45.0 | 27.0 | Moderately Susceptible |
| 3 | Mukthi | 55.6 | 19.4 | 10.8 | Moderately Resistant |
| 4 | LE-1-2 | 83.3 | 25.0 | 20.8 | Moderately Susceptible |
| 5 | LE-626 | 88.9 | 33.3 | 29.6 | Moderately Susceptible |
| TESTERS | | | | | |
| 6 | IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 7 | IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 8 | H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 9 | H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 10 | Hawaii-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 11 | LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 12 | LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| HYBRIDS | | | | | |
| 13 | Anagha x IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 14 | Anagha x IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 15 | Anagha x H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 16 | Anagha x H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 17 | Anagha x H-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 18 | Anagha x LE-474 | 71.4 | 40.2 | 28.7 | Highly Resistant |
| 19 | Anagha x LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| | | | | | |
| 20 | Sakthi x IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 21 | Sakthi x IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 22 | Sakthi x H-24 | 96.4 | 42.9 | 41.3 | Suceptible |
| 23 | Sakthi x H-86 | 92.9 | 43.8 | 40.6 | Suceptible |
| 24 | Sakthi x H-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 25 | Sakthi x LE-474 | 53.6 | 27.7 | 14.8 | Moderatley Resistant |
| 26 | Sakthi x LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |

| S.No | Hybrids/Parents | PDI | PDS | CI | Disease Reaction |
|---|---|---|---|---|---|
| 27 | Mukthi x IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 28 | Mukthi x IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 29 | Mukthi x H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 30 | Mukthi x H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 31 | Mukthi x H-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 32 | Mukthi x LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 33 | Mukthi x LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| | | | | | |
| 34 | LE-1-2 x IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 35 | LE-1-2 x IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 36 | LE-1-2 x H-24 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 37 | LE-1-2 x H-86 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 38 | LE-1-2 x H-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 39 | LE-1-2 x LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 40 | LE-1-2 x LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| | | | | | |
| 41 | LE-626 x IIHR-2195 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 42 | LE-626 x IIHR-2196 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 43 | LE-626 x H-24 | 35.7 | 14.3 | 5.1 | Resistant |
| 44 | LE-626 x H-86 | 28.6 | 8.9 | 2.6 | Highly Resistant |
| 45 | LE-626 x H-7998 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 46 | LE-626 x LE-474 | 0.0 | 0.0 | 0.0 | Highly Resistant |
| 47 | LE-626 x LE-640 | 0.0 | 0.0 | 0.0 | Highly Resistant |

2195 was moderately susceptible with a CI of 28.7. Sakthi x H-24 (41.3) and Sakthi x H-86 (40.6) were susceptible to ToLCV.

### 4.3.2 Screening of $F_1$ hybrids for bacterial wilt resistance

The genotypes were classified into four groups based on their reaction to bacterial wilt (Table-8).

Among the parents Anagha, Sakthi, Mukthi, LE-1-2, LE-626, Hawaii-7998, LE-474 and LE-640 were resistant to bacterial wilt with a PDI of 0.0, 0.0, 0.0, 3.6, 0.0, 7.1, 0.0 and 0.0 respectively. IIHR-2195 and IIHR-2196 were moderately resistant with a PDI 28.6 and 25.0 respectively. H-24 and H-86 were categorized to moderately susceptible group as PDI values were 50.0 and 42.9 respectively.

Among the hybrids, Mukthi x Hawaii-7998 (0.0), Mukthi x LE-474 (0.0), Mukthi x LE-640 (0.0), LE-1-2 x IIHR-2195 (0.0), LE-626 x LE-474 (0.0), LE-1-2 x LE-474 (0.0), Sakthi x LE-640 (3.6), LE-1-2 x Hawaii-7998 (3.6), LE-1-2 x IIHR-2196 (7.1), LE-626 x IIHR-2196 (7.1), Anagha x Hawaii-7998 (14.3), LE-626 x LE-640 (14.3), Anagha x LE-474 (17.9), Anagha x LE-640 (17.9), Sakthi x Hawaii-7998 (17.9), Sakthi x LE-474 (17.9) were resistant to bacterial wilt. Mukthi x H-86, LE-1-2 x LE-640, LE-626 x H-24, LE-626 x H-86 and LE-626 x Hawaii-7998 were moderately resistant to bacterial wilt with a PDI of 35.7, 25.0, 35.7, 28.6 and 25.0 respectively. There were 9 moderately susceptible hybrids and 5 susceptible hybrids.

### 4.3.3 Line x Tester analysis for yield attributes

#### 4.3.3.1 Combining ability and gene action

The analysis of variance revealed highly significant differences for all the characters studied among the 47 genotypes (Appendix III). Based on line x tester analysis, general combining ability (gca) effects of parents and

Table-8 Reaction of $F_1$ hybrids and parents to bacterial wilt in transfer of resistance to ToLCV

| S.No | Hybrids/Parents | PDI | Disease Reaction |
|---|---|---|---|
| LINES | | | |
| 1 | Anagha | 0.0 | Resistant |
| 2 | Sakthi | 0.0 | Resistant |
| 3 | Mukthi | 0.0 | Resistant |
| 4 | LE-1-2 | 3.6 | Resistant |
| 5 | LE-626 | 0.0 | Resistant |
| TESTERS | | | |
| 6 | IIHR-2195 | 28.6 | Moderately Resistant |
| 7 | IIHR-2196 | 25.0 | Moderately Resistant |
| 8 | H-24 | 50.0 | Moderately Susceptible |
| 9 | H-86 | 42.9 | Moderately Susceptible |
| 10 | Hawaii-7998 | 7.1 | Resistant |
| 11 | LE-474 | 0.0 | Resistant |
| 12 | LE-640 | 0.0 | Resistant |
| HYBRIDS | | | |
| 13 | Anagha x IIHR-2195 | 60.7 | Susceptible |
| 14 | Anagha x IIHR-2196 | 42.9 | Moderately Susceptible |
| 15 | Anagha x H-24 | 89.3 | Susceptible |
| 16 | Anagha x H-86 | 78.6 | Susceptible |
| 17 | Anagha x H-7998 | 14.3 | Resistant |
| 18 | Anagha x LE-474 | 17.9 | Resistant |
| 19 | Anagha x LE-640 | 17.9 | Resistant |
| | | | |
| 20 | Sakthi x IIHR-2195 | 78.6 | Susceptible |
| 21 | Sakthi x IIHR-2196 | 89.3 | Susceptible |
| 22 | Sakthi x H-24 | 42.9 | Moderately Susceptible |
| 23 | Sakthi x H-86 | 46.4 | Moderately Susceptible |
| 24 | Sakthi x H-7998 | 17.9 | Resistant |
| 25 | Sakthi x LE-474 | 17.9 | Resistant |
| 26 | Sakthi x LE-640 | 3.6 | Resistant |

| S.No | Hybrids/Parents | PDI | Disease Reaction |
|---|---|---|---|
| 27 | Mukthi x IIHR-2195 | 42.9 | Moderately Susceptible |
| 28 | Mukthi x IIHR-2196 | 53.6 | Moderately Susceptible |
| 29 | Mukthi x H-24 | 46.4 | Moderately Susceptible |
| 30 | Mukthi x H-86 | 35.7 | Moderately Resistant |
| 31 | Mukthi x H-7998 | 0.0 | Resistant |
| 32 | Mukthi x LE-474 | 0.0 | Resistant |
| 33 | Mukthi x LE-640 | 0.0 | Resistant |
| | | | |
| 34 | LE-1-2 x IIHR-2195 | 0.0 | Resistant |
| 35 | LE-1-2 x IIHR-2196 | 7.1 | Resistant |
| 36 | LE-1-2 x H-24 | 42.9 | Moderately Susceptible |
| 37 | LE-1-2 x H-86 | 46.4 | Moderately Susceptible |
| 38 | LE-1-2 x H-7998 | 3.6 | Resistant |
| 39 | LE-1-2 x LE-474 | 0.0 | Resistant |
| 40 | LE-1-2 x LE-640 | 25.0 | Moderately Resistant |
| | | | |
| 41 | LE-626 x IIHR-2195 | 42.9 | Moderately Susceptible |
| 42 | LE-626 x IIHR-2196 | 7.1 | Resistant |
| 43 | LE-626 x H-24 | 35.7 | Moderately Resistant |
| 44 | LE-626 x H-86 | 28.6 | Moderately Resistant |
| 45 | LE-626 x H-7998 | 25.0 | Moderately Resistant |
| 46 | LE-626 x LE-474 | 0.0 | Resistant |
| 47 | LE-626 x LE-640 | 14.3 | Resistant |

specific combining ability (sca) effects of hybrid combinations were estimated (Table 9-10). Components of additive and non-additive variances and heritability were also estimated (Appendix IV).

**4.3.3.2 Yield and its components**

**4.3.3.2.1 Plant height**

Significant positive gca effects were observed for Hawaii-7998 (39.92) followed by LE-1-2 (13.94) and Mukthi (7.65). Significant negative gca effects were noted for LE-474 (-13.24) followed by Sakthi (-12.61) and LE-640 (-11.16). Sakthi x LE-640 (19.84) showed the highest positive value for sca effect followed by LE-1-2 x Hawaii-7998 (17.71) and Anagha x H-24 (17.39). Significant highest negative value for sca effect was observed in Anagha x Hawaii-7998 (-26.51) followed by Sakthi x H-24 (-18.84) and Sakthi x H-86 (-17.39). Heritability was 0.99. Preponderance of additive variance was also observed for plant height 691.34.

**4.3.3.2.2 Days to flowering**

Significant high negative gca effects were noted for H-24 (-1.77) followed by IIHR-2196 (-0.90) and Sakthi (-0.69). LE-640 (-0.65) and Mukthi (-0.37) also showed significant negative gca effects. Anagha x LE-640 (-3.24) showed the highest value for sca effect followed by LE-626 x LE-474 (-2.67) and Anagha x Hawaii-7998 (-2.32). Significant highest positive value for sca effect was observed in Anagha x IIHR-2195 (5.10) followed by Sakthi x H-24 (3.97) and LE-1-2 x LE-640 (3.85). Heritability was 0.99. Preponderance of additive variance was also observed for days to flowering -0.49.

**4.3.3.2.3 Days to first harvest**

The parents with significant high negative gca effects were H-24 (-1.75) followed by IIHR-2196 (-0.83) and Sakthi (-0.78). LE-640 (-0.43) and

Mukthi (-0.27) also showed significant negative gca effects. Anagha x LE-640 (-3.28) showed the highest negative value for sca effect followed by LE-626 x IIHR-2196 (-2.49) and LE-1-2 x H-24 (-2.37). Heritability was 0.99. Preponderance of additive variance was also observed for days to flowering -1.06.

#### 4.3.3.2.4 Number of branches per plant

Mukthi, H-86 and LE-640 were good general combiners for number of branches/plant as evidenced by gca effects (8.02, 2.56 and 2.16 respectively). Anagha (-4.83), H-24 (-3.41) and Sakthi (-1.58) were poor general combiners for this character. LE-626 x H-86, LE-1-2 x Hawaii-7998 and LE-1-2 x H-86 showed significant positive sca effects (5.17, 3.69 and 3.55 respectively). The heritability for number of branches/plant was 0.93 and additive variance was 56.05.

#### 4.3.3.2.5 Number of fruits per plant

Mukthi, Hawaii-7998 and LE-640 were good general combiners for number of fruits/plant as evidenced by gca effects (4.43, 3.21 and 3.12 respectively). Anagha (-4.52), IIHR-2196 (-3.57) and LE-474 (-2.98) were poor general combiners for number of fruits/plant. LE-1-2 x Hawaii-7998, Sakthi x LE-640 and Mukthi x H-86 showed significant positive sca effects (15.95, 11.58 and 7.19 respectively). The heritability for number of fruits/plant was 0.87 and additive variance was 18.03.

#### 4.3.3.2.6 Yield per plant

Mukthi and LE-640 were good general combiners for yield/plant as evidenced by gca effects (265.91 and 285.38 respectively). Anagha (-201.7), IIHR-2195 (-137.66) and IIHR-2196 (-134.99) were poor general combiners. Sakthi x LE-640, LE-1-2 x Hawaii-7998, LE-626 x H-24, Mukthi x H-86, Mukthi x LE-474 and LE-1-2 x LE-640 showed significant

positive sca effects (583.10, 497.76, 465.27, 387.82, 215.25 and 105.67 respectively). The heritability for yield/plant was 0.94 and additive variance was 60105.69.

#### 4.3.3.2.7 Average fruit weight

Sakthi, LE-474 and LE-640 showed significant gca effects for average fruit weight (7.05, 2.93 and 2.80 respectively). Hybrids Anagha x IIHR-2195 (25.70), LE-1-2 x LE-474 (11.12), Anagha x LE-474 (9.71) and Mukthi x IIHR-2196 (8.18) expressed highly significant positive sca effects for average fruit weight. The heritability in narrow sense was 0.99. Preponderance of additive variance was observed for this trait 0.25.

#### 4.3.3.2.8 Number of locules per fruit

Hawaii-7998 (0.52), LE-474 (0.39) and H-24 (0.23) showed significant gca effects for number of locules per fruit. LE-626 x H-86 (0.86), Sakthi x IIHR-2195 (0.83) and LE-1-2 x H-86 (0.56) showed significant positive sca effects. Heritability was 0.98 and preponderance of additive variance was observed (0.08).

#### 4.3.3.2.9 Ascorbic acid (mg/100g)

Out of the 12 parents, only LE-626 (2.36), IIHR-2196 (0.98) and Anagha (0.78) showed highly significant positive gca effects when compared to other parents. LE-1-2 x LE-474 (3.45), Sakthi x H-86 (3.34) and Anagha x LE-640 (3.03) hybrids showed significant positive sca effects. Heritability was 0.99 and preponderance additive genetic variance was observed (3.76).

#### 4.3.3.2.10 Acidity

Out of the 12 parents, only Anagha (0.06), Sakthi (0.05) and Mukthi (0.04) showed highly significant positive gca effects compared to other parents. LE-1-2 x IIHR-2195 (0.07), Sakthi x LE-640 (0.06), Anagha x LE-474 (0.05), Sakthi x LE-474 (0.05) and Mukthi x H-24 (0.05) hybrid combinations exhibited considerable positive values for specific combining ability. Heritability was 0.94 and preponderance additive genetic variance was observed (0.01).

#### 4.3.3.2.11 Total sugars

H-86, LE-626 and IIHR-2195 were good general combiners for total sugars as evidenced by gca effects (0.24, 0.21 and 0.13 respectively). LE-1-2 x H-24, Anagha x H-86, Mukthi x LE-640 and Mukthi x IIHR-2196 showed significant positive sca effects (0.83, 0.82, 0.40 and 0.39 respectively). The heritability for total sugars was 0.94 and additive variance was 0.02.

#### 4.3.3.2.12 Reducing sugars

LE-626 (0.21) exhibited high positive gca effect. Mukthi (-0.09) showed negative gca effect for reducing sugars. The hybrids with high sca effects for reducing sugars were Sakthi x LE-474 (0.33), LE-1-2 x IIHR-2195 (0.29) and LE-626 x IIHR-2196 (0.25). The heritability for reducing sugars was 0.72 and additive variance was 0.02.

#### 4.3.3.2.13 Total soluble solids (TSS)

Mukthi (0.62) and Anagha (0.31) exhibited significant positive general combining ability. LE-626 (-0.64) and LE-1-2 (-0.42) showed significant negative gca effects. Significant high positive specific combining ability effects were exhibited by LE-626 x LE-640 (0.75), Mukthi x IIHR-2196 (0.62) and LE-1-2 x H-86 (0.61). The heritability for total soluble solids was 0.60 and additive variance was 0.56.

Table-9 Estimates of general combining ability effects of lines and testers for yield and its components in tomato

| | Plant height | Days to flower | Days to harvest | Number of branches | Number of Fruits/Plant | Yield/plant | Average fruit weight |
|---|---|---|---|---|---|---|---|
| **LINES** | | | | | | | |
| Anagha | -6.69** | 0.04 | -0.09 | -4.83** | -4.64** | -212.87** | -6.75** |
| Sakthi | -12.61** | -0.69** | -0.78** | -1.58** | -0.05 | -6.48 | 7.05** |
| Mukthi | 7.65** | -0.37** | -0.27** | 8.02** | 4.32** | 265.91** | 1.74** |
| LE-1-2 | 13.94** | 0.67** | 0.85** | -1.04* | 1.95** | 17.35 | 1.02** |
| LE-626 | -2.29** | 0.36** | 0.29** | -0.56 | -1.59** | -76.88** | -3.06** |
| SE (gi) | 0.41 | 0.04 | 0.05 | 0.45 | 0.45 | 11.92 | 0.11 |
| SE (gi-gj) | 0.58 | 0.06 | 0.07 | 0.64 | 0.64 | 16.86 | 0.16 |
| **TESTERS** | | | | | | | |
| IIHR-2195 | -5.22** | 1.67** | 1.43** | -2.47** | -0.21 | -138.72** | -2.88** |
| IIHR-2196 | -3.09** | -0.90** | -0.83** | -1.40* | -3.69** | -146.15** | 2.23** |
| H-24 | -4.23** | -1.77** | -1.75** | -3.41** | 0.77 | 4.99 | -1.39** |
| H-86 | -2.98** | 0.39** | 0.18** | 2.56** | 0.10 | 6.00 | -4.46** |
| Hawaii-7998 | 39.92** | 1.35** | 1.21** | 1.25* | 3.12** | 16.79 | 0.76** |
| LE-474 | -13.24** | -0.10* | 0.20** | 1.31* | -3.09** | -18.32 | 2.93** |
| LE-640 | -11.16** | -0.65** | -0.43** | 2.16** | 3.21** | 285.38** | 2.80** |
| SE (gi) | 0.50 | 0.04 | 0.06 | 0.55 | 0.55 | 14.60 | 0.14 |
| SE (gi-gj) | 0.71 | 0.06 | 0.08 | 0.78 | 0.78 | 20.65 | 0.20 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-9 (Continued)

| | Number of locules per fruit | Ascorbic acid | Acidity | Total sugars | Reducing sugars | Total soluble solids |
|---|---|---|---|---|---|---|
| **LINES** | | | | | | |
| Anagha | -0.02 | 0.78** | 0.06 | -0.21** | -0.05 | 0.31** |
| Sakthi | -0.18** | -0.51** | 0.05 | 0.04 | -0.01 | 0.14 |
| Mukthi | 0.09** | -1.83** | 0.04 | -0.13** | -0.09* | 0.62** |
| LE-1-2 | -0.07** | -0.80** | -0.06 | 0.10** | -0.06 | -0.42** |
| LE-626 | 0.19** | 2.36** | -0.09 | 0.20** | 0.21** | -0.64** |
| SE (gi) | 0.02 | 0.15 | 0.00 | 0.02 | 0.04 | 0.07 |
| SE (gi-gj) | 0.03 | 0.21 | 0.00 | 0.03 | 0.06 | 0.10 |
| **TESTERS** | | | | | | |
| IIHR-2195 | -0.30** | -0.66** | 0.00 | 0.13** | 0.01 | 0.18 |
| IIHR-2196 | -0.39** | 0.98** | 0.03 | -0.37** | -0.02 | 0.02 |
| H-24 | 0.23** | 0.10 | 0.03 | 0.07* | 0.05 | 0.18 |
| H-86 | -0.26** | 0.05 | -0.01 | 0.24** | -0.03 | 0.02 |
| Hawaii-7998 | 0.52** | -1.11** | -0.03 | 0.05 | -0.08 | 0.04 |
| LE-474 | 0.39** | 0.02 | -0.03 | 0.04 | 0.06 | -0.18 |
| LE-640 | -0.19** | 0.61** | 0.00 | -0.15** | 0.01 | -0.25** |
| SE (gi) | 0.02 | 0.18 | 0.00 | 0.03 | 0.04 | 0.09 |
| SE (gi-gj) | 0.03 | 0.25 | 0.00 | 0.04 | 0.06 | 0.13 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-9 (Continued)

| | Shelf Life (days) | Fruit Shape Index | Fruit cracking |
|---|---|---|---|
| **LINES** | | | |
| Anagha | -3.42** | -0.04** | -0.65** |
| Sakthi | -2.77** | -0.07** | -0.36 |
| Mukthi | 3.49** | -0.02 | 0.79** |
| LE-1-2 | 1.37** | 0.06** | -0.32 |
| LE-626 | 1.33** | 0.07** | 0.53* |
| SE (gi) | 0.32 | 0.01 | 0.20 |
| SE (gi-gj) | 0.45 | 0.01 | 0.28 |
| **TESTERS** | | | |
| IIHR-2195 | -0.78 | -0.06** | -0.65** |
| IIHR-2196 | 0.25 | -0.01 | -0.65** |
| H-24 | -0.55 | 0.05** | -0.47* |
| H-86 | 0.14 | 0.02 | -0.10 |
| Hawaii-7998 | -0.63 | -0.04** | -0.48* |
| LE-474 | 0.96* | 0.06** | 0.16 |
| LE-640 | 0.61 | -0.02 | 2.18** |
| SE (gi) | 0.39 | 0.01 | 0.20 |
| SE (gi-gj) | 0.55 | 0.01 | 0.28 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-9A Components of additive and non-additive variance and heritability for yield and its components in tomato

| Variations | Mean Squares | | | | | |
|---|---|---|---|---|---|---|
| | Plant height | Days to flower | Days to harvest | Number of branches | Number of fruits per plant | Yield per plant |
| $C_{ov}$ HS | 172.83 | -0.122 | -0.265 | 14.01 | 4.5 | 15026.42 |
| $\sigma^2A$ | 691.34 | -0.49 | -1.06 | 56.05 | 18.03 | 60105.69 |
| $C_{ov}$ FS | 526.32 | 5.32 | 5.44 | 35.91 | 36.81 | 84505.83 |
| $\sigma^2D$ | 180.66 | 22.28 | 23.92 | 31.55 | 111.19 | 217811.94 |
| Heritability | 0.99 | 0.99 | 0.99 | 0.93 | 0.87 | 0.94 |

| Variations | Mean Squares | | | | | |
|---|---|---|---|---|---|---|
| | Average fruit weight | Locules per fruit | Ascorbic acid | Acidity | Total sugars | Reducing sugars |
| $C_{ov}$ HS | 0.063 | 0.02 | 0.939 | 0.002 | 0.043 | 0.005 |
| $\sigma^2A$ | 0.25 | 0.08 | 3.76 | 0.01 | 0.02 | 0.02 |
| $C_{ov}$ FS | 116.35 | 0.327 | 6.34 | 0.007 | 0.178 | 0.02 |
| $\sigma^2D$ | 464.92 | 1.14 | 17.88 | 0.01 | 0.68 | 0.01 |
| Heritability | 0.99 | 0.98 | 0.99 | 0.94 | 0.94 | 0.72 |

Table-9A (Continued)

| Variations | Mean Squares | | | |
|---|---|---|---|---|
| | Total soluble solids | Shelf life | Fruit shape index | Fruit cracking |
| $C_{ov}$ HS | 0.139 | 4.02 | 0.001 | 0.304 |
| $\sigma^2A$ | 0.56 | 16.10 | 0.01 | 1.22 |
| $C_{ov}$ FS | 0.391 | 14.68 | 0.01 | 2.20 |
| $\sigma^2D$ | 0.45 | 26.53 | 0.03 | 6.39 |
| Heritability | 0.60 | 0.88 | 0.80 | 0.97 |

Table-10 Estimates of specific combining ability effects of hybrids for yield and its components in tomato hybrids

| | Plant height | Days to flower | Days to harvest | Number of branches | Number of Fruits/Plant | Yield/plant | Average fruit weight |
|---|---|---|---|---|---|---|---|
| **HYBRIDS** | | | | | | | |
| Anagha x IIHR-2195 | 7.63** | 5.10** | 5.23** | 1.35 | -2.06 | 74.99* | 25.70** |
| Anagha x IIHR-2196 | 14.60** | 0.93** | 1.27** | 0.39 | 2.92* | 57.42 | -9.58** |
| Anagha x H-24 | 17.39** | 0.23* | 0.37** | -1.20 | 1.81 | -51.52* | 2.71** |
| Anagha x H-86 | 16.79** | -1.19** | -0.95** | -1.95 | -3.30** | 7.49 | -8.18** |
| Anagha x H-7998 | -26.51** | -2.32** | -2.30** | 0.70 | -0.13 | 118.37** | -5.91** |
| Anagha x LE-474 | -13.55** | 0.49** | -0.35** | -0.43 | 1.04 | 84.59* | 9.71** |
| Anagha x LE-640 | -16.38** | -3.24** | -3.28** | 1.14 | -0.28 | -291.34** | -14.45** |
| | | | | | | | |
| Sakthi x IIHR-2195 | -4.30** | -2.10** | -2.26** | 1.53 | 2.83** | 136.19** | -20.10** |
| Sakthi x IIHR-2196 | -1.28 | -0.79** | -0.85** | 0.69 | 0.03 | 89.74** | 5.96** |
| Sakthi x H-24 | -18.84** | 3.97** | 3.87** | 0.72 | -2.59 | -187.54** | -2.06** |
| Sakthi x H-86 | -17.39** | -0.64** | -0.59** | -5.00** | -4.83** | -195.75** | 7.67** |
| Sakthi x H-7998 | -0.84 | -1.05** | -0.70** | 0.01 | -6.94** | -254.32** | 3.54** |
| Sakthi x LE-474 | 14.22** | 0.75** | 0.53** | 3.14** | -0.07 | -171.43** | -1.09** |
| Sakthi x LE-640 | 19.84** | -0.14 | 0.00 | -1.10 | 11.58** | 583.10** | 6.08** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Plant height | Days to flower | Days to harvest | Number of branches | Number of Fruits/Plant | Yield/plant | Average fruit weight |
|---|---|---|---|---|---|---|---|
| Mukthi x IIHR-2195 | -6.76** | -1.40** | -1.86** | 1.65 | 3.97** | -41.57 | -3.26** |
| Mukthi x IIHR-2196 | -7.89** | 1.32** | 1.80** | 1.22 | -0.34 | -31.91 | 8.18** |
| Mukthi x H-24 | 2.05* | 0.00 | 0.14 | 0.46 | 1.37 | -121.97** | 5.75** |
| Mukthi x H-86 | 10.30** | -0.41** | -0.42** | -1.78 | 7.19** | 387.82** | 4.38** |
| Mukthi x H-7998 | 13.00** | -0.28** | -0.45** | 1.73 | -3.53** | -274.18** | 8.36** |
| Mukthi x LE-474 | -10.34** | 0.87** | 1.26** | -2.46* | -1.32 | 215.25** | -7.77** |
| Mukthi x LE-640 | -0.37 | -0.10 | -0.47** | 0.82 | -7.34** | -133.45** | 1.09** |
| | | | | | | | |
| LE-1-2 x IIHR-2195 | -5.15** | -2.18** | -1.96** | -5.87** | -1.00 | -171.90** | -9.05** |
| LE-1-2 x IIHR-2196 | -4.13** | 0.38** | 0.27* | -5.32** | -3.18** | -232.80** | -12.30** |
| LE-1-2 x H-24 | 2.51* | -2.12** | -2.37** | -0.16 | -6.59** | -104.24** | 1.14** |
| LE-1-2 x H-86 | -6.99** | -1.08** | -1.34** | 3.55** | -2.93** | -91.07* | 2.58** |
| LE-1-2 x H-7998 | 17.71** | 0.58** | 0.31* | 3.69** | 15.95** | 497.76** | 2.32** |
| LE-1-2 x LE-474 | 5.02** | 0.56** | 0.86** | 1.19 | 0.49 | -3.41 | 11.12** |
| LE-1-2 x LE-640 | -8.96** | 3.85** | 4.22** | 2.92* | -2.75 | 105.67** | 4.19** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Plant height | Days to flower | Days to harvest | Number of branches | Number of Fruits/Plant | Yield/plant | Average fruit weight |
|---|---|---|---|---|---|---|---|
| LE-626 x IIHR-2195 | -0.02 | 0.59** | 0.85** | 1.34 | -3.74** | 2.28 | 6.71** |
| LE-626 x IIHR-2196 | -1.30 | 1.84** | -2.49** | 3.01** | 0.57 | 117.55** | 7.74** |
| LE-626 x H-24 | -3.11** | 2.09** | -2.01** | 0.19 | 6.00** | 465.27** | -7.54** |
| LE-626 x H-86 | -2.71* | 3.32** | 3.29** | 5.17** | 3.87** | -108.49** | -6.44** |
| LE-626 x H-7998 | -3.36** | 3.07** | 3.13** | -6.12** | -5.35** | -87.62** | 8.41** |
| LE-626 x LE-474 | 4.65** | -2.67** | -2.30** | -1.44 | -0.14 | -125.01** | -11.97** |
| LE-626 x LE-640 | 5.87** | -0.38** | -0.47** | -2.14 | -1.21 | -263.99** | 3.10** |
| SE (Sij) | 1.00 | 0.09 | 0.12 | 1.10 | 1.11 | 29.21 | 0.27 |
| SE (Sij-Slk) | 1.41 | 0.13 | 0.17 | 1.56 | 1.57 | 41.31 | 0.38 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Number of locules per fruit | Ascorbic Acid | Acidity | Total Sugars | Reducing Sugars | TSS |
|---|---|---|---|---|---|---|
| | | | | | | |
| Anagha x IIHR-2195 | 0.33** | 1.66** | -0.02 | -0.30** | -0.10 | 0.02 |
| Anagha x IIHR-2196 | -0.13* | 0.38 | -0.02 | -0.07 | -0.08 | -0.22 |
| Anagha x H-24 | -0.20** | -0.59 | -0.03** | -0.79** | -0.10 | -0.23 |
| Anagha x H-86 | -0.39** | -0.13 | 0.03** | 0.82** | -0.05 | -0.27 |
| Anagha x H-7998 | 0.29** | -2.28** | 0.03** | 0.11* | 0.14 | 0.51** |
| Anagha x LE-474 | 0.09 | 2.08** | 0.05** | 0.24** | -0.04 | 0.18 |
| Anagha x LE-640 | 0.00 | 3.03** | -0.02 | 0.01 | 0.23* | 0.00 |
| | | | | | | |
| Sakthi x IIHR-2195 | 0.83** | -0.47 | -0.02 | 0.09 | -0.13 | 0.29 |
| Sakthi x IIHR-2196 | 0.37** | -0.85* | -0.01 | -0.31** | -0.13 | 0.25 |
| Sakthi x H-24 | 0.28** | 1.95** | -0.04** | 0.34** | 0.08 | -0.46* |
| Sakthi x H-86 | -0.67** | 3.34** | -0.04** | 0.13* | -0.04 | 0.00 |
| Sakthi x H-7998 | 0.33** | 0.10 | 0.00 | 0.38** | -0.04 | 0.33 |
| Sakthi x LE-474 | -0.75** | -3.22** | 0.05** | -0.44** | 0.33** | -0.45* |
| Sakthi x LE-640 | -0.40** | -0.09 | 0.06** | -0.19** | -0.07 | 0.02 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Number of locules per fruit | Ascorbic Acid | Acidity | Total Sugars | Reducing Sugars | TSS |
|---|---|---|---|---|---|---|
| Mukthi x IIHR-2195 | -0.33** | 0.08 | -0.02 | 0.18** | -0.08 | -0.14 |
| Mukthi x IIHR-2196 | -0.46** | 1.48** | 0.08** | 0.39** | 0.05 | 0.62** |
| Mukthi x H-24 | 0.01 | -1.77** | 0.05** | -0.37** | -0.02 | 0.36 |
| Mukthi x H-86 | -0.37** | -2.81** | 0.05** | -0.36** | 0.12 | -0.28 |
| Mukthi x H-7998 | 0.29** | 2.57** | -0.03** | -0.48** | -0.02 | -0.30 |
| Mukthi x LE-474 | 0.42** | 0.85* | -0.09** | 0.25** | -0.07 | -0.08 |
| Mukthi x LE-640 | 0.45** | 0.40 | -0.05** | 0.40** | 0.02 | -0.21 |
| | | | | | | |
| LE-1-2 x IIHR-2195 | -0.84** | -1.21** | 0.07** | 0.19** | 0.29** | -0.40* |
| LE-1-2 x IIHR-2196 | 0.35** | -1.25** | -0.04** | -0.33** | -0.09 | 0.06 |
| LE-1-2 x H-24 | 0.29** | -0.21 | 0.01 | 0.83** | 0.07 | 0.35 |
| LE-1-2 x H-86 | 0.56** | -1.47** | -0.06** | -0.38** | -0.10 | 0.61** |
| LE-1-2 x H-7998 | -0.78** | -1.22** | 0.04** | -0.02 | 0.02 | -0.21 |
| LE-1-2 x LE-474 | -0.09 | 3.45** | -0.02 | -0.02 | -0.22* | 0.16 |
| LE-1-2 x LE-640 | 0.49** | 1.91** | 0.00 | -0.28** | 0.04 | -0.57** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Number of locules per fruit | Ascorbic Acid | Acidity | Total sugars | Reducing sugars | TSS |
|---|---|---|---|---|---|---|
| LE-626 x IIHR-2195 | 0.00 | -0.07 | -0.01 | -0.16** | 0.01 | 0.22 |
| LE-626 x IIHR-2196 | -0.13** | 0.25 | -0.01 | 0.32** | 0.25** | -0.72** |
| LE-626 x H-24 | 0.39** | 1.37** | 0.01 | -0.01 | -0.03 | -0.03 |
| LE-626 x H-86 | 0.86** | 1.07** | 0.01 | -0.21** | 0.07 | -0.07 |
| LE-626 x H-7998 | -0.14** | 0.83* | -0.03** | 0.02 | -0.10 | -0.34 |
| LE-626 x LE-474 | 0.33** | 1.00** | 0.01 | -0.03 | 0.01 | 0.18 |
| LE-626 x LE-640 | -0.55** | -4.44** | 0.02 | 0.06 | -0.21* | 0.75** |
| SE (Sij) | 0.05 | 0.36 | 0.01 | 0.05 | 0.09 | 0.18 |
| SE (Sij-Slk) | 0.07 | 0.51 | 0.01 | 0.07 | 0.13 | 0.25 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Shelf life | Fruit shape Index | Fruit cracking |
|---|---|---|---|
| | | | |
| Anagha x IIHR-2195 | -0.79 | -0.04 | 0.65 |
| Anagha x IIHR-2196 | -0.70 | 0.00 | 0.65 |
| Anagha x H-24 | -0.01 | 0.18** | 0.47 |
| Anagha x H-86 | 1.41 | -0.02 | 0.10 |
| Anagha x H-7998 | 1.51 | -0.08** | 0.48 |
| Anagha x LE-474 | -0.85 | 0.03 | -0.16 |
| Anagha x LE-640 | -0.56 | -0.06** | -2.18** |
| | | | |
| Sakthi x IIHR-2195 | 4.40** | 0.08** | 0.36 |
| Sakthi x IIHR-2196 | 4.38** | -0.04 | 0.36 |
| Sakthi x H-24 | -2.03* | -0.12** | 0.18 |
| Sakthi x H-86 | -2.82** | 0.16** | -0.19 |
| Sakthi x H-7998 | -3.03** | -0.04 | 0.19 |
| Sakthi x LE-474 | -2.92** | -0.07** | -0.45 |
| Sakthi x LE-640 | 2.03* | 0.02 | -0.44 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Shelf Life | Fruit Shape Index | Fruit Cracking |
|---|---|---|---|
| Mukthi x IIHR-2195 | -2.93** | -0.05* | -0.79 |
| Mukthi x IIHR-2196 | -1.94* | 0.00 | -0.79 |
| Mukthi x H-24 | 2.58** | -0.06** | -0.96 |
| Mukthi x H-86 | 4.28** | 0.02 | 1.40** |
| Mukthi x H-7998 | -3.55** | 0.03 | -0.12 |
| Mukthi x LE-474 | -0.06 | 0.07** | 2.45** |
| Mukthi x LE-640 | 1.62* | 0.04 | -1.19* |
| | | | |
| LE-1-2 x IIHR-2195 | 0.14 | -0.02 | 0.32 |
| LE-1-2 x IIHR-2196 | -2.65** | -0.06** | 0.32 |
| LE-1-2 x H-24 | -0.05 | 0.01 | 1.02* |
| LE-1-2 x H-86 | -1.17 | 0.05* | -0.23 |
| LE-1-2 x H-7998 | 4.87** | -0.05* | 0.15 |
| LE-1-2 x LE-474 | 2.25** | 0.00 | -0.49 |
| LE-1-2 x LE-640 | -3.40** | 0.07** | -1.09* |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-10 (Continued)

| | Shelf Life | Fruit Shape Index | Fruit Cracking |
|---|---|---|---|
| LE-626 x IIHR-2195 | -0.82 | 0.03 | -0.53 |
| LE-626 x IIHR-2196 | 0.91 | 0.10** | -0.53 |
| LE-626 x H-24 | -0.49 | 0.00 | -0.71 |
| LE-626 x H-86 | -1.70* | -0.16** | -1.08* |
| LE-626 x H-7998 | 0.20 | 0.14** | -0.70 |
| LE-626 x LE-474 | 1.59* | -0.03 | -1.34** |
| LE-626 x LE-640 | 0.32 | -0.07** | 4.91** |
| SE (Sij) | 0.78 | 0.02 | 0.49 |
| SE (Sij-Slk) | 1.10 | 0.03 | 0.69 |

** Significant at 1 per cent level

* Significant at 5 per cent level

#### 4.3.3.2.14 Shelf life

Mukthi (3.49), LE-1-2 (1.37) and LE-626 (1.33) recorded significant high positive gca effects for shelf life. Hybrids LE-1-2 x Hawaii-7998 (4.87), Sakthi x IIHR-2195 (4.40), Sakthi x IIHR-2196 (4.38) and Mukthi x H-86 (4.28) showed significant positive specific combining ability effects for increased shelf life. Heritability was 0.88 and preponderance of additive variance was observed (16.10).

#### 4.3.3.2.15 Fruit shape index

Significant positive gca effects were noticed for fruit shape index in LE-626 (0.07), LE-1-2 (0.06), LE-474 (0.06) and H-24 (0.05). The crosses with high positive specific combining ability effects for fruit shape index were Anagha x H-24 (0.18), Sakthi x H-86 (0.16) and LE-626 x Hawaii-7998 (0.14). The heritability was 0.80 and additive variance was 0.01.

#### 4.3.3.2.16 Fruit cracking

Significant negative gca effects were observed for fruit cracking in Anagha (-0.65), IIHR-2195 (-0.65) and IIHR-2196 (-0.65). Hybrid combination Anagha x LE-640 showed the highest negative value for sca effect (-2.18) followed by Mukthi x LE-640 (-1.19) and LE-1-2 x LE-640 (-1.09). Heritability was 0.97. Preponderance of additive variance was also observed for fruit cracking 1.22.

### 4.3.4 Heterosis in tomato

Analysis of variance showed significant differences among the genotypes for all characters studied (Appendix-III). The mean performance of parents and hybrids and heterosis over better patent (Heterobeltiosis) mid parent (Relative heterosis) and standard parent (Standard heterosis) are presented in Table 11-26

### 4.3.4.1 Plant height

Estimates of heterobeltiosis, relative heterosis and standard heterosis ranged from -36.24 to 24.81 per cent, -33.23 to 35.69 per cent and -23.35 to 105.10 per cent respectively. Maximum heterobeltiosis was found in Mukthi x H-24 (24.81 per cent) followed by Mukthi x LE-640 (14.73 per cent) and LE-1-2 x Hawaii-7998 (12.15 per cent). Maximum relative heterosis was observed in the cross Mukthi x Hawaii-7998 (35.69 per cent) followed by 25.37 per cent in Mukthi x H-24 and 23.02 per cent in Mukthi x H-86. Maximum standard heterosis was found in LE-1-2 x Hawaii-7998 (105.92 per cent) followed by Mukthi x Hawaii-7998 (91.92 per cent) and LE-626 x Hawaii-7998 (60.42 per cent). Maximum negative heterobeltiosis and negative relative heterosis were found in the cross Anagha x LE-640 (-36.24 per cent and -29.60 per cent respectively) and in Sakthi x H-24 (-23.35 per cent) maximum negative standard heterosis was found. Sakthi x H-24 (64.00 cm) was the dwarf hybrid and LE-1-2 x Hawaii-7998 (171.26 cm) was the tallest hybrid among the 35 hybrids.

### 4.3.4.2 Days to flowering

Significant and negative standard heterosis was observed in nine hybrids (Table-12) Estimates of heterobeltiosis, relative heterosis and standard heterosis ranged from -13.33 to 4.94 per cent, -0.43 to 4.30 per cent and -0.61 to 14.69 per cent respectively. For heterobeltiosis, relative heterosis and standard heterosis maximum negative value was recorded in Anagha x LE-640 (-13.13, -13.66 and -5.07 per cent respectively) followed by LE-626 x H-24 (-12.91, -13.63 and -4.40 per cent respectively). Anagha x IIHR-2195 expressed maximum positive heterobeltiosis, relative heterosis and standard heterosis 4.94, 4.30 and 14.69 per cent respectively. Among the $F_1$ hybrids Anagah x LE-640 was the earliest to flower (51.26 days) while Anagha x IIHR-2195 was late taking 61.93 days to flower.

Table-11 Mean performance of parental lines and heterosis of $F_1$ hybrids for plant height in tomato

| Parents/Hybrids | Plant height | | | |
|---|---|---|---|---|
| Parents | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 102.65 | | | |
| Sakthi | 96.90 | | | |
| Mukthi | 83.50 | | | |
| LE-1-2 | 141.20 | | | |
| LE-626 | 124.85 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 103.45 | | | |
| IIHR-2196 | 125.40 | | | |
| H-24 | 84.25 | | | |
| H-86 | 102.90 | | | |
| Hawaii-7998 | 152.70 | | | |
| LE-474 | 72.20 | | | |
| LE-640 | 83.30 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 95.40 | -7.78** | -7.42** | 14.25** |
| Anagha x IIHR-2196 | 104.50 | -16.67** | -8.35** | 25.15** |
| Anagha x H-24 | 106.15 | 3.41 | 13.59** | 27.13** |
| Anagha x H-86 | 106.80 | 3.79 | 3.92* | 27.90** |
| Anagha x H-7998 | 106.40 | -30.32** | -16.66** | 27.43** |
| Anagha x LE-474 | 66.20 | -35.51** | -24.22** | -20.72** |
| Anagha x LE-640 | 65.45 | -36.24** | -29.60** | -21.62** |
| | | | | |
| Sakthi x IIHR-2195 | 86.15 | -16.72** | -14.00** | 3.17 |
| Sakthi x IIHR-2196 | 82.70 | -34.05** | -25.60** | -0.96 |
| Sakthi x H-24 | 64.00 | -33.95** | -29.34** | -23.35** |
| Sakthi x H-86 | 66.70 | -35.18** | -33.23** | -20.12** |
| Sakthi x H-7998 | 126.15 | -17.39** | 1.08 | 51.08** |
| Sakthi x LE-474 | 88.05 | -9.13** | 4.14* | 5.45** |
| Sakthi x LE-640 | 95.75 | -1.19 | 6.27** | 14.71** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-11 Contd.

| Parents/Hybrids | Plant height | | | |
|---|---|---|---|---|
| Hybrids | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 95.35 | -7.83** | 2.01 | 14.19** |
| Mukthi x IIHR-2196 | 96.35 | -23.17** | -7.75** | 15.39** |
| Mukthi x H-24 | 105.15 | 24.81** | 25.37** | 25.93** |
| Mukthi x H-86 | 114.65 | 11.42** | 23.02** | 37.31** |
| Mukthi x H-7998 | 160.25 | 4.94* | 35.69** | 91.92** |
| Mukthi x LE-474 | 83.75 | 0.30 | 7.58** | 0.30 |
| Mukthi x LE-640 | 95.00 | 14.73** | 14.87** | 13.77** |
| | | | | |
| LE-1-2 x IIHR-2195 | 103.25 | -26.88** | -15.59** | 23.65** |
| LE-1-2 x IIHR-2196 | 106.41 | -24.65** | -20.18** | 27.44** |
| LE-1-2 x H-24 | 111.90 | -20.75** | -0.73 | 34.01** |
| LE-1-2 x H-86 | 103.64 | -26.59** | -15.08** | 24.12** |
| LE-1-2 x H-7998 | 171.26 | 12.15** | 16.54** | 105.10** |
| LE-1-2 x LE-474 | 105.40 | -25.35** | -1.22 | 26.23** |
| LE-1-2 x LE-640 | 93.52 | -33.78** | -16.70** | 12.00** |
| | | | | |
| LE-626 x IIHR-2195 | 92.15 | -26.19** | -19.27** | 10.36** |
| LE-626 x IIHR-2196 | 93.02 | -25.84** | -25.67** | 11.40** |
| LE-626 x H-24 | 90.07 | -27.87** | -13.87** | 7.87** |
| LE-626 x H-86 | 91.71 | -26.55** | -19.47** | 9.83** |
| LE-626 x H-7998 | 133.95 | -12.28** | -3.48 | 60.42** |
| LE-626 x LE-474 | 88.82 | -28.87** | -9.87** | 6.37** |
| LE-626 x LE-640 | 92.09 | -26.23** | -11.51** | 10.29** |
| SEm | | 1.97 | 1.71 | 1.97 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-12 Mean performance of parental lines and heterosis of $F_1$ hybrids for days to flower in tomato

| Parents/Hybrids | Days to flower | | | |
|---|---|---|---|---|
| Parents | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 59.74 | | | |
| Sakthi | 59.46 | | | |
| Mukthi | 54.00 | | | |
| LE-1-2 | 59.46 | | | |
| LE-626 | 60.28 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 59.01 | | | |
| IIHR-2196 | 58.67 | | | |
| H-24 | 59.28 | | | |
| H-86 | 54.36 | | | |
| Hawaii-7998 | 60.18 | | | |
| LE-474 | 60.93 | | | |
| LE-640 | 59.01 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 61.93 | 4.94** | 4.30** | 14.69** |
| Anagha x IIHR-2196 | 55.18 | -5.94** | -6.79** | 2.19** |
| Anagha x H-24 | 53.63 | -9.53** | -9.88** | -0.69** |
| Anagha x H-86 | 54.36 | 0.00 | -4.71** | 0.67** |
| Anagha x H-7998 | 54.19 | -9.27** | -9.61** | 0.36 |
| Anagha x LE-474 | 55.56 | -7.00** | -7.92** | 2.88** |
| Anagha x LE-640 | 51.26 | -13.13** | -13.66** | -5.07** |
| | | | | |
| Sakthi x IIHR-2195 | 54.00 | -8.50** | -8.84** | 0.00 |
| Sakthi x IIHR-2196 | 52.74 | -10.11** | -10.71** | -2.34** |
| Sakthi x H-24 | 56.64 | -4.45** | -4.59** | 4.89** |
| Sakthi x H-86 | 54.18 | -0.33** | -4.80** | 0.33 |
| Sakthi x H-7998 | 54.74 | -7.95** | -8.50** | 1.36** |
| Sakthi x LE-474 | 55.08 | -7.36** | -8.49** | 2.01** |
| Sakthi x LE-640 | 53.64 | -9.11** | -9.45** | -0.61* |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-12 Contd.

| Parents/Hybrids | Days to flower | | | |
|---|---|---|---|---|
| **HYBRIDS** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 55.01 | 0.45** | -3.30** | 1.88** |
| Mukthi x IIHR-2196 | 55.17 | 0.72** | -2.74** | 2.16** |
| Mukthi x H-24 | 52.99 | -3.26** | -7.08** | -1.88** |
| Mukthi x H-86 | 54.74 | -0.06** | 0.31 | 1.36** |
| Mukthi x H-7998 | 55.82 | 1.92** | -2.88** | 3.37** |
| Mukthi x LE-474 | 55.53 | -1.38** | -4.02** | 2.83** |
| Mukthi x LE-640 | 54.00 | -1.41** | -5.08** | 0.00 |
| | | | | |
| LE-1-2 x IIHR-2195 | 55.28 | -6.34** | -6.69** | 2.37** |
| LE-1-2 x IIHR-2196 | 55.26 | -5.80** | -6.43** | 2.34** |
| LE-1-2 x H-24 | 51.90 | -12.44** | -12.58** | -3.88** |
| LE-1-2 x H-86 | 55.10 | -1.36** | -3.18** | 2.03** |
| LE-1-2 x H-7998 | 57.72 | -2.92** | 3.50** | 6.89** |
| LE-1-2 x LE-474 | 56.25 | -5.40** | 6.55** | 4.17** |
| LE-1-2 x LE-640 | 58.99 | -0.05** | -0.43 | 9.23** |
| | | | | |
| LE-626 x IIHR-2195 | 57.74 | -2.17** | -3.20** | 6.92** |
| LE-626 x IIHR-2196 | 52.74 | -10.11** | -11.33** | -2.34** |
| LE-626 x H-24 | 51.63 | -12.91** | -13.63** | -4.40** |
| LE-626 x H-86 | 59.19 | -8.89** | 3.28** | 9.62** |
| LE-626 x H-7998 | 59.90 | -0.47* | -0.54* | 10.93** |
| LE-626 x LE-474 | 52.71 | -12.55** | -13.02** | -2.39** |
| LE-626 x LE-640 | 54.44 | -7.74** | -8.72** | 0.82** |
| SEm | | 0.24 | 0.21 | 0.24 |

** Significant at 1 per cent level

* Significant at 5 per cent level

### 4.3.4.3 Days to harvest

Anagha x LE-640 (83.78 days) (Table-13) was the earliest to harvest among the hybrids and parents tested. This hybrid had a heterobeltiosis of -8.71 per cent, relative heterosis of -8.91 per cent and standard heterosis of -2.84 per cent followed by hybrid combinations LE-626 x H-24 (-8.37, -8.22 and -2.46 per cent respectively) and LE-1-2 x H-24 (-7.72, -8.18 and -2.23 per cent respectively). Anagha x IIHR-2195 showed positive heterobeltiosis, relative heterosis and standard heterosis (5.52, 3.14 and 9.18 per cent respectively).

### 4.3.4.4 Number of branches per plant

Maximum heterobeltiosis of 21.52 per cent was found in Mukthi x LE-474 followed by 15.51 per cent in Mukthi x IIHR-2196 and 12.96 per cent in Mukthi x Hawaii-7998. Maximum relative heterosis was observed in the cross Mukthi x LE-474 (26.85 per cent) followed by 25.28 per cent in Mukthi x Hawaii-7998 and 20.55 per cent in Mukthi x IIHR-2196. Standard heterosis was found maximum in the cross Mukthi x Hawaii-7998 (40.64 per cent) followed by Mukthi x LE-640 (33.06 per cent) and Mukthi x H-86 (30.50 per cent) for number of branches per plant (Table-14).

### 4.3.4.5 Number of fruits per plant

Maximum number of fruits was produced by LE-474 (30.58) among the parents (Table-15). Among the hybrids maximum number of fruits were produced by LE-1-2 x Hawaii-7998 (39.67 fruits/plant). This hybrid had maximum heterobeltiosis (49.71 per cent), relative heterosis (80.79 per cent) and standard heterosis (89.24 per cent) followed by Mukthi x H-86 which had a heterobeltiosis of 43.39 per cent, relative heterosis of 58.94 per cent and standard heterosis 43.39 per cent.

Table-13 Mean performance of parental lines and heterosis of $F_1$ hybrids for days to harvest in tomato

| Parents/Hybrids | Days to harvest | | | |
|---|---|---|---|---|
| Parents | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 91.77 | | | |
| Sakthi | 92.03 | | | |
| Mukthi | 86.22 | | | |
| LE-1-2 | 91.85 | | | |
| LE-626 | 92.88 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 90.78 | | | |
| IIHR-2196 | 90.82 | | | |
| H-24 | 91.78 | | | |
| H-86 | 86.55 | | | |
| Hawaii-7998 | 92.11 | | | |
| LE-474 | 93.11 | | | |
| LE-640 | 90.78 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 94.14 | 3.70** | 3.14** | 9.18** |
| Anagha x IIHR-2196 | 87.93 | -3.19** | -3.69** | 1.98** |
| Anagha x H-24 | 86.10 | -6.18** | -6.18** | -0.14 |
| Anagha x H-86 | 86.71 | -0.20** | -2.74** | 0.57** |
| Anagha x H-7998 | 86.40 | -5.85** | -6.02** | 0.21 |
| Anagha x LE-474 | 87.34 | -4.83** | -5.52** | 1.30** |
| Anagha x LE-640 | 83.78 | -7.72** | -8.91** | -2.84** |
| | | | | |
| Sakthi x IIHR-2195 | 85.96 | -5.31** | -5.96** | -0.31 |
| Sakthi x IIHR-2196 | 85.11 | -6.29** | -6.91** | -1.29** |
| Sakthi x H-24 | 88.91 | 3.39** | -3.26** | 3.12** |
| Sakthi x H-86 | 86.38 | -0.18** | -3.25** | 0.19 |
| Sakthi x H-7998 | 87.31 | -5.13** | -5.17** | 1.26** |
| Sakthi x LE-474 | 87.53 | -4.89** | -5.44** | 1.52** |
| Sakthi x LE-640 | 86.35 | -4.88** | -5.53** | 0.15 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-13 Contd.

| Parents/Hybrids | Days to harvest | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 86.87 | 0.74** | -1.85** | 0.75** |
| Mukthi x IIHR-2196 | 88.27 | 2.37** | -0.29 | 2.37** |
| Mukthi x H-24 | 85.69 | -0.62** | -3.72** | -0.62** |
| Mukthi x H-86 | 87.06 | 0.97** | 0.78** | 0.97** |
| Mukthi x H-7998 | 88.06 | 2.13** | -1.24** | 2.13** |
| Mukthi x LE-474 | 88.76 | 2.94** | -1.01** | 2.94** |
| Mukthi x LE-640 | 86.39 | -0.19** | -2.39** | 0.19 |
| | | | | |
| LE-1-2 x IIHR-2195 | 87.88 | -3.20** | -3.76** | 1.92** |
| LE-1-2 x IIHR-2196 | 87.86 | -3.27** | -3.81** | 1.90** |
| LE-1-2 x H-24 | 84.30 | -8.15** | -8.18** | -2.23** |
| LE-1-2 x H-86 | 87.26 | 0.83** | -2.71** | 1.20** |
| LE-1-2 x H-7998 | 89.94 | -2.07** | -2.21** | 4.31** |
| LE-1-2 x LE-474 | 89.48 | -2.57** | -3.24** | 3.78** |
| LE-1-2 x LE-640 | 92.20 | -2.90** | 0.97** | 6.94** |
| | | | | |
| LE-626 x IIHR-2195 | 90.13 | -0.72** | -1.85** | 4.53** |
| LE-626 x IIHR-2196 | 84.53 | -6.93** | -7.79** | -1.96** |
| LE-626 x H-24 | 84.10 | -8.37** | -8.22** | -2.46** |
| LE-626 x H-86 | 91.32 | 5.52** | 1.79** | 5.91** |
| LE-626 x H-7998 | 92.20 | 0.10 | -0.32 | 6.93** |
| LE-626 x LE-474 | 85.76 | -7.67** | -7.78** | -0.54** |
| LE-626 x LE-640 | 86.95 | -4.22** | -5.31** | 0.85** |
| SEm | | 0.20 | 0.17 | 0.20 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-14 Mean performance of parental lines and heterosis of $F_1$ hybrids for Number of branches per plant in tomato

| Parents/Hybrids | Number of branches/plant | | | |
|---|---|---|---|---|
| Parents | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 20.88 | | | |
| Sakthi | 24.94 | | | |
| Mukthi | 21.56 | | | |
| LE-1-2 | 22.22 | | | |
| LE-626 | 21.47 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 24.91 | | | |
| IIHR-2196 | 23.53 | | | |
| H-24 | 52.88 | | | |
| H-86 | 35.78 | | | |
| Hawaii-7998 | 26.84 | | | |
| LE-474 | 19.75 | | | |
| LE-640 | 27.41 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 13.39 | -46.26** | -41.52** | -37.92** |
| Anagha x IIHR-2196 | 13.50 | -42.65** | -39.22** | -37.41** |
| Anagha x H-24 | 9.89 | -81.30** | -73.19** | -54.16** |
| Anagha x H-86 | 15.12 | -57.76** | -46.64** | -29.90** |
| Anagha x H-7998 | 16.45 | -38.72** | -31.06** | -23.71** |
| Anagha x LE-474 | 15.39 | -22.10** | -24.26** | -28.65** |
| Anagha x LE-640 | 17.80 | -35.07** | -26.28** | -17.47** |
| | | | | |
| Sakthi x IIHR-2195 | 16.82 | -32.56** | -32.51** | -21.99** |
| Sakthi x IIHR-2196 | 17.05 | -31.64** | -29.65** | -20.93** |
| Sakthi x H-24 | 15.06 | -71.52** | -61.29** | -30.16** |
| Sakthi x H-86 | 15.33 | -57.17** | -49.52** | -28.93** |
| Sakthi x H-7998 | 19.01 | -29.19** | -26.58** | -11.84** |
| Sakthi x LE-474 | 22.21 | -10.95** | -0.60 | 3.00 |
| Sakthi x LE-640 | 18.82 | -31.34** | -28.11** | -12.74** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-14 Contd.

| Parents/Hybrids | Number of branches/plant | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 26.53 | 6.52** | 14.18** | 23.04** |
| Mukthi x IIHR-2196 | 27.18 | 15.51** | 20.55** | 26.05** |
| Mukthi x H-24 | 24.40 | -53.86** | -34.46** | 13.14** |
| Mukthi x H-86 | 28.14 | -21.35** | -1.86 | 30.50** |
| Mukthi x H-7998 | 30.33 | 12.96** | 25.28** | 40.64** |
| Mukthi x LE-474 | 26.21 | 21.52** | 26.85** | 21.53** |
| Mukthi x LE-640 | 28.69 | 4.69* | 17.17** | 33.06** |
| | | | | |
| LE-1-2 x IIHR-2195 | 9.95 | -60.05** | -57.77** | -53.86** |
| LE-1-2 x IIHR-2196 | 11.58 | -50.81** | -49.40** | -46.32** |
| LE-1-2 x H-24 | 14.72 | -72.17** | -60.81** | -31.76** |
| LE-1-2 x H-86 | 24.41 | -31.78** | -15.83** | 13.21** |
| LE-1-2 x H-7998 | 23.23 | -13.48** | -5.33** | 7.71** |
| LE-1-2 x LE-474 | 20.80 | -6.41 | -0.91 | -3.56 |
| LE-1-2 x LE-640 | 23.37 | -14.74** | -5.83** | 8.36** |
| | | | | |
| LE-626 x IIHR-2195 | 17.64 | -29.17** | -23.92** | -18.19** |
| LE-626 x IIHR-2196 | 20.39 | -13.34** | -9.38** | -5.44** |
| LE-626 x H-24 | 15.55 | -70.60** | -58.18** | -27.91** |
| LE-626 x H-86 | 26.51 | -25.92** | -7.41** | 22.92** |
| LE-626 x H-7998 | 13.90 | -48.24** | -42.48** | -35.56** |
| LE-626 x LE-474 | 18.65 | -13.13** | -9.51** | -13.51** |
| LE-626 x LE-640 | 18.79 | -31.45** | -23.13** | -12.88** |
| SEm | | 1.90 | 1.64 | 1.90 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-15 Mean performance of parental lines and heterosis of $F_1$ hybrids for Number of fruits per plant in tomato

| Parents/Hybrids | Number of fruits per plant | | | |
|---|---|---|---|---|
| Parents | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 19.55 | | | |
| Sakthi | 13.73 | | | |
| Mukthi | 20.96 | | | |
| LE-1-2 | 17.39 | | | |
| LE-626 | 15.20 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 16.93 | | | |
| IIHR-2196 | 16.49 | | | |
| H-24 | 17.06 | | | |
| H-86 | 16.86 | | | |
| Hawaii-7998 | 26.49 | | | |
| LE-474 | 30.58 | | | |
| LE-640 | 30.41 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 11.75 | -39.92** | -35.61** | -43.96** |
| Anagha x IIHR-2196 | 13.25 | -32.23** | -26.46** | -36.78** |
| Anagha x H-24 | 16.60 | -15.12** | -9.34** | -20.83** |
| Anagha x H-86 | 10.61 | -45.73** | -41.72** | -49.38** |
| Anagha x H-7998 | 17.00 | -35.84** | -26.16** | -18.90** |
| Anagha x LE-474 | 11.96 | -60.88** | -52.28** | -42.94** |
| Anagha x LE-640 | 16.94 | -44.27** | -32.16** | -19.16** |
| | | | | |
| Sakthi x IIHR-2195 | 21.22 | 25.34** | 38.42** | 1.25 |
| Sakthi x IIHR-2196 | 14.95 | -9.34** | -1.08 | -28.70** |
| Sakthi x H-24 | 16.78 | -1.64 | 9.00** | -19.94** |
| Sakthi x H-86 | 13.67 | -18.92** | -10.62** | -34.78** |
| Sakthi x H-7998 | 14.78 | -44.32** | -26.51** | -29.48** |
| Sakthi x LE-474 | 15.44 | -49.48** | -30.28** | -26.31** |
| Sakthi x LE-640 | 33.39 | -3.34 | 51.31** | 40.21** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-15 Contd.

| Parents/Hybrids | Number of fruits per plant | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 26.72 | 27.50** | 41.07** | 27.49** |
| Mukthi x IIHR-2196 | 18.94 | -9.61** | 1.19 | -9.61** |
| Mukthi x H-24 | 25.11 | 19.80** | 32.09** | 19.80** |
| Mukthi x H-86 | 30.06 | 43.39** | 58.94** | 43.39** |
| Mukthi x H-7998 | 22.56 | -14.87** | -4.94** | 7.61** |
| Mukthi x LE-474 | 18.56 | -39.31** | -27.99** | -11.47** |
| Mukthi x LE-640 | 18.83 | -38.05** | -26.66** | -10.14** |
| | | | | |
| LE-1-2 x IIHR-2195 | 19.39 | 11.53** | 13.01** | -7.49** |
| LE-1-2 x IIHR-2196 | 13.73 | -21.02** | -18.93** | -34.49** |
| LE-1-2 x H-24 | 14.78 | -14.98** | -14.18** | -29.48** |
| LE-1-2 x H-86 | 17.57 | 1.06 | 2.61 | -16.17** |
| LE-1-2 x H-7998 | 39.67 | 49.71** | 80.79** | 89.24** |
| LE-1-2 x LE-474 | 18.00 | -41.13** | -24.94** | -14.12** |
| LE-1-2 x LE-640 | 21.06 | -30.75** | -11.89** | 0.46 |
| | | | | |
| LE-626 x IIHR-2195 | 13.11 | -22.56** | -18.41** | -37.45** |
| LE-626 x IIHR-2196 | 13.95 | -15.41** | -11.99** | -33.47** |
| LE-626 x H-24 | 23.83 | 39.68** | 47.71** | 13.71** |
| LE-626 x H-86 | 20.84 | 23.58** | 29.95** | -0.60 |
| LE-626 x H-7998 | 14.83 | -44.01** | -28.85** | -29.22** |
| LE-626 x LE-474 | 13.83 | -54.75** | -39.56** | -34.00** |
| LE-626 x LE-640 | 19.06 | -37.33** | -16.44** | -9.09** |
| SEm | | 2.00 | 1.73 | 2.00 |

** Significant at 1 per cent level

* Significant at 5 per cent level

### 4.3.4.6 Yield per plant

Sakthi x LE-640 (1.4 kg/plant) (Table-16) (Plate-21a and 21b) gave the maximum yield among the hybrids and parents followed by Mukthi x H-86 (1.1 kg/plant) (Plate-22a and 22b) and LE-1-2 x Hawaii-7998 (1.06 kg/plant) (Plate-23a and 23b). Maximum heterobeltiosis of 123.01 per cent was found in LE-1-2 x Hawaii-7998 followed by Sakthi x LE-640 (103.62 per cent) and Mukthi x H-86 (68.60 per cent) (Plate-24a and 24b). Maximum relative heterosis was observed in the cross LE-1-2 x Hawaii-7998 (134.01 per cent) followed by 111.65 per cent in Sakthi x LE-640 and 94.93 per cent in Mukthi x H-86. Standard heterosis was found maximum in the cross Sakthi x LE-640 (99.14 per cent) followed by Mukthi x H-86 (72.87 per cent) and LE-1-2 x Hawaii-7998 (50.54 per cent) for fruit yield per plant.

### 4.3.4.7 Average fruit weight

The maximum sized fruits were produced by Anagha x IIHR-2195 (55.93 g) followed by Sakthi x LE-640 (55.78 g) and Sakthi x IIHR-2196 (55.09 g) (Table-17). Maximum heterobeltiosis of 41.86 per cent was found in Sakthi x LE-640 followed by LE-626 x Hawaii-7998 (33.84 per cent) and Sakthi x Hawaii-7998 (29.06 per cent). Maximum relative heterosis was observed in the cross Sakthi x LE-640 (41.23 per cent) followed by Sakthi x Hawaii-7998 (39.62 per cent) and LE-626 x Hawaii-7998 (35.16 per cent). Standard heterosis was found maximum in the cross Anagha x IIHR-2195 (31.41 per cent) followed by Sakthi x LE-640 (31.06 per cent) and Sakthi x IIHR-2196 (29.44 per cent) and LE-1-2 x LE-474 (29.06 per cent) for average fruit weight. The Heterobeltiosis, relative heterosis and standard heterosis were positive and significant.

### 4.3.4.8 Number of locules per fruit

Table-16 Mean performance of parental lines and heterosis of $F_1$ hybrids for Yield per plant in tomato

| Parents/Hybrids | Yield per plant | | | |
|---|---|---|---|---|
| Parents | Mean (g) | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 685.52 | | | |
| Sakthi | 637.86 | | | |
| Mukthi | 705.72 | | | |
| LE-1-2 | 476.40 | | | |
| LE-626 | 425.53 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 455.72 | | | |
| IIHR-2196 | 462.37 | | | |
| H-24 | 551.73 | | | |
| H-86 | 515.46 | | | |
| Hawaii-7998 | 410.68 | | | |
| LE-474 | 600.52 | | | |
| LE-640 | 690.23 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 253.89 | -62.96 | -55.51 | -64.02 |
| Anagha x IIHR-2196 | 228.89 | -66.61 | -60.12 | -67.57 |
| Anagha x H-24 | 261.11 | -61.91 | -57.79 | -63.00 |
| Anagha x H-86 | 331.11 | -51.70 | -44.86 | -53.08 |
| Anagha x H-7998 | 452.78 | -33.95 | -17.39 | -35.84 |
| Anagha x LE-474 | 383.89 | -44.00 | -40.30 | -45.60 |
| Anagha x LE-640 | 311.67 | -54.85 | -54.69 | -55.84 |
| | | | | |
| Sakthi x IIHR-2195 | 534.44 | -16.21 | -2.26 | -24.27 |
| Sakthi x IIHR-2196 | 480.55 | -24.66 | -12.64 | -31.91 |
| Sakthi x H-24 | 344.45 | -46.00 | -42.09 | -51.19 |
| Sakthi x H-86 | 347.23 | -45.56 | -39.79 | -50.80 |
| Sakthi x H-7998 | 299.45 | -53.05 | -42.88 | -57.57 |
| Sakthi x LE-474 | 347.23 | -45.56 | -43.92 | -50.80 |
| Sakthi x LE-640 | 1405.45 | 103.62 | 111.65 | 99.14 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-16 Contd.

| Parents/Hybrids | Yield per plant | | | |
|---|---|---|---|---|
| **Hybrids** | Mean (g) | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 616.11 | -12.70 | 6.10 | -12.70 |
| Mukthi x IIHR-2196 | 618.33 | -12.38 | 5.87 | -12.38 |
| Mukthi x H-24 | 669.44 | -5.14 | 6.48 | -5.14 |
| Mukthi x H-86 | 1190.23 | 68.60 | 94.93 | 72.87 |
| Mukthi x H-7998 | 539.02 | -23.62 | -3.44 | -26.62 |
| Mukthi x LE-474 | 993.34 | 40.76 | 52.09 | 40.75 |
| Mukthi x LE-640 | 948.33 | 34.38 | 35.87 | 34.38 |
| | | | | |
| LE-1-2 x IIHR-2195 | 237.23 | -50.20 | 59.83 | -73.47 |
| LE-1-2 x IIHR-2196 | 168.89 | -64.55 | -64.02 | -76.07 |
| LE-1-2 x H-24 | 438.61 | -20.50 | -14.68 | -37.85 |
| LE-1-2 x H-86 | 462.78 | -10.22 | -6.68 | -34.42 |
| LE-1-2 x H-7998 | 1062.39 | 123.01** | 139.53** | 50.54 |
| LE-1-2 x LE-474 | 526.11 | -12.39 | -2.29 | -25.45 |
| LE-1-2 x LE-640 | 938.89 | 36.02 | 60.96 | 33.04 |
| | | | | |
| LE-626 x IIHR-2195 | 317.17 | -30.51 | -28.13 | -55.13 |
| LE-626 x IIHR-2196 | 425.00 | -8.08 | -4.27 | -39.18 |
| LE-626 x H-24 | 913.89 | 65.64 | 87.03 | 29.50 |
| LE-626 x H-86 | 351.11 | -31.88 | -25.37 | -50.25 |
| LE-626 x H-7998 | 382.78 | -10.05 | -8.45 | -45.76 |
| LE-626 x LE-474 | 310.28 | -48.33 | -39.52 | -56.03 |
| LE-626 x LE-640 | 475.00 | -31.18 | -14.86 | -32.69 |
| SEm | | 58.46 | 50.63 | 58.46 |

** Significant at 1 per cent level

* Significant at 5 per cent level


2011/12/02
Sakthi x LE-640


2011/12/
Mukthi x H-86


Shakthi x LE-640
2010/12/09


Mukthi x H-86


LE-1-2 x Hawaii-7998


LE-1-2 x H-7998
2010/12/03


Mukthi x LE-474

Table-17 Mean performance of parental lines and heterosis of $F_1$ hybrids for average fruit weight in tomato

| Parents/Hybrids | Average fruit weight | | | |
|---|---|---|---|---|
| | Mean (g) | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 41.43 | | | |
| Sakthi | 39.67 | | | |
| Mukthi | 42.56 | | | |
| LE-1-2 | 50.00 | | | |
| LE-626 | 34.34 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 45.84 | | | |
| IIHR-2196 | 47.78 | | | |
| H-24 | 39.76 | | | |
| H-86 | 37.75 | | | |
| Hawaii-7998 | 33.67 | | | |
| LE-474 | 41.61 | | | |
| LE-640 | 44.30 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 55.93 | 22.01** | 28.18** | 31.41** |
| Anagha x IIHR-2196 | 25.76 | -46.09** | -42.25 | -39.47** |
| Anagha x H-24 | 34.43 | -16.90** | -15.19** | -19.10** |
| Anagha x H-86 | 20.47 | -50.59** | -48.30** | -51.90** |
| Anagha x H-7998 | 27.96 | -32.51** | -25.54** | -34.30** |
| Anagha x LE-474 | 45.74 | 9.93** | 10.16** | 7.47** |
| Anagha x LE-640 | 21.46 | -48.20** | -46.85** | -49.58** |
| | | | | |
| Sakthi x IIHR-2195 | 23.93 | -47.80** | -44.03** | -43.77** |
| Sakthi x IIHR-2196 | 55.09 | 15.30** | 25.99** | 29.44** |
| Sakthi x H-24 | 43.46 | 9.31** | 9.43** | 2.11** |
| Sakthi x H-86 | 50.11 | 26.32** | 29.45** | 17.74** |
| Sakthi x H-7998 | 51.20 | 29.06** | 39.62** | 20.30** |
| Sakthi x LE-474 | 48.74 | 17.14** | 19.93** | 14.52** |
| Sakthi x LE-640 | 55.78 | 41.86** | 32.86** | 31.06** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-17 Contd.

| Parents/Hybrids | Average fruit weight | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 35.46 | -22.64** | -19.77** | -16.68** |
| Mukthi x IIHR-2196 | 52.01 | 8.85** | 15.14** | 22.20** |
| Mukthi x H-24 | 45.96 | 7.99** | 11.66** | 7.99** |
| Mukthi x H-86 | 41.52 | -2.44** | 3.40** | -2.44** |
| Mukthi x H-7998 | 34.00 | -20.11** | -10.80** | -20.11** |
| Mukthi x LE-474 | 36.76 | -13.63** | -12.65** | -13.63** |
| Mukthi x LE-640 | 45.49 | 6.88** | 4.47** | 6.88** |
| | | | | |
| LE-1-2 x IIHR-2195 | 28.95 | -42.10** | -39.59** | -31.98** |
| LE-1-2 x IIHR-2196 | 30.81 | -38.38** | -36.98** | -27.61** |
| LE-1-2 x H-24 | 40.63 | -18.74** | -9.47** | -4.53** |
| LE-1-2 x H-86 | 39.00 | -22.00** | -11.11** | -8.36** |
| LE-1-2 x H-7998 | 43.97 | -12.07** | 5.09** | 3.30** |
| LE-1-2 x LE-474 | 54.93 | 9.86** | 19.92** | 29.06** |
| LE-1-2 x LE-640 | 47.87 | -4.26** | 1.53** | 12.48** |
| | | | | |
| LE-626 x IIHR-2195 | 40.63 | 11.37** | 1.35 | -4.53** |
| LE-626 x IIHR-2196 | 46.76 | -2.13** | 13.88** | 9.87** |
| LE-626 x H-24 | 27.87 | -29.90** | -24.78** | -34.52** |
| LE-626 x H-86 | 25.89 | -31.42** | -28.17** | -39.17** |
| LE-626 x H-7998 | 45.96 | 33.84** | 35.16** | 7.99** |
| LE-626 x LE-474 | 27.75 | -33.31** | -26.93** | -34.80** |
| LE-626 x LE-640 | 42.69 | 8.57** | 8.57** | 0.31 |
| SEm | | 0.74 | 0.64 | 0.74 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Maximum heterobeltiosis of 13.17 per cent was found in Anagha x IIHR-2195 followed by Mukthi x LE-474 (5.05 per cent) (Plate-24a and 24b). Maximum relative heterosis was observed in the cross Anagha x IIHR-2195 (33.10 per cent) followed by Sakthi x IIHR-2195 (25.61 per cent) and Anagha x IIHR-2196 (20.60 per cent). Standard heterosis was found maximum in the cross LE-626 x LE-474 (10.90 per cent) followed by Mukthi x LE-474 (10.53 per cent) and LE-626 x H-86 (8.06 per cent) for number of locules per fruit (Table-18).

**4.3.4.9 Ascorbic acid (mg/100g)**

Highly positive significant heterosis was observed in all crosses for ascorbic acid content (Table-19). Among the hybrids, Anagha x LE-640 has the maximum ascorbic acid content (28.44 mg/100g) followed by LE-626 x H-24 (27.85 mg/100g). Heterobeltiosis, relative heterosis and standard heterosis were positive, significant and maximum in the same hybrid (232.63 per cent, 243.69 per cent and 240.60 per cent respectively).

**4.3.4.10 Acidity**

Significant heterosis was observed in all crosses for acidity per cent (Table-20). Among the hybrids Mukthi x IIHR-2196 has the maximum acidity per cent (0.59 per cent) followed by Mukthi x H-24 (0.55 per cent). Heterobeltiosis, relative heterosis and standard heterosis were positive, significant and maximum in the hybrid Mukthi x IIHR-2196 (58.11 per cent, 64.79 per cent and 72.06 per cent respectively) followed by Mukthi x H-24 (43.42 per cent, 51.39 per cent and 60.29 per cent respectively).

**4.3.4.11 Total sugars**

Maximum heterobeltiosis was found in Anagha x H-86 (41.92 per cent) followed by Sakthi x H-86 (38.59 per cent) and LE-1-2 x H-24 (32.32 per cent). Maximum relative heterosis was observed in the cross Anagha x H-86

Table-18 Mean performance of parental lines and heterosis of $F_1$ hybrids for Number of locules per fruit in tomato

| Parents/Hybrids | Number of locules per fruit | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 3.34 | | | |
| Sakthi | 4.22 | | | |
| Mukthi | 4.22 | | | |
| LE-1-2 | 4.78 | | | |
| LE-626 | 4.56 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 2.34 | | | |
| IIHR-2196 | 2.00 | | | |
| H-24 | 4.22 | | | |
| H-86 | 4.22 | | | |
| Hawaii-7998 | 4.44 | | | |
| LE-474 | 4.44 | | | |
| LE-640 | 4.70 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 3.78 | 13.17** | 33.10** | -10.43** |
| Anagha x IIHR-2196 | 3.22 | -3.59** | 20.60** | -23.70** |
| Anagha x H-24 | 3.78 | -10.43** | 0.00 | -10.43** |
| Anagha x H-86 | 3.10 | -26.54** | -17.99** | -26.54** |
| Anagha x H-7998 | 4.56 | 2.70** | 17.22** | 8.06** |
| Anagha x LE-474 | 4.22 | -4.95** | 8.48** | 0.00 |
| Anagha x LE-640 | 3.56 | -25.52** | -12.32** | -15.64** |
| | | | | |
| Sakthi x IIHR-2195 | 4.12 | -2.37** | 25.61** | -2.37** |
| Sakthi x IIHR-2196 | 3.56 | -15.64** | 14.47** | -15.64** |
| Sakthi x H-24 | 4.10 | -2.84** | -2.84** | -2.84** |
| Sakthi x H-86 | 2.66 | -36.97** | -36.97** | -36.97** |
| Sakthi x H-7998 | 4.44 | 0.00 | 2.54** | 5.21** |
| Sakthi x LE-474 | 3.22 | -27.48** | -25.64** | -23.70** |
| Sakthi x LE-640 | 3.00 | -37.24** | -33.33** | -28.91** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-18 Contd.

| Parents/Hybrids | Number of locules per fruit | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 3.22 | -23.70** | -1.83** | -23.70** |
| Mukthi x IIHR-2196 | 3.00 | -28.91** | -3.54** | -28.91** |
| Mukthi x H-24 | 4.10 | -2.84** | -2.84** | -2.84** |
| Mukthi x H-86 | 3.22 | -23.70** | -23.70** | -23.70** |
| Mukthi x H-7998 | 4.66 | 4.95** | 7.62** | 10.43** |
| Mukthi x LE-474 | 4.76 | 5.05** | 7.72** | 10.53** |
| Mukthi x LE-640 | 4.12 | -13.81** | -8.44** | -2.37** |
| | | | | |
| LE-1-2 x IIHR-2195 | 2.56 | -46.44** | -28.09** | -39.34** |
| LE-1-2 x IIHR-2196 | 3.66 | -23.43** | 7.96** | -13.27** |
| LE-1-2 x H-24 | 4.22 | -11.72** | -6.22** | 0.00 |
| LE-1-2 x H-86 | 4.00 | -16.32** | -11.11** | -5.21** |
| LE-1-2 x H-7998 | 3.44 | -28.03** | -25.38** | -18.48** |
| LE-1-2 x LE-474 | 4.00 | -16.32** | -13.23** | -5.21** |
| LE-1-2 x LE-640 | 4.00 | -16.32** | -16.32** | -5.21** |
| | | | | |
| LE-626 x IIHR-2195 | 3.66 | -19.74** | 6.09** | -13.27** |
| LE-626 x IIHR-2196 | 3.44 | -24.56** | 4.88** | -18.48** |
| LE-626 x H-24 | 3.80 | -16.67** | -13.44** | -9.95** |
| LE-626 x H-86 | 4.56 | 0.00 | 3.87** | 8.06** |
| LE-626 x H-7998 | 4.34 | -4.82** | -3.56** | 2.84** |
| LE-626 x LE-474 | 4.68 | 2.63** | 4.00** | 10.90** |
| LE-626 x LE-640 | 3.22 | -32.64** | -31.05** | -23.70** |
| SEm | | 0.08 | 0.07 | 0.08 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-19 Mean performance of parental lines and heterosis of $F_1$ hybrids for Ascorbic acid 100g-1 in tomato

| Parents/Hybrids | Ascorbic acid 100g-1 | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 8.55 | | | |
| Sakthi | 7.70 | | | |
| Mukthi | 8.35 | | | |
| LE-1-2 | 7.55 | | | |
| LE-626 | 11.75 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 9.35 | | | |
| IIHR-2196 | 10.10 | | | |
| H-24 | 11.80 | | | |
| H-86 | 12.45 | | | |
| Hawaii-7998 | 9.45 | | | |
| LE-474 | 10.70 | | | |
| LE-640 | 8.00 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 25.80 | 175.94** | 188.27** | 208.98** |
| Anagha x IIHR-2196 | 26.16 | 159.01** | 180.54** | 213.29** |
| Anagha x H-24 | 24.32 | 106.01** | 139.02** | 191.26** |
| Anagha x H-86 | 24.73 | 98.63** | 135.52** | 196.17** |
| Anagha x H-7998 | 21.42 | 126.67** | 138.00** | 156.53** |
| Anagha x LE-474 | 22.74 | 112.52** | 136.26** | 172.34** |
| Anagha x LE-640 | 28.44 | 232.63** | 243.69** | 240.60** |
| | | | | |
| Sakthi x IIHR-2195 | 22.38 | 139.36** | 162.52** | 168.02** |
| Sakthi x IIHR-2196 | 23.64 | 134.01** | 165.56** | 183.05** |
| Sakthi x H-24 | 24.81 | 110.25** | 154.46** | 197.13** |
| Sakthi x H-86 | 26.91 | 116.14** | 167.10** | 222.28** |
| Sakthi x H-7998 | 22.51 | 138.20** | 162.51** | 169.58** |
| Sakthi x LE-474 | 20.31 | 89.81** | 120.51** | 143.23** |
| Sakthi x LE-640 | 24.03 | 200.37** | 206.11** | 187.78** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-19 Contd.

| Parents/Hybrids | Ascorbic acid 100g-1 | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 21.61 | 131.12** | 144.18** | 158.80** |
| Mukthi x IIHR-2196 | 24.64 | 143.96** | 167.10** | 195.09** |
| Mukthi x H-24 | 20.53 | 73.94** | 103.72** | 145.81** |
| Mukthi x H-86 | 19.43 | 56.06** | 86.83** | 132.69** |
| Mukthi x H-7998 | 23.66 | 150.32** | 165.79** | 183.29** |
| Mukthi x LE-474 | 23.07 | 115.56** | 142.15** | 176.23** |
| Mukthi x LE-640 | 22.40 | 168.26** | 174.01** | 168.26** |
| | | | | |
| LE-1-2 x IIHR-2195 | 21.35 | 128.34** | 152.66** | 155.69** |
| LE-1-2 x IIHR-2196 | 22.95 | 127.23** | 160.06** | 174.85** |
| LE-1-2 x H-24 | 23.12 | 95.93** | 138.97** | 176.89** |
| LE-1-2 x H-86 | 21.81 | 75.18** | 118.10** | 161.20** |
| LE-1-2 x H-7998 | 20.90 | 121.11** | 145.82** | 150.24** |
| LE-1-2 x LE-474 | 26.70 | 149.53** | 192.60** | 219.76** |
| LE-1-2 x LE-640 | 25.75 | 221.88** | 231.19** | 208.38** |
| | | | | |
| LE-626 x IIHR-2195 | 25.65 | 118.30** | 143.12** | 207.19** |
| LE-626 x IIHR-2196 | 27.60 | 134.89** | 152.63** | 230.54** |
| LE-626 x H-24 | 27.85 | 136.02** | 136.52** | 233.53** |
| LE-626 x H-86 | 27.50 | 120.00** | 127.27** | 229.34** |
| LE-626 x H-7998 | 26.10 | 122.13** | 146.23** | 212.57** |
| LE-626 x LE-474 | 27.40 | 133.19** | 144.10** | 228.14** |
| LE-626 x LE-640 | 22.55 | 91.91** | 128.35** | 170.06** |
| SEm | | 0.66 | 0.57 | 0.66 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-20 Mean performance of parental lines and heterosis of $F_1$ hybrids for Acidity per cent in tomato

| Parents/Hybrids | Acidity per cent | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 0.34 | | | |
| Sakthi | 0.58 | | | |
| Mukthi | 0.34 | | | |
| LE-1-2 | 0.31 | | | |
| LE-626 | 0.37 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 0.40 | | | |
| IIHR-2196 | 0.37 | | | |
| H-24 | 0.38 | | | |
| H-86 | 0.35 | | | |
| Hawaii-7998 | 0.38 | | | |
| LE-474 | 0.39 | | | |
| LE-640 | 0.38 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 0.47 | 17.50** | 27.52** | 39.71** |
| Anagha x IIHR-2196 | 0.50 | 35.14** | 39.86** | 47.06** |
| Anagha x H-24 | 0.49 | 28.20** | 33.79** | 42.65** |
| Anagha x H-86 | 0.50 | 42.86** | 43.88** | 47.06** |
| Anagha x H-7998 | 0.49 | 27.27** | 34.25** | 44.12** |
| Anagha x LE-474 | 0.50 | 29.49** | 37.41** | 48.53** |
| Anagha x LE-640 | 0.46 | 21.05** | 26.90** | 35.29** |
| | | | | |
| Sakthi x IIHR-2195 | 0.45 | -21.55** | -7.14** | 33.82** |
| Sakthi x IIHR-2196 | 0.50 | -13.79** | 5.26** | 47.06** |
| Sakthi x H-24 | 0.47 | -18.97** | -2.08** | 38.24** |
| Sakthi x H-86 | 0.43 | -26.72** | -8.60** | 25.00** |
| Sakthi x H-7998 | 0.44 | -23.28** | -7.77** | 30.88** |
| Sakthi x LE-474 | 0.50 | -13.79** | 3.09** | 47.06** |
| Sakthi x LE-640 | 0.53 | -8.62** | 10.42** | 55.88** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-20 Contd.

| Parents/Hybrids | Acidity per cent | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 0.45 | 13.75** | 22.97** | 33.82** |
| Mukthi x IIHR-2196 | 0.58 | 58.11** | 64.79** | 72.06** |
| Mukthi x H-24 | 0.55 | 43.42** | 51.39** | 60.29** |
| Mukthi x H-86 | 0.50 | 44.29** | 46.38** | 48.53** |
| Mukthi x H-7998 | 0.42 | 7.79** | 14.48** | 22.06** |
| Mukthi x LE-474 | 0.35 | -10.26** | -4.11** | 2.94** |
| Mukthi x LE-640 | 0.41 | 7.89** | 13.98** | 20.59** |
| | | | | |
| LE-1-2 x IIHR-2195 | 0.44 | 10.00** | 24.82** | 29.41** |
| LE-1-2 x IIHR-2196 | 0.36 | -2.70** | 6.67** | 5.88** |
| LE-1-2 x H-24 | 0.41 | 9.21** | 21.17** | 22.06** |
| LE-1-2 x H-86 | 0.30 | -14.29** | -8.40** | -11.76** |
| LE-1-2 x H-7998 | 0.38 | -1.30** | 10.14** | 11.76** |
| LE-1-2 x LE-474 | 0.32 | -17.95** | -7.91** | -5.88** |
| LE-1-2 x LE-640 | 0.37 | -2.63** | 8.03** | 8.82** |
| | | | | |
| LE-626 x IIHR-2195 | 0.33 | -16.25** | -12.99** | -1.47** |
| LE-626 x IIHR-2196 | 0.36 | -2.70** | -2.70** | 5.88** |
| LE-626 x H-24 | 0.38 | 0.00 | 1.33** | 11.76** |
| LE-626 x H-86 | 0.34 | -4.29** | -6.94** | -1.47** |
| LE-626 x H-7998 | 0.28 | -27.27** | -25.83** | -17.65** |
| LE-626 x LE-474 | 0.31 | -19.23** | -17.11** | -7.35** |
| LE-626 x LE-640 | 0.35 | -7.89** | -6.67** | 2.94** |
| SEm | | 0.02 | 0.02 | 0.02 |

** Significant at 1 per cent level

* Significant at 5 per cent level

(48.92 per cent) followed by Sakthi x H-86 (39.46 per cent in) and Sakthi x Hawaii-7998 (33.60 per cent). Standard heterosis was found maximum in the cross LE-1-2 x H-24 (23.58 per cent) followed by Anagha x H-86 (18.71 per cent) and Sakthi x Hawaii-7998 (6.92 per cent) for total sugars per cent (Table-21).

**4.3.4.12 Reducing sugars**

LE-626 x IIHR-2196 (2.72 per cent) (Table-22) has the highest per cent of reducing sugars among the hybrids and parents tested. Maximum heterobeltiosis was found in LE-626 x H-86 (70.03 per cent) followed by LE-626 x H-24 (68.01 per cent) and LE-626 x Hawaii-7998 (55.22 per cent). Maximum relative heterosis was observed in the cross LE-626 x H-24 (87.59 per cent) followed by 74.44 per cent in LE-626 x H-86 and 55.22 per cent in LE-626 x Hawaii-7998. Standard heterosis was found maximum in the cross LE-626 x IIHR-2196 (13.36 per cent) followed by Sakthi x LE-474 (10.23 per cent) and LE-626 x LE-474 (6.47 per cent) for reducing sugars per cent. The hybrid showing maximum negative heterobeltiosis, relative heterosis and standard heterosis was Sakthi x IIHR-2196 (-19.92 per cent, -12.43 per cent and -11.90 per cent respectively).

**4.3.4.13 Total soluble solids (TSS)**

Mukthi x IIHR-2196 (6.40 per cent) (Table -23) has the highest per cent of total soluble solids among the hybrids and parents tested. Maximum heterobeltiosis was observed in Mukthi x IIHR-2196 (5.79 per cent) followed by Mukthi x H-24 (4.13 per cent in). Maximum relative heterosis was found in Anagha x Hawaii-7998 (18.81 per cent) followed by Mukthi x IIHR-2196 (12.28 per cent) and Mukthi x H-24 (12.00 per cent). Standard heterosis was found maximum in Mukthi x IIHR-2196 (5.44 per cent) followed by Mukthi x H-24 (3.79 per cent) for total soluble solids (TSS) per cent. LE-1-2 x LE-640 combination showed negative heterobeltiosis,

Table-21 Mean performance of parental lines and heterosis of $F_1$ hybrids for Total sugars per cent in tomato

| Parents/Hybrids | Total sugars per cent | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 2.66 | | | |
| Sakthi | 2.38 | | | |
| Mukthi | 3.18 | | | |
| LE-1-2 | 2.97 | | | |
| LE-626 | 2.57 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 3.16 | | | |
| IIHR-2196 | 2.49 | | | |
| H-24 | 2.95 | | | |
| H-86 | 2.41 | | | |
| Hawaii-7998 | 2.71 | | | |
| LE-474 | 3.36 | | | |
| LE-640 | 3.28 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 2.55 | -19.30** | -12.37** | -19.81** |
| Anagha x IIHR-2196 | 2.28 | -14.47** | -11.65** | -28.46** |
| Anagha x H-24 | 1.99 | -32.54** | -29.06** | -37.42** |
| Anagha x H-86 | 3.78 | 41.92** | 48.92** | 18.71** |
| Anagha x H-7998 | 2.88 | 6.27** | 7.26** | -9.43** |
| Anagha x LE-474 | 2.99 | -11.01** | -0.66 | -5.97** |
| Anagha x LE-640 | 2.57 | -21.53** | -13.40** | -19.18** |
| | | | | |
| Sakthi x IIHR-2195 | 3.19 | 0.95** | 15.16** | 0.31** |
| Sakthi x IIHR-2196 | 2.29 | -8.23** | -6.16** | -28.14** |
| Sakthi x H-24 | 3.38 | 14.58** | 26.83** | 6.29** |
| Sakthi x H-86 | 3.34 | 38.59** | 39.46** | 5.03** |
| Sakthi x H-7998 | 3.40 | 25.46** | 33.60** | 6.92** |
| Sakthi x LE-474 | 2.57 | -23.51** | -10.45** | -19.18** |
| Sakthi x LE-640 | 2.63 | -19.69** | -6.98** | -17.30** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-21 Contd.

| Parents/Hybrids | Total sugars per cent | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 3.11 | -2.20** | -1.89** | -2.20** |
| Mukthi x IIHR-2196 | 2.82 | -11.32** | -0.53** | -11.32** |
| Mukthi x H-24 | 2.49 | -21.70** | -18.76** | -21.70** |
| Mukthi x H-86 | 2.68 | -15.72** | -4.11** | -15.72** |
| Mukthi x H-7998 | 2.37 | -25.47** | -19.52** | -25.47** |
| Mukthi x LE-474 | 3.08 | -8.33** | -5.81** | -3.14** |
| Mukthi x LE-640 | 3.04 | -7.18** | -5.81** | -4.40** |
| | | | | |
| LE-1-2 x IIHR-2195 | 3.35 | 6.01** | 9.30** | 5.35** |
| LE-1-2 x IIHR-2196 | 2.33 | -21.55** | -14.65** | -26.73** |
| LE-1-2 x H-24 | 3.93 | 32.32** | 32.77** | 23.58** |
| LE-1-2 x H-86 | 2.89 | -2.69** | 7.43** | -9.12** |
| LE-1-2 x H-7998 | 3.07 | 3.37** | 8.10** | -3.46** |
| LE-1-2 x LE-474 | 3.05 | -9.23** | -3.63** | -4.09** |
| LE-1-2 x LE-640 | 2.60 | -20.61** | -16.73** | -18.24** |
| | | | | |
| LE-626 x IIHR-2195 | 3.10 | -1.90** | 8.20** | -2.52** |
| LE-626 x IIHR-2196 | 3.08 | 19.84** | 21.74** | -3.14** |
| LE-626 x H-24 | 3.19 | 8.14** | 15.58** | 0.31** |
| LE-626 x H-86 | 3.16 | 22.96** | 26.91** | -0.63** |
| LE-626 x H-7998 | 3.20 | 18.08** | 21.21** | 0.63** |
| LE-626 x LE-474 | 3.14 | -6.55** | 5.90** | -1.26** |
| LE-626 x LE-640 | 3.04 | -7.18** | 4.02** | -4.40** |
| SEm | | 0.09 | 0.08 | 0.09 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-22 Mean performance of parental lines and heterosis of $F_1$ hybrids for Reducing sugars per cent in tomato

| Parents/Hybrids | Reducing sugars per cent | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 2.40 | | | |
| Sakthi | 2.64 | | | |
| Mukthi | 2.40 | | | |
| LE-1-2 | 2.11 | | | |
| LE-626 | 1.49 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 2.07 | | | |
| IIHR-2196 | 2.19 | | | |
| H-24 | 1.18 | | | |
| H-86 | 1.41 | | | |
| Hawaii-7998 | 1.17 | | | |
| LE-474 | 1.74 | | | |
| LE-640 | 2.11 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 2.13 | -11.27** | -4.82** | -11.27** |
| Anagha x IIHR-2196 | 2.12 | -11.69** | -7.64** | -11.69** |
| Anagha x H-24 | 2.16 | -9.81** | 21.01** | -9.81** |
| Anagha x H-86 | 2.14 | -10.86** | 12.22** | -10.86** |
| Anagha x H-7998 | 2.28 | -5.01** | 27.81** | -5.01** |
| Anagha x LE-474 | 2.24 | -6.68** | 8.23** | -6.68** |
| Anagha x LE-640 | 2.45 | 2.30** | 8.89** | 2.30** |
| | | | | |
| Sakthi x IIHR-2195 | 2.14 | -18.79** | -9.03** | -10.65** |
| Sakthi x IIHR-2196 | 2.11 | -19.92** | -12.43** | -11.90** |
| Sakthi x H-24 | 2.38 | -9.68** | 24.93** | -0.63** |
| Sakthi x H-86 | 2.19 | -16.89** | 8.28** | -8.56** |
| Sakthi x H-7998 | 2.14 | -18.98** | 12.37** | -10.86** |
| Sakthi x LE-474 | 2.64 | 0.19 | 20.82** | 10.23** |
| Sakthi x LE-640 | 2.19 | -17.08** | -7.81** | -8.77** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-22 Contd.

| Parents/Hybrids | Reducing sugars per cent | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 2.12 | -11.69** | -5.26** | -11.69** |
| Mukthi x IIHR-2196 | 2.21 | -7.72** | -3.49** | -7.72** |
| Mukthi x H-24 | 2.21 | -7.93** | 23.53** | -7.93** |
| Mukthi x H-86 | 2.28 | -5.01** | 19.58** | -5.01** |
| Mukthi x H-7998 | 2.08 | -13.36** | 16.57** | -13.36** |
| Mukthi x LE-474 | 2.17 | -9.60** | 4.84** | -9.60** |
| Mukthi x LE-640 | 2.20 | -8.14** | -2.22** | -8.14** |
| | | | | |
| LE-1-2 x IIHR-2195 | 2.52 | 19.19** | 20.33** | 5.01** |
| LE-1-2 x IIHR-2196 | 2.10 | -0.47* | -2.21** | -12.32** |
| LE-1-2 x H-24 | 2.33 | 10.19** | 41.55** | -2.92** |
| LE-1-2 x H-86 | 2.09 | -1.18** | 18.47** | -12.94** |
| LE-1-2 x H-7998 | 2.15 | 1.66** | 30.99** | -10.44** |
| LE-1-2 x LE-474 | 2.05 | 3.08** | 6.37** | -14.61** |
| LE-1-2 x LE-640 | 2.25 | 6.64** | 6.76** | -6.05** |
| | | | | |
| LE-626 x IIHR-2195 | 2.51 | 21.01** | 40.93** | 4.59** |
| LE-626 x IIHR-2196 | 2.72 | 24.26** | 47.96** | 13.36** |
| LE-626 x H-24 | 2.50 | 68.01** | 87.59** | 4.18** |
| LE-626 x H-86 | 2.53 | 70.03** | 74.44** | 5.43** |
| LE-626 x H-7998 | 2.31 | 55.22** | 73.96** | -3.76** |
| LE-626 x LE-474 | 2.55 | 46.97** | 58.39** | 6.47** |
| LE-626 x LE-640 | 2.28 | 8.31** | 27.02** | -4.80** |
| SEm | | 0.19 | 0.16 | 0.19 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-23 Mean performance of parental lines and heterosis of $F_1$ hybrids for Total soluble solids per cent in tomato

| Parents/Hybrids | Total soluble solids per cent | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 6.12 | | | |
| Sakthi | 6.16 | | | |
| Mukthi | 6.07 | | | |
| LE-1-2 | 6.14 | | | |
| LE-626 | 5.38 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 5.20 | | | |
| IIHR-2196 | 5.36 | | | |
| H-24 | 5.21 | | | |
| H-86 | 4.82 | | | |
| Hawaii-7998 | 4.02 | | | |
| LE-474 | 5.59 | | | |
| LE-640 | 5.50 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 5.65 | -7.38** | 0.00 | -6.92** |
| Anagha x IIHR-2196 | 5.25 | -13.93** | -8.30** | -13.51** |
| Anagha x H-24 | 5.40 | -11.48** | -4.42** | -11.04** |
| Anagha x H-86 | 5.20 | -14.75** | -4.59** | -14.33** |
| Anagha x H-7998 | 6.00 | -1.64** | 18.81** | -1.15** |
| Anagha x LE-474 | 5.45 | -10.66** | -6.84** | -10.21** |
| Anagha x LE-640 | 5.20 | -14.75** | -10.34** | -14.33** |
| | | | | |
| Sakthi x IIHR-2195 | 5.75 | -6.50** | 1.32** | -5.27** |
| Sakthi x IIHR-2196 | 5.55 | -9.76** | -3.48** | -8.57** |
| Sakthi x H-24 | 5.00 | -18.70** | -11.89** | -17.63** |
| Sakthi x H-86 | 5.30 | -13.82** | -3.20** | -12.69** |
| Sakthi x H-7998 | 5.65 | -8.13** | 11.33** | -6.92** |
| Sakthi x LE-474 | 4.65 | -24.39** | -20.85** | -23.39** |
| Sakthi x LE-640 | 5.05 | -17.89** | -13.30** | -16.80** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-23 Contd.

| Parents/Hybrids | Total soluble solids per cent | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 5.80 | -4.13** | 3.11** | -4.45** |
| Mukthi x IIHR-2196 | 6.40 | 5.79** | 12.28** | 5.44** |
| Mukthi x H-24 | 6.30 | 4.13** | 12.00** | 3.79** |
| Mukthi x H-86 | 5.50 | -9.09** | 1.38** | -9.39** |
| Mukthi x H-7998 | 5.50 | -9.09** | 9.45** | -9.39** |
| Mukthi x LE-474 | 5.50 | -9.09** | -5.58** | -9.39** |
| Mukthi x LE-640 | 5.30 | -12.40** | -8.23** | -12.69** |
| | | | | |
| LE-1-2 x IIHR-2195 | 4.50 | -26.03** | -20.70** | -25.86** |
| LE-1-2 x IIHR-2196 | 4.80 | -21.95** | -16.52** | -20.92** |
| LE-1-2 x H-24 | 5.25 | -14.63** | -7.49** | -13.51** |
| LE-1-2 x H-86 | 5.35 | -13.01** | -2.28** | -11.86** |
| LE-1-2 x H-7998 | 4.55 | -26.02** | -10.34** | -25.04** |
| LE-1-2 x LE-474 | 4.70 | -23.58** | -20.00** | -22.57** |
| LE-1-2 x LE-640 | 3.90 | -36.59** | -33.05** | -35.75** |
| | | | | |
| LE-626 x IIHR-2195 | 4.90 | -9.26** | -7.55** | -19.28** |
| LE-626 x IIHR-2196 | 3.80 | -29.63** | -29.30** | -37.40** |
| LE-626 x H-24 | 4.65 | -13.89** | -12.26** | -23.39** |
| LE-626 x H-86 | 4.45 | -17.59** | -12.75** | -26.69** |
| LE-626 x H-7998 | 4.20 | -22.22** | -10.64** | -30.81** |
| LE-626 x LE-474 | 4.50 | -19.64** | -18.18** | -25.86** |
| LE-626 x LE-640 | 5.00 | -9.09** | -8.26** | -17.63** |
| SEm | | 0.39 | 0.34 | 0.39 |

** Significant at 1 per cent level

* Significant at 5 per cent level

relative heterosis and standard heterosis (-36.59, -33.05 and -35.75 per cent respectively).

#### 4.3.4.14 Shelf life

IIHR-2196 had the maximum shelf life (24.47 days) (Table-24) among the parents. Among the hybrids Mukthi x H-86 has the maximum shelf life (28.28 days) followed by LE-1-2 x Hawaii-7998 (25.99 days) and Mukthi x H-24 (25.89 days). Maximum heterobeltiosis was found in LE-1-2 x Hawaii-7998 (107.55 per cent) followed by LE-1-2 x LE-474 (79.66 per cent) and LE-626 x LE-474 (74.55 per cent). Maximum relative heterosis was observed in the cross LE-1-2 x Hawaii-7998 (122.14 per cent) followed by LE-1-2 x LE-474 (101.53 per cent) and LE-626 x LE-474 (82.05 per cent). Standard heterosis was found maximum in the cross Mukthi x H-86 (75.84 per cent) followed by Mukthi x LE-640 (62.25 per cent) (Plate-25a and 25b) and LE-1-2 x Hawaii-7998 (61.60 per cent) for shelf life. The Heterobeltiosis, relative heterosis and standard heterosis were positive and significant.

#### 4.3.4.15 Fruit shape index

Maximum heterobeltiosis was found in Sakthi x H-86 (15.68 per cent) followed by LE-626 x Hawaii-7998 (9.66 per cent) and LE-626 x IIHR-2196 (8.70 per cent). Maximum relative heterosis was observed in the cross LE-626 x IIHR-2196 (15.09 per cent) followed by the hybrid Sakthi x H-86 (14.13 per cent) and LE-626 x Hawaii-7998 (13.78 per cent). Standard heterosis was found maximum in the cross Anagha x H-24 (21.90 per cent) followed by LE-626 x Hawaii-7998 (21.83 per cent) and LE-626 x IIHR-2196 (20.35 per cent) for fruit shape index. Minimum negative heterobeltiosis, relative heterosis and standard heterosis for fruit shape index were observed in Anagha x Hawaii-7998 (-27.40 per cent, -22.63 per cent and -15.07 per cent respectively) (Table-25).

Table-24 Mean performance of parental lines and heterosis of $F_1$ hybrids for Storage life in days in tomato

| Parents/Hybrids | Storage life in days | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 15.99 | | | |
| Sakthi | 18.71 | | | |
| Mukthi | 16.08 | | | |
| LE-1-2 | 10.88 | | | |
| LE-626 | 12.75 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 22.23 | | | |
| IIHR-2196 | 24.47 | | | |
| H-24 | 16.59 | | | |
| H-86 | 16.77 | | | |
| Hawaii-7998 | 12.52 | | | |
| LE-474 | 13.89 | | | |
| LE-640 | 16.26 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 15.38 | -30.84** | -19.53** | -4.38** |
| Anagha x IIHR-2196 | 16.49 | -32.60** | -18.47** | 2.55 |
| Anagha x H-24 | 16.38 | -1.30 | 0.54 | 1.83 |
| Anagha x H-86 | 18.49 | 10.23** | 12.87** | 14.96** |
| Anagha x H-7998 | 17.82 | 11.48** | 25.03** | 10.82** |
| Anagha x LE-474 | 17.05 | 6.66** | 14.14** | 6.03** |
| Anagha x LE-640 | 16.99 | 4.46** | 5.35** | 5.63** |
| | | | | |
| Sakthi x IIHR-2195 | 21.22 | -4.45** | 3.68** | 31.97** |
| Sakthi x IIHR-2196 | 22.24 | -9.12** | 3.01* | 38.28** |
| Sakthi x H-24 | 15.02 | -19.70** | -14.89** | -6.59** |
| Sakthi x H-86 | 14.92 | -20.24** | -15.88** | -7.21** |
| Sakthi x H-7998 | 13.95 | -25.45** | -10.68** | -13.28** |
| Sakthi x LE-474 | 15.64 | -16.39** | -4.03** | -2.74 |
| Sakthi x LE-640 | 20.24 | 8.18** | 15.74** | 25.84** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-24 Contd.

| Parents/Hybrids | Storage life in days | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 20.16 | -9.33** | 5.22** | 25.34** |
| Mukthi x IIHR-2196 | 22.17 | -9.38** | 9.36** | 37.87** |
| Mukthi x H-24 | 25.89 | 56.06** | 58.49** | 61.01** |
| Mukthi x H-86 | 28.28 | 68.60** | 72.15** | 75.84** |
| Mukthi x H-7998 | 19.69 | 22.45** | 37.69** | 22.45** |
| Mukthi x LE-474 | 24.76 | 53.98** | 65.23** | 53.98** |
| Mukthi x LE-640 | 26.09 | 60.46** | 61.35** | 62.25** |
| | | | | |
| LE-1-2 x IIHR-2195 | 21.11 | -5.06** | 27.50** | 31.25** |
| LE-1-2 x IIHR-2196 | 19.34 | -20.97** | 9.42** | 20.24** |
| LE-1-2 x H-24 | 21.14 | 27.43** | 53.94** | 31.47** |
| LE-1-2 x H-86 | 20.71 | 23.46** | 49.79** | 28.76** |
| LE-1-2 x H-7998 | 25.99 | 107.55** | 122.14** | 61.60** |
| LE-1-2 x LE-474 | 24.96 | 79.66** | 101.53** | 55.19** |
| LE-1-2 x LE-640 | 18.94 | 16.48** | 39.60** | 17.79** |
| | | | | |
| LE-626 x IIHR-2195 | 20.10 | -9.60** | 14.91** | 24.97** |
| LE-626 x IIHR-2196 | 22.86 | -6.56** | 22.87** | 42.16** |
| LE-626 x H-24 | 20.65 | 24.47** | 40.79** | 28.42** |
| LE-626 x H-86 | 20.14 | 20.07** | 36.44** | 25.22** |
| LE-626 x H-7998 | 21.27 | 66.89** | 68.38** | 32.28** |
| LE-626 x LE-474 | 24.25 | 74.55** | 82.05** | 50.78** |
| LE-626 x LE-640 | 22.62 | 39.11** | 55.97** | 40.67** |
| SEm | | 1.44 | 1.25 | 1.44 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-25 Mean performance of parental lines and heterosis of $F_1$ hybrids for Fruit shape index in tomato

| Parents/Hybrids | Fruit shape index | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 1.09 | | | |
| Sakthi | 0.93 | | | |
| Mukthi | 0.93 | | | |
| LE-1-2 | 1.13 | | | |
| LE-626 | 1.04 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 0.94 | | | |
| IIHR-2196 | 0.92 | | | |
| H-24 | 1.18 | | | |
| H-86 | 0.95 | | | |
| Hawaii-7998 | 0.96 | | | |
| LE-474 | 1.12 | | | |
| LE-640 | 1.05 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 0.82 | -25.11** | -19.21** | -12.07** |
| Anagha x IIHR-2196 | 0.90 | -17.81** | -10.67** | -3.58** |
| Anagha x H-24 | 1.14 | -2.98** | 0.44** | 21.90** |
| Anagha x H-86 | 0.92 | -16.44** | -10.51** | -1.86** |
| Anagha x H-7998 | 0.79 | -27.40** | -22.63** | -15.07** |
| Anagha x LE-474 | 1.00 | -11.11** | -9.91** | 7.21** |
| Anagha x LE-640 | 0.84 | -23.29** | -21.68** | -9.88** |
| | | | | |
| Sakthi x IIHR-2195 | 0.91 | -1.62** | -2.15** | -2.38** |
| Sakthi x IIHR-2196 | 0.84 | -9.19** | -8.94** | -9.76** |
| Sakthi x H-24 | 0.82 | -30.21** | -21.90** | -12.11** |
| Sakthi x H-86 | 1.07 | 15.68** | 14.13** | 14.53** |
| Sakthi x H-7998 | 0.82 | -15.10** | -13.53** | -12.57** |
| Sakthi x LE-474 | 0.88 | -21.78** | -14.15** | -5.72** |
| Sakthi x LE-640 | 0.89 | -15.24** | -9.87** | -4.89** |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-25 Contd.

| Parents/Hybrids | Fruit shape index | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 0.84 | -10.70** | -10.70** | -10.50** |
| Mukthi x IIHR-2196 | 0.93 | -0.53** | 0.27** | -0.34** |
| Mukthi x H-24 | 0.93 | -20.85** | -11.85** | -0.31** |
| Mukthi x H-86 | 0.94 | -1.05** | -0.27** | 0.86** |
| Mukthi x H-7998 | 0.93 | -2.60** | 1.32** | -0.08 |
| Mukthi x LE-474 | 1.07 | -4.29** | 3.88** | 14.49** |
| Mukthi x LE-640 | 0.96 | -8.10** | -2.77** | 3.24** |
| | | | | |
| LE-1-2 x IIHR-2195 | 0.94 | -16.81** | -8.96** | 0.73** |
| LE-1-2 x IIHR-2196 | 0.95 | -15.93** | -7.32** | 1.79** |
| LE-1-2 x H-24 | 1.07 | -8.51** | -6.72** | 15.14** |
| LE-1-2 x H-86 | 1.09 | -3.98** | 4.33** | 16.35** |
| LE-1-2 x H-7998 | 0.93 | -17.26** | -10.53** | 0.08 |
| LE-1-2 x LE-474 | 1.08 | -4.87** | -4.66** | 15.38** |
| LE-1-2 x LE-640 | 1.07 | -5.75** | -2.29** | 14.27** |
| | | | | |
| LE-626 x IIHR-2195 | 1.00 | -3.38** | 1.52** | 7.39** |
| LE-626 x IIHR-2196 | 1.12 | 8.70** | 15.09** | 20.35** |
| LE-626 x H-24 | 1.08 | -8.09** | -2.26** | 15.55** |
| LE-626 x H-86 | 0.89 | -13.53** | -9.82** | -4.13** |
| LE-626 x H-7998 | 1.14 | 9.66** | 13.78** | 21.83** |
| LE-626 x LE-474 | 1.06 | -6.22** | -2.31** | 13.14** |
| LE-626 x LE-640 | 0.94 | -10.48** | -9.83** | 0.67** |
| SEm | | 0.04 | 0.04 | 0.04 |

** Significant at 1 per cent level

* Significant at 5 per cent level

#### 4.3.4.16 Fruit cracking

No fruit cracking was observed in the parents Anagha, Mukthi, IIHR-2195, IIHR-2196, H-24, H-86 and Hawaii-7998 where it was observed in the remaining parents LE-640 (1.70 per cent), LE-474 (2.45 per cent), LE-626 (3.25 per cent) Sakthi (4.65 per cent) and LE-1-2 (40 per cent) (Table-26). Among the 35 hybrids no fruit cracking was observed in 27 hybrids. While standard heterosis was not observed in all 35 hybrids. Heterobeltiosis and relative heterosis were negative, significant and maximum for fruit cracking in hybrid LE-626 x H-24 (-100.00 per cent and -100.00 per cent respectively) (Plate-26a and 26b) followed by LE-1-2 x H-7998 (-100.00 per cent and -100.00 per cent respectively) and LE-1-2 x LE-640 (-96.40 per cent and -93.10 per cent respectively) (Plate-27a and 27b)

### 4.4 Evaluation of $F_2$ progenies for combined resistance to bacterial wilt and ToLCV disease

Among the $F_2$ segregants Mukthi x IIHR-2195-$F_2$-24, Mukthi x IIHR-2195- $F_2$-25, Mukthi x IIHR-2195- $F_2$-31, Mukthi x IIHR-2195- $F_2$-34, Mukthi x IIHR-2195- $F_2$-36, Mukthi x IIHR-2195- $F_2$-38, Mukthi x IIHR-2195- $F_2$-40, Mukthi x IIHR-2195- $F_2$-41, Mukthi x IIHR-2195-F2-47, Mukthi x IIHR-2195- $F_2$-54, Mukthi x IIHR-2195- $F_2$-58, Mukthi x IIHR-2196- $F_2$-16, Mukthi x IIHR-2196- $F_2$-43, Mukthi x IIHR-2196- $F_2$-45, Mukthi x IIHR-2196- $F_2$-57, Mukthi x IIHR-2196- $F_2$-66, Mukthi x IIHR-2196- $F_2$-71, Mukthi x IIHR-2196- $F_2$-72, Mukthi x IIHR-2196- $F_2$-73, Mukthi x IIHR-2196- $F_2$-78, Mukthi x IIHR-2196- $F_2$-80, Mukthi x H-24-$F_2$-10, Mukthi x H-86- $F_2$-32, Sakthi x IIHR-2195- $F_2$-58, Sakthi x IIHR-2196- $F_2$-6, Sakthi x IIHR-2196- $F_2$-18, Sakthi x IIHR-2196- $F_2$-20, Sakthi x H-86- $F_2$-75, Sakthi x Hawaii-7998- $F_2$-81 and Sakthi x Hawaii-7998- $F_2$-91 were found promising and resistant to both ToLCV and bacterial wilt (Table-34) (Plate-28-48).

Table-26 Mean performance of parental lines and heterosis of $F_1$ hybrids for Fruit cracking per cent in tomato

| Parents/Hybrids | Fruit cracking per cent | | | |
|---|---|---|---|---|
| | Mean | HB % | RH % | SH% |
| **LINES** | | | | |
| Anagha | 0.00 | | | |
| Sakthi | 4.65 | | | |
| Mukthi | 0.00 | | | |
| LE-1-2 | 40.00 | | | |
| LE-626 | 3.25 | | | |
| **TESTERS** | | | | |
| IIHR-2195 | 0.00 | | | |
| IIHR-2196 | 0.00 | | | |
| H-24 | 0.00 | | | |
| H-86 | 0.00 | | | |
| Hawaii-7998 | 0.00 | | | |
| LE-474 | 2.45 | | | |
| LE-640 | 1.70 | | | |
| **HYBRIDS** | | | | |
| Anagha x IIHR-2195 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anagha x IIHR-2196 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anagha x H-24 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anagha x H-86 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anagha x H-7998 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anagha x LE-474 | 0.00 | 0.00 | -100.00** | 0.00 |
| Anagha x LE-640 | 0.00 | 0.00 | -100.00** | 0.00 |
| | | | | |
| Sakthi x IIHR-2195 | 0.00 | -100.00** | -100.00** | 0.00 |
| Sakthi x IIHR-2196 | 0.00 | -100.00** | -100.00** | 0.00 |
| Sakthi x H-24 | 0.00 | -100.00** | -100.00** | 0.00 |
| Sakthi x H-86 | 0.00 | -100.00** | -100.00** | 0.00 |
| Sakthi x H-7998 | 0.00 | 100.00** | -100.00** | 0.00 |
| Sakthi x LE-474 | 0.00 | -100.00** | -100.00** | 0.00 |
| Sakthi x LE-640 | 2.03 | -56.34** | -36.06** | 0.00 |

** Significant at 1 per cent level

* Significant at 5 per cent level

Table-26 Contd.

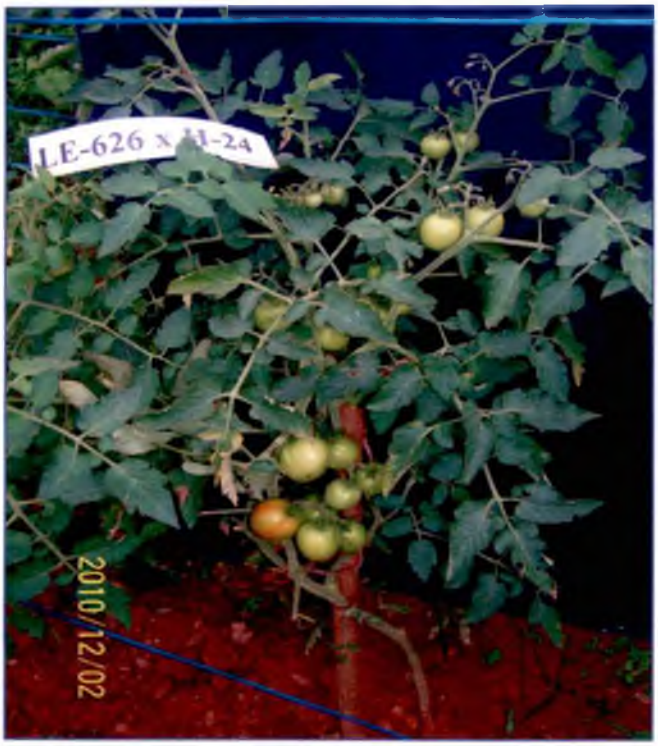
| Parents/Hybrids | Fruit cracking per cent | | | |
|---|---|---|---|---|
| **Hybrids** | Mean | HB % | RH % | SH% |
| Mukthi x IIHR-2195 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mukthi x IIHR-2196 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mukthi x H-24 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mukthi x H-86 | 2.74 | 0.00 | 0.00 | 0.00 |
| Mukthi x H-7998 | 0.83 | 0.00 | 0.00 | 0.00 |
| Mukthi x LE-474 | 4.04 | 65.10** | 230.20** | 0.00 |
| Mukthi x LE-640 | 2.43 | 42.94** | 185.88** | 0.00 |
| | | | | |
| LE-1-2 x IIHR-2195 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-1-2 x IIHR-2196 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-1-2 x H-24 | 0.87 | -97.80** | -95.59** | 0.00 |
| LE-1-2 x H-86 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-1-2 x H-7998 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-1-2 x LE-474 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-1-2 x LE-640 | 1.42 | -96.40** | -93.10** | 0.00 |
| | | | | |
| LE-626 x IIHR-2195 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x IIHR-2196 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x H-24 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x H-86 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x H-7998 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x LE-474 | 0.00 | -100.00** | -100.00** | 0.00 |
| LE-626 x LE-640 | 8.27 | 154.46** | 234.14** | 0.00 |
| SEm | | 0.85 | 0.73 | 0.73 |

** Significant at 1 per cent level

* Significant at 5 per cent level


Mukthi x LE-640
2010/12/03


Mukthi x LE-640


LE-626 x H-24
2010/12/02


LE-1-2 x LE-640


LE-626 x H-24
2010/12/03


LE-1-2 x LE-640
2010/12/03


2011/04/07
Mukthi x IIHR-2195-F2-47


2011/04/13
Mukthi x IIHR-2195-F2-34


Mukthi x IIHR-2195-F2-54
2011/04/07


Mukthi x IIHR-2195-F2-41


2011/04/13
Mukthi x IIHR-2195-F2-24


2011/04/13
Mukthi x IIHR-2195-F2-38


Mukthi x IIHR-2195-$F_2$-31


Mukthi x IIHR-2196-$F_2$-16

Mukthi x IIHR-2196-$F_2$-43


Mukthi x IIHR-2196-$F_2$-57


Mukthi x IIHR-2196-F2-66


Mukthi x IIHR-2196-$F_2$-72


Mukthi x IIHR-2196-$F_2$-73


Mukthi x IIHR-2196-$F_2$-80

Mukthi x IIHR-2196-F2-78

Mukkthi x H-86-$F_2$-32


Sakthi x IIHR-2195-F2-58


Sakthi x IIHR-2196-F2-18


Sakthi x IIHR-2196-F2-20


Sakthi x H-86-F2-75


Sakthi x Hawaii-7998-F2-81
2011/04/14

### 4.4.1 Plant height

Plant height ranged from 32.50 cm to 98.50 cm (Table-27) in the $F_2$ progenies. Maximum height was recorded in the $F_2$ progenies of Anagha x Hawaii-7998 (98.50 cm) followed by Mukthi x H-86 (97.80 cm) and the minimum was observed in the $F_2$ progenies of LE-1-2 x H-24 (30.10 cm) followed by LE-1-2 x IIHR-2195 (32.50 cm). Highest mean value for plant height was recorded in the hybrid Anagha x Hawaii-7998 (75.92 cm) followed by Anagha x IIHR-2196 (70.08 cm). Lowest mean value was observed in the hybrid LE-1-2 x IIHR-2195 (36.10 cm) followed by LE-1-2 x IIHR-2196 (37.40 cm).

### 4.4.2 Number of branches per plant

Number of branches per plant ranged from 9.00 to 38.00 (Table-28) in the $F_2$ progenies. Highest number of branches per plant was in $F_2$ progenies of Sakthi x IIHR-2196 (38.00) and LE-626 x IIHR-2195 (38.00) followed by Sakthi x H-24 (37.00), Sakthi x H-86 (37.00), Mukthi x Hawaii-7998 (37.00) and LE-626 x IIHR-2196 (37.00). Lowest number of branches per plant was produced by $F_2$ progenies of Anagha x IIHR-2195 (9.00) followed by Anagha x H-24 (10.00). Highest mean value for number of branches per plant was recorded in the hybrid Sakthi x Hawaii-7998 (26.92) followed by Sakthi x IIHR-2196 (26.60). Lowest mean value was observed in the hybrid Anagha x IIHR-2196 (19.20) followed by Anagha x IIHR-2195 (20.40).

### 4.4.3 Days to flowering

Days to flowering in the $F_2$ progenies ranged from 40 to 70 days. The $F_2$ progenies of Anagha x IIHR-2195 were the earliest to flower (40.00 days) followed by Anagha x IIHR-2196 $F_2$ progenies (41 days). The lowest mean value was recorded by Anagha x IIHR-2195 (42.32 days) followed by Mukthi x IIHR-2196 (42.48 days). Highest mean value for days to

Table-27 Mean performance of $F_2$ progenies for plant height (cm)

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 36.20 | 51.60 | 87.80 | 65.32 | 2.40 |
| Anagha x IIHR-2196 | 35.30 | 56.20 | 91.50 | 70.08 | 2.26 |
| Anagha x H-24 | 7.20 | 52.40 | 59.60 | 56.00 | 0.44 |
| Anagha x H-86 | 36.50 | 51.30 | 87.80 | 63.81 | 2.56 |
| Anagha x H-7998 | 44.50 | 54.00 | 98.50 | 75.92 | 2.81 |
| Anagha x LE-474 | 20.40 | 49.40 | 69.80 | 55.24 | 1.44 |
| Anagha x LE-640 | 11.20 | 49.40 | 60.60 | 55.84 | 0.77 |
| | | | | | |
| Sakthi x IIHR-2195 | 7.20 | 60.80 | 68.00 | 64.40 | 0.44 |
| Sakthi x IIHR-2196 | 11.10 | 49.40 | 60.50 | 51.84 | 0.65 |
| Sakthi x H-24 | 36.50 | 51.30 | 87.80 | 60.56 | 2.37 |
| Sakthi x H-86 | 33.80 | 51.80 | 85.60 | 61.76 | 1.89 |
| Sakthi x H-7998 | 28.60 | 49.80 | 78.40 | 62.43 | 1.60 |
| Sakthi x LE-474 | 20.40 | 49.40 | 69.80 | 55.24 | 1.44 |
| Sakthi x LE-640 | 20.40 | 52.70 | 73.10 | 58.54 | 1.44 |
| | | | | | |
| Mukthi x IIHR-2195 | 20.40 | 52.70 | 73.10 | 58.54 | 1.44 |
| Mukthi x IIHR-2196 | 24.90 | 51.50 | 76.40 | 59.92 | 1.73 |
| Mukthi x H-24 | 27.10 | 51.80 | 78.90 | 60.73 | 1.53 |
| Mukthi x H-86 | 42.70 | 55.10 | 97.80 | 67.23 | 3.05 |
| Mukthi x H-7998 | 17.70 | 54.10 | 71.80 | 63.34 | 1.39 |
| Mukthi x LE-474 | 19.80 | 53.30 | 73.10 | 60.71 | 1.19 |
| Mukthi x LE-640 | 21.30 | 55.10 | 76.40 | 66.34 | 1.24 |

Table-27 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 7.20 | 33.80 | 41.00 | 37.40 | 0.44 |
| LE-1-2 x H-24 | 35.70 | 30.10 | 65.80 | 43.50 | 2.55 |
| LE-1-2 x H-86 | 22.50 | 51.00 | 73.50 | 59.23 | 1.27 |
| LE-1-2 x H-7998 | 20.40 | 49.40 | 69.80 | 56.70 | 1.30 |
| LE-1-2 x LE-474 | 26.90 | 51.00 | 77.90 | 57.76 | 1.25 |
| LE-1-2 x LE-640 | 20.00 | 53.50 | 73.50 | 64.51 | 1.01 |
| | | | | | |
| LE-626 x IIHR-2195 | 10.50 | 57.50 | 68.00 | 61.44 | 0.60 |
| LE-626 x IIHR-2196 | 12.70 | 50.90 | 63.60 | 55.86 | 0.90 |
| LE-626 x H-24 | 24.10 | 53.20 | 77.30 | 60.64 | 1.35 |
| LE-626 x H-86 | 37.20 | 54.50 | 91.70 | 64.49 | 2.04 |
| LE-626 x H-7998 | 18.60 | 52.30 | 70.90 | 62.87 | 0.96 |
| LE-626 x LE-474 | 11.70 | 51.80 | 63.50 | 57.95 | 0.74 |
| LE-626 x LE-640 | 17.10 | 55.10 | 72.20 | 62.43 | 0.92 |

Table-28 Mean performance of $F_2$ progenies for Number of branches per plant

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 26.00 | 9.00 | 35.00 | 20.40 | 1.23 |
| Anagha x IIHR-2196 | 16.00 | 12.00 | 28.00 | 19.20 | 0.91 |
| Anagha x H-24 | 21.00 | 10.00 | 31.00 | 21.64 | 1.33 |
| Anagha x H-86 | 14.00 | 13.00 | 27.00 | 21.08 | 0.72 |
| Anagha x H-7998 | 18.00 | 18.00 | 36.00 | 26.12 | 1.07 |
| Anagha x LE-474 | 20.00 | 14.00 | 34.00 | 21.52 | 0.94 |
| Anagha x LE-640 | 17.00 | 19.00 | 36.00 | 25.44 | 0.98 |
| | | | | | |
| Sakthi x IIHR-2195 | 19.00 | 14.00 | 33.00 | 21.60 | 0.99 |
| Sakthi x IIHR-2196 | 18.00 | 20.00 | 38.00 | 26.60 | 0.97 |
| Sakthi x H-24 | 19.00 | 17.00 | 36.00 | 24.72 | 1.00 |
| Sakthi x H-86 | 22.00 | 15.00 | 37.00 | 24.36 | 1.00 |
| Sakthi x H-7998 | 19.00 | 18.00 | 37.00 | 26.92 | 1.04 |
| Sakthi x LE-474 | 18.00 | 18.00 | 36.00 | 23.68 | 0.88 |
| Sakthi x LE-640 | 20.00 | 16.00 | 36.00 | 24.56 | 1.04 |
| | | | | | |
| Mukthi x IIHR-2195 | 18.00 | 14.00 | 32.00 | 21.00 | 0.76 |
| Mukthi x IIHR-2196 | 17.00 | 19.00 | 36.00 | 25.52 | 0.99 |
| Mukthi x H-24 | 21.00 | 14.00 | 35.00 | 22.28 | 1.12 |
| Mukthi x H-86 | 17.00 | 19.00 | 36.00 | 24.36 | 0.90 |
| Mukthi x H-7998 | 18.00 | 19.00 | 37.00 | 25.08 | 0.97 |
| Mukthi x LE-474 | 19.00 | 17.00 | 36.00 | 25.24 | 1.02 |
| Mukthi x LE-640 | 19.00 | 14.00 | 33.00 | 21.68 | 0.79 |

Table-28 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 17.00 | 19.00 | 36.00 | 25.32 | 0.99 |
| LE-1-2 x H-24 | 18.00 | 14.00 | 32.00 | 20.84 | 0.79 |
| LE-1-2 x H-86 | 17.00 | 19.00 | 36.00 | 26.28 | 1.01 |
| LE-1-2 x H-7998 | 17.00 | 18.00 | 35.00 | 23.64 | 0.80 |
| LE-1-2 x LE-474 | 18.00 | 18.00 | 36.00 | 25.72 | 1.04 |
| LE-1-2 x LE-640 | 18.00 | 14.00 | 32.00 | 20.64 | 0.79 |
| | | | | | |
| LE-626 x IIHR-2195 | 18.00 | 20.00 | 38.00 | 26.00 | 0.89 |
| LE-626 x IIHR-2196 | 20.00 | 17.00 | 37.00 | 25.44 | 1.08 |
| LE-626 x H-24 | 21.00 | 15.00 | 36.00 | 23.08 | 0.84 |
| LE-626 x H-86 | 17.00 | 19.00 | 36.00 | 25.44 | 0.96 |
| LE-626 x H-7998 | 20.00 | 15.00 | 35.00 | 23.44 | 1.01 |
| LE-626 x LE-474 | 22.00 | 14.00 | 36.00 | 22.76 | 1.02 |
| LE-626 x LE-640 | 17.00 | 18.00 | 35.00 | 24.52 | 0.98 |

flowering was recorded by LE-626 x LE-640 (62.08 days) followed by LE-626 x H-86 (60.20 days) (Table-29).

### 4.4.4 Days to harvest

Days to harvest in the $F_2$ progenies ranged from 62 to 98 days. The $F_2$ progenies of Anagha x IIHR-2195 were the earliest to harvest (62.00 days) followed by Anagha x IIHR-2196 $F_2$ (64 days). LE-626 x LE-640 $F_2$ progenies took 98.00 days to harvest. The lowest mean value was recorded in Anagha x IIHR-2195 (71.32 days) followed by Mukthi x IIHR-2196 (72.80 days). Highest mean value for days to harvest was recorded by LE-626 x LE-640 (93.80 days) followed by LE-626 x H-86 (93.56 days) (Table-30).

### 4.4.5 Average fruit weight

The average fruit weight ranged from 20.30 g to 71.20 g in $F_2$ population (Table-31). $F_2$ progeny of Mukthi x IIHR-2196 produced fruits with maximum fruit weight (71.20 g) followed by LE-1-2 x LE-640 (59.40 g) and Mukthi x LE-640 (59.00 g). The minimum weight was in the $F_2$ progenies Anagha x IIHR-2195 (20.30 g) followed by Anagha x Hawaii-7998 (20.50 g). Highest mean value for average fruit weight was recorded by the $F_2$ progenies of LE-1-2 x LE-640 (43.32 g) followed by Mukthi x LE-640 (42.92 g). Lowest mean value for average fruit weight was recorded by the $F_2$ progenies of LE-626 x IIHR-2195 (35.62 g) followed by Sakthi x IIHR-2195 (35.98 g).

### 4.4.6 Number of fruits per plant

Number of fruits per plant ranged from 10.00 to 46.00 in $F_2$ population. The highest number of fruits was produced by $F_2$ population of Mukthi x H-24 (46.00 fruits/plant) followed by Mukthi x H-86 (44.00 fruits/plant) and Mukthi x IIHR-2195 (43.00 fruits/plant). Lowest number of fruits per plant

Table-29 Mean performance of $F_2$ progenies for days to flowering

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 25.00 | 40.00 | 58.00 | 42.32 | 1.39 |
| Anagha x IIHR-2196 | 27.00 | 41.00 | 62.00 | 46.04 | 1.55 |
| Anagha x H-24 | 6.00 | 51.00 | 57.00 | 54.24 | 0.28 |
| Anagha x H-86 | 6.00 | 52.00 | 58.00 | 54.92 | 0.29 |
| Anagha x H-7998 | 8.00 | 52.00 | 60.00 | 56.88 | 0.60 |
| Anagha x LE-474 | 8.00 | 53.00 | 61.00 | 58.40 | 0.51 |
| Anagha x LE-640 | 11.00 | 51.00 | 62.00 | 55.88 | 0.56 |
| | | | | | |
| Sakthi x IIHR-2195 | 11.00 | 51.00 | 62.00 | 55.88 | 0.56 |
| Sakthi x IIHR-2196 | 19.00 | 44.00 | 60.00 | 53.48 | 0.96 |
| Sakthi x H-24 | 25.00 | 45.00 | 60.00 | 43.80 | 1.30 |
| Sakthi x H-86 | 4.00 | 55.00 | 59.00 | 56.76 | 0.23 |
| Sakthi x H-7998 | 9.00 | 53.00 | 62.00 | 57.64 | 0.53 |
| Sakthi x LE-474 | 8.00 | 54.00 | 62.00 | 59.56 | 0.55 |
| Sakthi x LE-640 | 9.00 | 55.00 | 64.00 | 59.80 | 0.59 |
| | | | | | |
| Mukthi x IIHR-2195 | 20.00 | 49.00 | 59.00 | 51.84 | 1.37 |
| Mukthi x IIHR-2196 | 21.00 | 46.00 | 55.00 | 42.48 | 1.25 |
| Mukthi x H-24 | 19.00 | 44.00 | 63.00 | 54.16 | 0.86 |
| Mukthi x H-86 | 4.00 | 54.00 | 58.00 | 55.80 | 0.18 |
| Mukthi x H-7998 | 9.00 | 52.00 | 61.00 | 56.68 | 0.59 |
| Mukthi x LE-474 | 7.00 | 55.00 | 62.00 | 59.44 | 0.44 |
| Mukthi x LE-640 | 11.00 | 52.00 | 63.00 | 57.76 | 0.64 |

Table-29 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 23.00 | 47.00 | 57.00 | 44.40 | 1.28 |
| LE-1-2 x H-24 | 19.00 | 45.00 | 64.00 | 55.64 | 0.72 |
| LE-1-2 x H-86 | 4.00 | 53.00 | 57.00 | 55.92 | 0.25 |
| LE-1-2 x H-7998 | 8.00 | 53.00 | 61.00 | 57.80 | 0.58 |
| LE-1-2 x LE-474 | 8.00 | 55.00 | 63.00 | 59.80 | 0.50 |
| LE-1-2 x LE-640 | 11.00 | 53.00 | 64.00 | 58.28 | 0.64 |
| | | | | | |
| LE-626 x IIHR-2195 | 6.00 | 53.00 | 59.00 | 56.20 | 0.30 |
| LE-626 x IIHR-2196 | 7.00 | 54.00 | 61.00 | 57.12 | 0.33 |
| LE-626 x H-24 | 9.00 | 53.00 | 62.00 | 58.80 | 0.64 |
| LE-626 x H-86 | 8.00 | 55.00 | 63.00 | 60.20 | 0.49 |
| LE-626 x H-7998 | 11.00 | 53.00 | 64.00 | 57.36 | 0.56 |
| LE-626 x LE-474 | 12.00 | 52.00 | 64.00 | 57.28 | 0.63 |
| LE-626 x LE-640 | 15.00 | 55.00 | 70.00 | 62.08 | 0.87 |

Table-30 Mean performance of $F_2$ progenies for days to harvest

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 25.00 | 62.00 | 87.00 | 71.32 | 1.39 |
| Anagha x IIHR-2196 | 27.00 | 64.00 | 91.00 | 75.04 | 1.55 |
| Anagha x H-24 | 6.00 | 80.00 | 86.00 | 83.24 | 0.28 |
| Anagha x H-86 | 6.00 | 81.00 | 87.00 | 83.92 | 0.29 |
| Anagha x H-7998 | 8.00 | 81.00 | 89.00 | 85.88 | 0.60 |
| Anagha x LE-474 | 8.00 | 82.00 | 90.00 | 87.40 | 0.51 |
| Anagha x LE-640 | 11.00 | 80.00 | 91.00 | 84.88 | 0.56 |
| | | | | | |
| Sakthi x IIHR-2195 | 19.00 | 72.00 | 91.00 | 84.96 | 0.98 |
| Sakthi x IIHR-2196 | 25.00 | 66.00 | 91.00 | 75.16 | 1.30 |
| Sakthi x H-24 | 27.00 | 69.00 | 93.00 | 84.76 | 1.36 |
| Sakthi x H-86 | 4.00 | 86.00 | 90.00 | 88.04 | 0.23 |
| Sakthi x H-7998 | 8.00 | 85.00 | 93.00 | 89.00 | 0.54 |
| Sakthi x LE-474 | 8.00 | 86.00 | 94.00 | 91.28 | 0.55 |
| Sakthi x LE-640 | 9.00 | 87.00 | 96.00 | 91.56 | 0.59 |
| | | | | | |
| Mukthi x IIHR-2195 | 19.00 | 70.00 | 89.00 | 82.48 | 0.96 |
| Mukthi x IIHR-2196 | 25.00 | 64.00 | 89.00 | 72.80 | 1.30 |
| Mukthi x H-24 | 27.00 | 66.00 | 93.00 | 82.08 | 1.36 |
| Mukthi x H-86 | 4.00 | 84.00 | 88.00 | 85.76 | 0.23 |
| Mukthi x H-7998 | 9.00 | 82.00 | 91.00 | 86.64 | 0.53 |
| Mukthi x LE-474 | 8.00 | 83.00 | 91.00 | 88.56 | 0.55 |
| Mukthi x LE-640 | 9.00 | 84.00 | 93.00 | 88.80 | 0.59 |

Table-30 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2195 | 19.00 | 75.00 | 93.00 | 87.48 | 0.96 |
| LE-1-2 x IIHR-2196 | 25.00 | 69.00 | 93.00 | 77.80 | 1.30 |
| LE-1-2 x H-24 | 27.00 | 71.00 | 95.00 | 87.08 | 1.36 |
| LE-1-2 x H-86 | 4.00 | 89.00 | 93.00 | 90.76 | 0.23 |
| LE-1-2 x H-7998 | 9.00 | 87.00 | 93.00 | 91.64 | 0.53 |
| LE-1-2 x LE-474 | 8.00 | 88.00 | 93.00 | 89.56 | 0.55 |
| LE-1-2 x LE-640 | 9.00 | 89.00 | 95.00 | 89.80 | 0.59 |
| | | | | | |
| LE-626 x IIHR-2195 | 19.00 | 71.00 | 90.00 | 83.48 | 0.96 |
| LE-626 x IIHR-2196 | 25.00 | 65.00 | 90.00 | 73.80 | 1.30 |
| LE-626 x H-24 | 27.00 | 67.00 | 94.00 | 83.08 | 1.36 |
| LE-626 x H-86 | 4.00 | 85.00 | 89.00 | 86.76 | 0.23 |
| LE-626 x H-7998 | 9.00 | 83.00 | 94.00 | 87.64 | 0.53 |
| LE-626 x LE-474 | 8.00 | 84.00 | 94.00 | 93.56 | 0.55 |
| LE-626 x LE-640 | 9.00 | 85.00 | 98.00 | 93.80 | 0.59 |

Table-31 Mean performance of $F_2$ progenies for average fruit weight (g)

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 35.90 | 20.30 | 56.20 | 38.39 | 2.66 |
| Anagha x IIHR-2196 | 27.30 | 28.70 | 56.00 | 40.87 | 1.60 |
| Anagha x H-24 | 29.50 | 25.70 | 55.20 | 40.53 | 1.72 |
| Anagha x H-86 | 19.70 | 33.50 | 53.20 | 42.08 | 1.10 |
| Anagha x H-7998 | 35.40 | 20.50 | 55.90 | 40.33 | 2.14 |
| Anagha x LE-474 | 29.00 | 25.90 | 54.90 | 40.36 | 1.58 |
| Anagha x LE-640 | 35.50 | 20.70 | 56.20 | 41.15 | 2.15 |
| | | | | | |
| Sakthi x IIHR-2195 | 33.50 | 21.70 | 55.20 | 38.76 | 1.65 |
| Sakthi x IIHR-2196 | 45.20 | 25.50 | 55.70 | 35.98 | 2.34 |
| Sakthi x H-24 | 35.40 | 20.30 | 55.70 | 40.04 | 2.15 |
| Sakthi x H-86 | 29.00 | 25.70 | 54.70 | 40.30 | 1.59 |
| Sakthi x H-7998 | 34.50 | 22.30 | 56.80 | 39.84 | 1.88 |
| Sakthi x LE-474 | 33.50 | 23.90 | 57.40 | 40.99 | 1.65 |
| Sakthi x LE-640 | 35.10 | 23.40 | 58.50 | 42.35 | 1.93 |
| | | | | | |
| Mukthi x IIHR-2195 | 34.60 | 35.20 | 56.80 | 40.12 | 1.54 |
| Mukthi x IIHR-2196 | 60.10 | 39.10 | 71.20 | 42.12 | 2.58 |
| Mukthi x H-24 | 35.50 | 20.80 | 56.30 | 40.61 | 2.14 |
| Mukthi x H-86 | 29.08 | 26.22 | 55.30 | 40.86 | 1.59 |
| Mukthi x H-7998 | 34.47 | 22.89 | 57.36 | 40.39 | 1.88 |
| Mukthi x LE-474 | 33.50 | 24.40 | 57.90 | 41.55 | 1.65 |
| Mukthi x LE-640 | 35.00 | 24.00 | 59.00 | 42.92 | 1.92 |

Table-31 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 45.20 | 26.50 | 56.70 | 36.92 | 2.34 |
| LE-1-2 x H-24 | 35.50 | 21.20 | 56.70 | 41.01 | 2.14 |
| LE-1-2 x H-86 | 29.10 | 26.60 | 55.70 | 41.26 | 1.59 |
| LE-1-2 x H-7998 | 34.50 | 23.30 | 57.80 | 40.80 | 1.88 |
| LE-1-2 x LE-474 | 33.50 | 24.80 | 58.30 | 41.95 | 1.65 |
| LE-1-2 x LE-640 | 35.00 | 24.40 | 59.40 | 43.32 | 1.92 |
| | | | | | |
| LE-626 x IIHR-2195 | 33.50 | 21.30 | 54.80 | 38.41 | 1.65 |
| LE-626 x IIHR-2196 | 45.20 | 22.20 | 55.40 | 35.62 | 2.34 |
| LE-626 x H-24 | 35.50 | 26.90 | 55.40 | 39.71 | 2.14 |
| LE-626 x H-86 | 29.10 | 25.30 | 54.40 | 39.96 | 1.59 |
| LE-626 x H-7998 | 34.50 | 22.00 | 56.50 | 39.50 | 1.88 |
| LE-626 x LE-474 | 33.50 | 23.50 | 57.00 | 40.65 | 1.65 |
| LE-626 x LE-640 | 35.00 | 23.10 | 58.10 | 42.02 | 1.92 |

was produced by $F_2$ population of Anagha x IIHR-2195 (10.00 fruits/plant). Highest mean value was recorded by Mukthi x IIHR-2196 (42.00 fruits/plant) followed by Mukthi x IIHR-2195 (40.64 fruits/plant). Lowest mean value for number of fruits per plant was recorded by Anagha x IIHR-2195 (15.08 fruits/plant) followed by LE-626 x IIHR-2195 (16.88 fruits/plant) (Table-32).

### 4.4.7 Yield per plant

Yield per plant varied from 154.44 g to 1750.90 g in the $F_2$ population. Among the $F_2$ population, Mukthi x IIHR-2195 (1750.90 g), Mukthi x IIHR-2196 (1540.30 g), Sakthi x Hawaii-7998 (1450.30 g), Sakthi x H-86 (1120.10 g), Mukthi x H-86 (1090.70 g), Sakthi x IIHR-2195 (1040.50 g), Sakthi x IIHR-2196 (923.50 g) and Mukthi x H-24 (800.50 g) were the high yielding $F_2$'s. Minimum was recorded for Anagha x IIHR-2196 (154.44 g). Highest mean value was recorded by $F_2$ population of Mukthi x IIHR-2196 (750.48 g), Mukthi x IIHR-2195 (709.86), Mukthi x H-86 (674.75 g) and Sakthi x H-86 (673.95 g). Lowest mean value was recorded by $F_2$ population of Anagha x IIHR-2195 (351.02 g), Anagha x IIHR-2196 (375.82) and LE-1-2 x IIHR-2195 (385.52 g) (Table-33).

## 4.5 Selection for combined resistance to bacterial wilt and ToLCV disease

The $F_2$ population was evaluated for combined resistance to bacterial wilt and ToLCV. 30 $F_2$ plants were having combined resistance to bacterial wilt and ToLCV (Table -34).

Mukthi x H-86- $F_2$-32 (42 fruits/plant) recorded highest number of fruits per plant followed by Mukthi x IIHR-2195- $F_2$-34 (42 fruits/plant) and Mukthi x IIHR-2195-$F_2$-47 (41 fruits/plant) and Mukthi x IIHR-2196- $F_2$-57 (40 fruits/plant).

Table-32 Mean performance of $F_2$ progenies for number of fruits per plant

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 12.00 | 10.00 | 22.00 | 15.08 | 0.63 |
| Anagha x IIHR-2196 | 19.00 | 13.00 | 32.00 | 21.16 | 1.09 |
| Anagha x H-24 | 30.00 | 11.00 | 41.00 | 19.36 | 1.45 |
| Anagha x H-86 | 19.00 | 13.00 | 32.00 | 21.28 | 1.20 |
| Anagha x H-7998 | 20.00 | 11.00 | 31.00 | 18.36 | 1.16 |
| Anagha x LE-474 | 17.00 | 13.00 | 30.00 | 19.16 | 0.89 |
| Anagha x LE-640 | 21.00 | 11.00 | 32.00 | 19.64 | 1.40 |
| | | | | | |
| Sakthi x IIHR-2195 | 17.00 | 13.00 | 30.00 | 19.96 | 0.89 |
| Sakthi x IIHR-2196 | 19.00 | 15.00 | 34.00 | 23.32 | 1.17 |
| Sakthi x H-24 | 19.00 | 13.00 | 32.00 | 19.76 | 1.09 |
| Sakthi x H-86 | 17.00 | 15.00 | 32.00 | 21.32 | 0.94 |
| Sakthi x H-7998 | 21.00 | 13.00 | 34.00 | 20.84 | 1.28 |
| Sakthi x LE-474 | 20.00 | 14.00 | 34.00 | 21.24 | 1.16 |
| Sakthi x LE-640 | 21.00 | 12.00 | 33.00 | 19.04 | 1.08 |
| | | | | | |
| Mukthi x IIHR-2195 | 22.00 | 21.00 | 43.00 | 40.64 | 1.53 |
| Mukthi x IIHR-2196 | 45.00 | 20.00 | 39.00 | 42.00 | 2.31 |
| Mukthi x H-24 | 35.00 | 20.00 | 46.00 | 39.64 | 2.15 |
| Mukthi x H-86 | 29.00 | 25.00 | 44.00 | 39.80 | 1.60 |
| Mukthi x H-7998 | 34.00 | 22.00 | 37.00 | 39.36 | 1.88 |
| Mukthi x LE-474 | 33.00 | 24.00 | 41.00 | 31.48 | 1.64 |
| Mukthi x LE-640 | 35.00 | 23.00 | 35.00 | 36.68 | 1.94 |

Table-32 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 19.00 | 14.00 | 33.00 | 22.16 | 1.09 |
| LE-1-2 x H-24 | 30.00 | 12.00 | 31.00 | 20.36 | 1.45 |
| LE-1-2 x H-86 | 19.00 | 14.00 | 33.00 | 22.08 | 1.20 |
| LE-1-2 x H-7998 | 20.00 | 12.00 | 32.00 | 19.36 | 1.16 |
| LE-1-2 x LE-474 | 17.00 | 14.00 | 31.00 | 20.08 | 0.90 |
| LE-1-2 x LE-640 | 21.00 | 12.00 | 33.00 | 20.24 | 1.32 |
| | | | | | |
| LE-626 x IIHR-2195 | 12.00 | 12.00 | 24.00 | 16.88 | 0.62 |
| LE-626 x IIHR-2196 | 19.00 | 15.00 | 34.00 | 23.00 | 1.10 |
| LE-626 x H-24 | 30.00 | 13.00 | 33.00 | 21.36 | 1.45 |
| LE-626 x H-86 | 19.00 | 15.00 | 34.00 | 23.00 | 1.21 |
| LE-626 x H-7998 | 19.00 | 13.00 | 32.00 | 20.28 | 1.14 |
| LE-626 x LE-474 | 17.00 | 15.00 | 32.00 | 20.92 | 0.89 |
| LE-626 x LE-640 | 21.00 | 13.00 | 34.00 | 21.20 | 1.31 |

Table-33 Mean performance of $F_2$ progenies for yield per plant (g)

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| Anagha x IIHR-2195 | 352.22 | 207.78 | 560.00 | 351.02 | 20.18 |
| Anagha x IIHR-2196 | 467.78 | 154.44 | 622.22 | 375.82 | 29.93 |
| Anagha x H-24 | 509.65 | 165.56 | 675.21 | 433.80 | 30.74 |
| Anagha x H-86 | 303.00 | 369.92 | 672.92 | 508.18 | 18.23 |
| Anagha x H-7998 | 461.35 | 228.89 | 690.24 | 431.74 | 26.09 |
| Anagha x LE-474 | 536.34 | 168.89 | 705.23 | 473.55 | 31.45 |
| Anagha x LE-640 | 402.22 | 216.67 | 618.89 | 434.19 | 22.61 |
| | | | | | |
| Sakthi x IIHR-2195 | 352.22 | 277.58 | 1040.50 | 620.82 | 20.18 |
| Sakthi x IIHR-2196 | 467.78 | 224.24 | 923.50 | 545.62 | 29.93 |
| Sakthi x H-24 | 475.05 | 235.36 | 710.41 | 489.47 | 26.97 |
| Sakthi x H-86 | 280.32 | 439.72 | 1120.10 | 673.95 | 17.12 |
| Sakthi x H-7998 | 461.35 | 298.69 | 1450.30 | 601.54 | 26.09 |
| Sakthi x LE-474 | 460.55 | 238.69 | 699.24 | 531.35 | 28.57 |
| Sakthi x LE-640 | 402.22 | 286.47 | 688.69 | 503.99 | 22.61 |
| | | | | | |
| Mukthi x IIHR-2195 | 1472.52 | 278.38 | 1750.90 | 709.86 | 77.94 |
| Mukthi x IIHR-2196 | 1261.92 | 278.38 | 1540.30 | 750.48 | 72.21 |
| Mukthi x H-24 | 475.05 | 236.16 | 800.50 | 590.27 | 26.97 |
| Mukthi x H-86 | 280.32 | 440.52 | 1090.70 | 674.75 | 17.12 |
| Mukthi x H-7998 | 461.35 | 299.49 | 760.84 | 502.34 | 26.09 |
| Mukthi x LE-474 | 536.34 | 239.49 | 775.83 | 544.15 | 31.45 |
| Mukthi x LE-640 | 402.22 | 287.27 | 689.49 | 504.79 | 22.61 |

Tabale-33 Contd.

| | Range | Minimum | Maximum | Mean | Standard error |
|---|---|---|---|---|---|
| LE-1-2 x IIHR-2196 | 467.78 | 188.94 | 656.72 | 410.32 | 29.93 |
| LE-1-2 x H-24 | 501.11 | 200.06 | 701.17 | 463.24 | 29.26 |
| LE-1-2 x H-86 | 280.32 | 404.42 | 684.74 | 540.67 | 17.57 |
| LE-1-2 x H-7998 | 461.35 | 263.39 | 624.74 | 466.24 | 26.09 |
| LE-1-2 x LE-474 | 536.34 | 203.39 | 639.73 | 508.05 | 31.45 |
| LE-1-2 x LE-640 | 402.22 | 251.17 | 653.39 | 468.69 | 22.61 |
| | | | | | |
| LE-626 x IIHR-2195 | 352.22 | 276.78 | 629.00 | 420.02 | 20.18 |
| LE-626 x IIHR-2196 | 467.78 | 223.44 | 691.22 | 444.82 | 29.93 |
| LE-626 x H-24 | 475.05 | 234.56 | 709.61 | 488.67 | 26.97 |
| LE-626 x H-86 | 280.32 | 438.92 | 619.24 | 573.15 | 17.12 |
| LE-626 x H-7998 | 461.35 | 297.89 | 659.24 | 500.74 | 26.09 |
| LE-626 x LE-474 | 536.34 | 237.89 | 674.23 | 542.55 | 31.45 |
| LE-626 x LE-640 | 402.22 | 285.67 | 687.89 | 503.19 | 22.61 |

Table-34 Biometric characters of selected $F_2$ segregants with combined resistant ToLCV and bacterial wilt

| S.No | Selected $F_2$ Segregants | ToLCV | BWR | Plant height (cm) | Number of branches per plant | Days to flower | Days to harvest |
|---|---|---|---|---|---|---|---|
| 1 | Mukthi x IIHR-2195-$F_2$-24 | R | R | 61.2 | 15 | 55 | 90 |
| 2 | Mukthi x IIHR-2195- $F_2$-25 | R | R | 67.9 | 17 | 56 | 84 |
| 3 | Mukthi x IIHR-2195- $F_2$-31 | R | R | 70.2 | 21 | 56 | 89 |
| 4 | Mukthi x IIHR-2195- $F_2$-34 | R | R | 61.5 | 19 | 55 | 84 |
| 5 | Mukthi x IIHR-2195- $F_2$-36 | R | R | 72.5 | 18 | 56 | 89 |
| 6 | Mukthi x IIHR-2195- $F_2$-38 | R | R | 69.3 | 17 | 54 | 86 |
| 7 | Mukthi x IIHR-2195- $F_2$-40 | R | R | 72.3 | 16 | 54 | 91 |
| 8 | Mukthi x IIHR-2195- $F_2$-41 | R | R | 75.6 | 12 | 55 | 83 |
| 9 | Mukthi x IIHR-2195-$F_2$-47 | R | R | 71.5 | 15 | 55 | 88 |
| 10 | Mukthi x IIHR-2195- $F_2$-54 | R | R | 68.5 | 18 | 55 | 85 |
| 11 | Mukthi x IIHR-2195- $F_2$-58 | R | R | 65.4 | 13 | 55 | 89 |
| 12 | Mukthi x IIHR-2196- $F_2$-16 | R | R | 79.6 | 15 | 52 | 85 |
| 13 | Mukthi x IIHR-2196- $F_2$-43 | R | R | 81.1 | 18 | 52 | 91 |
| 14 | Mukthi x IIHR-2196- $F_2$-45 | R | R | 77.6 | 15 | 55 | 86 |
| 15 | Mukthi x IIHR-2196- $F_2$-57 | R | R | 75.9 | 15 | 55 | 85 |

Table-34 Contd.

| S.No | Selected $F_2$ Segregants | ToLCV | BW | Plant height (cm) | Number of branches per plant | Days to flower | Days to harvest |
|---|---|---|---|---|---|---|---|
| 16 | Mukthi x IIHR-2196- $F_2$-66 | R | R | 69.9 | 11 | 54 | 89 |
| 17 | Mukthi x IIHR-2196- $F_2$-71 | R | R | 74.8 | 15 | 54 | 95 |
| 18 | Mukthi x IIHR-2196- $F_2$-72 | R | R | 73.5 | 12 | 54 | 88 |
| 19 | Mukthi x IIHR-2196- $F_2$-73 | R | R | 76.9 | 14 | 54 | 93 |
| 20 | Mukthi x IIHR-2196- $F_2$-78 | R | R | 79.8 | 10 | 54 | 82 |
| 21 | Mukthi x IIHR-2196- $F_2$-80 | R | R | 67.5 | 11 | 56 | 87 |
| 22 | Mukthi x H-24- $F_2$-10 | R | R | 80.8 | 13 | 48 | 75 |
| 23 | Mukthi x H-86- $F_2$-32 | R | R | 95.6 | 18 | 51 | 86 |
| 24 | Sakthi x IIHR-2195- $F_2$-58 | R | R | 85.6 | 15 | 50 | 89 |
| 25 | Sakthi x IIHR-2196- $F_2$-6 | R | R | 79.8 | 17 | 54 | 91 |
| 26 | Sakthi x IIHR-2196- $F_2$-18 | R | R | 83.5 | 12 | 54 | 90 |
| 27 | Sakthi x IIHR-2196- $F_2$-20 | R | R | 84.5 | 18 | 53 | 81 |
| 28 | Sakthi x H-86- $F_2$-75 | R | R | 68.9 | 18 | 53 | 83 |
| 29 | Sakthi x Hawaii-7998- $F_2$-81 | R | R | 59.6 | 17 | 57 | 88 |
| 30 | Sakthi x Hawaii-7998- $F_2$-91 | R | R | 55.8 | 15 | 57 | 85 |

Table-34 Contd.

| S.No | $F_2$ Segregants | Average fruit weight (g) | Fruits/Plants | Yield/Plant (g) | Number of locules per fruit | Fruit Shape Index | Cracking (%) | TSS (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | Mukthi x IIHR-2195-$F_2$-24 | 32.5 | 35 | 1052.50 | 3.8 | 1.07 | 0.00 | 5.9 |
| 2 | Mukthi x IIHR-2195- $F_2$-25 | 35.4 | 32 | 880.40 | 3.2 | 1.08 | 0.00 | 4.4 |
| 3 | Mukthi x IIHR-2195- $F_2$-31 | 35.6 | 29 | 915.80 | 3.8 | 0.91 | 0.00 | 4.9 |
| 4 | Mukthi x IIHR-2195- $F_2$-34 | 40.9 | 42 | 1540.60 | 3.0 | 0.90 | 0.00 | 4.9 |
| 5 | Mukthi x IIHR-2195- $F_2$-36 | 27.5 | 30 | 701.80 | 4.6 | 1.12 | 0.00 | 5.2 |
| 6 | Mukthi x IIHR-2195- $F_2$-38 | 42.8 | 28 | 1009.70 | 4.2 | 0.98 | 0.00 | 5.7 |
| 7 | Mukthi x IIHR-2195- $F_2$-40 | 36.7 | 30 | 810.80 | 3.6 | 0.98 | 0.00 | 5.9 |
| 8 | Mukthi x IIHR-2195- $F_2$-41 | 51.8 | 25 | 1080.70 | 4.2 | 1.10 | 0.00 | 6.5 |
| 9 | Mukthi x IIHR-2195-F2-47 | 48.9 | 41 | 1750.90 | 3.6 | 1.09 | 0.00 | 6.3 |
| 10 | Mukthi x IIHR-2195- $F_2$-54 | 56.8 | 23 | 1150.80 | 4.0 | 0.86 | 0.00 | 6.4 |
| 11 | Mukthi x IIHR-2195- $F_2$-58 | 41.5 | 20 | 850.60 | 2.6 | 0.89 | 0.00 | 6.2 |
| 12 | Mukthi x IIHR-2196- $F_2$-16 | 35.6 | 25 | 815.70 | 4.4 | 1.26 | 0.00 | 5.6 |
| 13 | Mukthi x IIHR-2196- $F_2$-43 | 71.2 | 23 | 1540.30 | 3.2 | 0.89 | 0.00 | 5.4 |
| 14 | Mukthi x IIHR-2196- $F_2$-45 | 36.8 | 26 | 940.50 | 3.0 | 0.80 | 0.00 | 5.2 |
| 15 | Mukthi x IIHR-2196- $F_2$-57 | 41.5 | 40 | 1450.50 | 3.2 | 1.02 | 0.00 | 5.8 |

Table-34 Contd.

| S.No | F2 Segregants | Average fruit weight (g) | Fruits/Plants | Yield/Plant (g) | Number of locules per fruit | Fruit Shape Index | Cracking (%) | TSS (%) |
|---|---|---|---|---|---|---|---|---|
| 16 | Mukthi x IIHR-2196- $F_2$-66 | 38.6 | 31 | 1050.20 | 4.0 | 0.90 | 0.00 | 5.6 |
| 17 | Mukthi x IIHR-2196- $F_2$-71 | 40.5 | 22 | 850.50 | 3.2 | 0.83 | 0.00 | 5.1 |
| 18 | Mukthi x IIHR-2196- $F_2$-72 | 45.6 | 25 | 970.50 | 4.6 | 0.81 | 0.00 | 5.5 |
| 19 | Mukthi x IIHR-2196- $F_2$-73 | 43.2 | 27 | 1041.80 | 4.6 | 1.05 | 0.00 | 4.3 |
| 20 | Mukthi x IIHR-2196- $F_2$-78 | 60.5 | 25 | 1400.80 | 4.2 | 0.78 | 0.00 | 4.7 |
| 21 | Mukthi x IIHR-2196- $F_2$-80 | 54.5 | 24 | 1110.60 | 2.6 | 0.89 | 0.00 | 4.9 |
| 22 | Mukthi x H-24- $F_2$-10 | 25.6 | 35 | 800.50 | 3.6 | 0.91 | 0.00 | 4.7 |
| 23 | Mukthi x H-86- $F_2$-32 | 32.9 | 42 | 1090.70 | 4.2 | 0.82 | 0.00 | 5.1 |
| 24 | Sakthi x IIHR-2195- $F_2$-58 | 34.8 | 35 | 1040.50 | 4.0 | 0.91 | 0.00 | 5.4 |
| 25 | Sakthi x IIHR-2196- $F_2$-6 | 35.5 | 29 | 910.50 | 3.4 | 0.95 | 0.00 | 5.2 |
| 26 | Sakthi x IIHR-2196- $F_2$-18 | 45.8 | 21 | 923.50 | 2.0 | 0.92 | 0.00 | 5.5 |
| 27 | Sakthi x IIHR-2196- $F_2$-20 | 41.2 | 15 | 850.30 | 2.0 | 0.96 | 0.00 | 4.3 |
| 28 | Sakthi x H-86- $F_2$-75 | 50.5 | 27 | 1220.10 | 3.6 | 1.13 | 0.00 | 4.8 |
| 29 | Sakthi x Hawaii-7998- $F_2$-81 | 52.3 | 25 | 1120.80 | 3.4 | 0.98 | 0.00 | 4.9 |
| 30 | Sakthi x Hawaii-7998- $F_2$-91 | 54.6 | 28 | 1450.30 | 4.0 | 0.83 | 0.00 | 5.4 |

The average fruit weight was found maximum in Mukthi x IIHR-2196-$F_2$-43 (71.2 g) followed by Mukthi x IIHR-2195- $F_2$-54 (56.8 g) and Sakthi x Hawaii-7998- $F_2$-91 (54.6 g).

Mukthi x IIHR-2195-$F_2$-47 (1750.90 g/plant), Mukthi x IIHR-2195- $F_2$-34 (1540.60 g/plant), Mukthi x IIHR-2196- $F_2$-43 (1540.30 g/plant), Mukthi x IIHR-2196- $F_2$-57 (1450.50 g/plant) and Mukthi x IIHR-2196- $F_2$-78 (1400.80 g/plant) recorded the highest yield per plant among the selected progenies resistant to both bacterial wilt and ToLCV.

## 4.6 Genetics of resistance to ToLCV

Inheritance of resistance to ToLCV was studied using the parents, $F_1$, $F_2$, $B_1$, and $B_2$ populations of cross involving susceptible and resistant genotypes. The cross combination was Pusa Ruby x IIHR-2195. The populations of six generations were screened for ToLCV resistance.

In the $F_1$, 16 plants out of 20 showed resistance and in the $F_2$ generation out of the total 200 plants 146 were resistant (85R and 61MR) while 54 showed susceptibility. This fitted very well into the monogenic Mendelian ratio 3:1 ($\chi 2$=0.24, $p$= 0.7-0.5). In the $B_1$ generation, 17 were resistant and 13 were susceptible which fitted well into the ratio of 1:1 ($\chi 2$= 0.53, $p$= 0.5-0.3) while in the $B_2$, 25 plants (12R and 13MR) were resistant and 5 were susceptible which fitted well into the ratio 1:0 ($\chi 2$=0.08, $p$= 0.95-0.90) (Table-35).

Table-35 Reaction of the parents, $F_1$, $F_2$, and backcross generations of the cross Pusa Ruby x IIHR-2195 to ToLCV

| Parent/Cross | Total plants taken | Score Resistant | | Score Susceptible | | | Ratio | Expected ratio | $\chi 2$ | Probability ($p$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | | | | |
| Pusa Ruby | 20 | 0 | 0 | 2 | 9 | 9 | - | - | | |
| IIHR-2195 | 20 | 20 | 0 | 0 | 0 | 0 | - | - | | |
| Pusa Ruby x IIHR-2195 | 20 | 8 | 8 | 0 | 4 | 0 | - | - | | |
| Pusa Ruby x IIHR-2195 ($F_2$) | 200 | 85 | 61 | 18 | 16 | 20 | 3:1 | 3:1 | 0.24 | 0.7-0.5 |
| (Pusa Ruby x IIHR-2195) x Pusa Ruby ($B_1$) | 30 | 9 | 8 | 5 | 3 | 5 | 1:1 | 1:1 | 0.53 | 0.5-0.3 |
| (Pusa Ruby x IIHR-2195) x IIHR-2195 ($B_2$) | 30 | 12 | 13 | 2 | 3 | 0 | 1:0 | 1:0 | 0.08 | 0.95-0.90 |

# *Discussion*

# 5. DISCUSSION

Tomato Leaf Curl Virus (ToLCV) disease and bacterial wilt are the two serious diseases of tomato in Kerala. Because of the devastating nature of these diseases, the area under tomato in Kerala is getting reduced year after year. Attempts on management of these diseases could not result in the formulation of any effective and efficient control strategy. Therefore the viable technology left to combat the diseases is the use of resistant varieties. Resistance breeding taken up in Kerala Agricultural University has resulted in the development of three bacterial wilt resistant varieties *viz.*, Sakthi, Mukthi, Anagha and one tolerant variety Vellayani Vijay. But these varieties are found susceptible to tomato leaf curl virus disease.

When sources of resistance to tomato leaf curl virus and bacterial wilt are available, these two characters can be combined in a single genotype and such an eventuality will be a turning point in tomato cultivation. Keeping this as the ultimate aim, the present investigation was undertaken.

Response of tomato genotypes to tomato leaf curl virus disease and bacterial wilt, reaction of 35 $F_1$ hybrids to both these diseases and reaction of resultant $F_2$ segregants for combined resistance to ToLCV and bacterial wilt are discussed in detail. Genetics of resistance to ToLCV is also being discussed.

## 5.1 Identification of sources of resistance to tomato leaf curl virus

Among the 80 genotypes screened against ToLCV, 26 genotypes (LE-474, LE-635, LE-640, LE-641, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998, Rani, LE-683, LE-688, LE-692 and LE-697) were highly resistant with coefficients of infection ranging from zero to two. The

resistance in H-24 and H-86 was earlier reported by Kalloo and Banerjee (1993), Kalloo and Banerjee (2000). The resistance in IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199, IIHR-2202, IIHR-2747, TLBRH-1 and TLBRH-6 were earlier reported by Sadashiva *et al.* (2003) and Singh and Sadashiva (2007). The resistance in Hawaii-7998, H-24, H-86, LE-474 and LE-640 were earlier reported by Anjali (2007).

Remaining genotypes showed varying degrees of systemic symptoms against the ToLCV. LE-66 and TLBRH-9 were resistant to ToLCV with a coefficient of infection values of 5.0 and 7.0 respectively. There was one moderately resistant and nine moderately susceptible genotypes. The remaining 18 genotypes were susceptible and 24 were highly susceptible. Bacterial wilt resistant tomato varieties Anagha, Sakthi and Mukthi were highly susceptible with CI values of 66.7, 94.4 and 75.0 respectively.

Confirmation studies were carried out in order to ascertain the nature of resistance, since the resistant reaction expressed consequent to virus inoculation can be either due to escape or due to true resistance. Graft and vector transmission were done to confirm the resistance. Of the 26 highly resistant genotypes tested, only six genotypes showed symptoms and other 20 genotypes were completely free of disease in graft transmission confirming the true resistance of these genotypes to ToLCV even after grafting with the infected scion. Friedmann *et al.* (1998) and Gomez *et al.* (2004) also effectively used the same technique for artificial screening against ToLCV in tomato.

Whitefly, *Bemisia tabaci* is the vector responsible for the spread of ToLCV in natural conditions. Whitefly-mediated inoculation techniques have been able to ensure almost cent per cent infection of susceptible ones allowing reliable screening of *Lycopersicon* germplasm (Santana *et al.*, 2001). All 20 genotypes highly resistant in graft transmission were found

highly resistant to ToLCV on whitefly transmission also and only susceptible Pusa Ruby showed symptoms of the disease. Pilowsky and Cohen (1990), Friedmann *et al.* (1998) and Gomez *et al.* (2004) also used the whitefly transmission for screening against ToLCV in tomato.

**5.2 Identification of sources of resistance to bacterial wilt**

Seventy six tomato genotypes were evaluated for its reaction to bacterial wilt during August-November, 2009. Anagha recorded the lowest PDI (10.0) to bacterial wilt among the resistant genotypes. This was followed by LE-1-2, LE-474, LE-628, Sakthi, LE-626, LE-640, Mukthi and LE-649 with a PDI of 13.3, 13.3, 13.3, 16.7, 16.7, 16.7, 19.0 and 20.0 respectively. The resistance of these genotypes to bacterial wilt has been reported earlier by Sadhankumar, (1995), Mathew *et al.* (1997), Devi *et al.* (2002) and Karumannil *et al.* (2008). The newly identified lines LE-628, LE-640 and LE-649 can well form additional sources of resistance to bacterial wilt.

Genotypes LE-656, GA-1565, Swarna Naveen, Swarna Lalima, Hawaii-7998, TLBRH-6, LE-688, LE-692 and LE-709 which were highly resistant in other states found moderately resistant to this disease in Kerala conditions. This may be due to the existence of different biovar at this place. Mathew *et al.* (2001) reported that race-1 biovar-III, biovar-IIIa and biovar-V of *R. solanacearum* infecting tomato in Kerala.

In the present study, spot planting with known suscept Pusa Ruby was done to confirm the presence of virulent pathogen in the field. Earlier Naryanankutty (1985) and Sadhankumar (1995) have found the efficacy of this method in eliminating the escapes. Confirmation of bacterial wilt incidence was done by ooze test. Sadhankumar (1995), Rani (2000), Gudi Jacob (2003), Karumannil *et al.* (2008) and Techawongstien *et al.* (2009)

also used the same ooze test to confirm the incidence of bacterial wilt in tomato.

## 5.3 Transfer of resistance to tomato leaf curl virus to bacterial wilt resistant tomato

Bacterial wilt resistant genotypes Anagha, Sakthi, Mukthi, LE-1-2 and LE-626 (Plate-7-11) were crossed with the tomato leaf curl virus resistant genotypes IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640 (Plate-12-20) in a line x tester fashion. The performance of important hybrids is discussed below.

### 5.3.1 Evaluation of $F_1$ hybrids for ToLCV disease resistance

Thirty five hybrids and twelve parents were evaluated for their reaction to ToLCV.

Among the parents, ToLCV was not observed in IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640 which all fell into highly resistant group. Anagha, Sakthi, LE-1-2 and LE-626 were moderately susceptible. Mukthi was moderately resistant.

Among the thirty five hybrids thirty hybrids were resistant to ToLCV disease. LE-626 x H-86 (CI=2.6) showed mild symptoms to ToLCV. LE-626 x H-24 was resistant with a CI of 5.1.

### 5.3.2 Evaluation of $F_1$ hybrids for bacterial wilt resistance

Thirty five hybrids and twelve parents were evaluated for their reaction to bacterial wilt incidence.

Among the parents, Anagha, Sakthi, Mukthi, LE-626, LE-474 and LE-640 were completely free from disease. Followed by LE-1-2 and Hawaii-7998 recorded 3.6 and 7.1 PDI respectively which were classified as

resistant as per Mew and Ho (1976). IIHR-2196 and IIHR-2195 were moderately resistant with a PDI 25.0 and 28.6 respectively. H-86 and H-24 recorded PDI of 42.9 and 50.0 respectively. This is in confirmation with the findings of Sadhankumar (1995) and Rani (2000) who reported the resistance in Anagha, Mukthi and Sakthi to bacterial wilt disease.

Among the 35 hybrids, no wilt incidence was observed in Mukthi x H-7998, Mukthi x LE-474, Mukthi x LE-640, LE-1-2 x LE-474, LE-626 x LE-474. This might be happened as the parents involved in the crosses were resistant to bacterial wilt. Rani (2000) also succeeded in obtaining bacterial wilt resistant hybrids by crossing two bacterial wilt resistant parents.

$F_1$ hybrids of LE-1-2 x Hawaii-7998, Sakthi x LE-640, Anagha x Hawaii-7998, LE-626 x LE-640, Anagha x LE-474, Anagha x LE-640, Sakthi x Hawaii-7998, Sakthi x LE-474 also were resistant to bacterial wilt with PDI of 3.6, 3.6, 14.3, 14.3, 17.9, 17.9, 17.9, 17.9 respectively, where both the parents involved in the crosses are resistant to bacterial wilt.

### 5.3.3 Combining ability, gene action and heterosis

In heterosis breeding programme, selection of parents based on information on gene action and knowledge of combining ability leads to fruitful result in the isolation of promising $F_1$ hybrids for further exploitation. Analysis of combining ability provides guidelines for early assessment of the relative breeding potential of parent materials. It also helps the breeder in identifying the best combiners which can be hybridized either to exploit heterosis or to build up favourable fixable genes.

In the present study, there were 35 crosses along with 5 lines and 7 testers. The significance of variance due to both gca and sca indicated the role of both additive and non-additive gene action for the control of biometrical characters. The mean squares for the genotypes were significant

for all the vegetative and reproductive characters indicating the presence of adequate variability which could be exploited by selection.

### 5.3.3.1 Plant height

Significant positive gca effect in Hawaii-7998 (39.92) shows that Hawaii-7998 is a good general combiner for increased plant height. Significant negative gca effect in LE-474 (-13.24) indicates that this genotype can be used as a good general combiner for dwarfness. Sakthi x LE-640 (19.84) showed the highest positive value for sca effect. Significant highest negative value for sca effect was observed in Anagha x Hawaii-7998 (-26.51). Significant heterobeltiosis, relative heterosis and standard heterosis were reported for plant height. Maximum heterobeltiosis of 24.81 per cent was found in Mukthi x H-24. Maximum relative heterosis was observed in the cross Mukthi x Hawaii-7998 (35.69 per cent). Standard heterosis was found maximum in the cross LE-1-2 x Hawaii-7998 (105.92 per cent) which was the tallest among the hybrids (171.26 cm) (Fig-1). Additive gene action was predominant, which shows that this character can be improved by appropriate selection method.

Plant height is usually indicative of its vegetative vigour which influences the productivity. Heterosis for plant height has already been reported by Bhushana (2000) and Patil (2001).

### 5.3.3.2 Days to flowering

H-24 (-1.77), IIHR-2196 (-0.90), Sakthi (-0.69), LE-640 (-0.65) and Mukthi (-0.37) were good general combiners for earliness since they showed high negative gca values. The crosses Anagha x LE-640 (51.26 days) was the earliest to flower (Fig-2). Additive gene action was predominant which shows that this character can be improved by appropriate selection method.

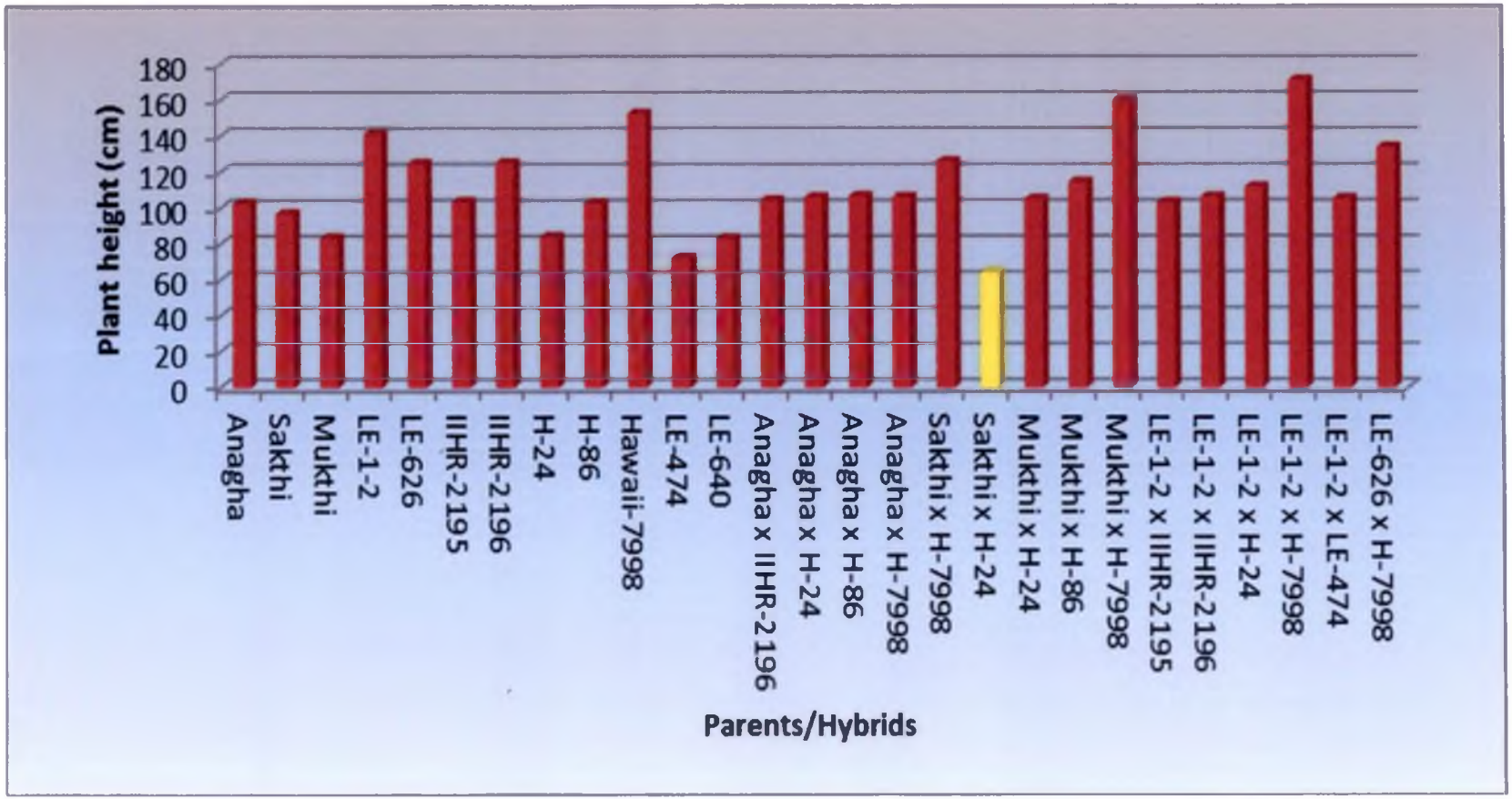



**Fig-1 Mean performance of parents and $F_1$ hybrids for plant height**

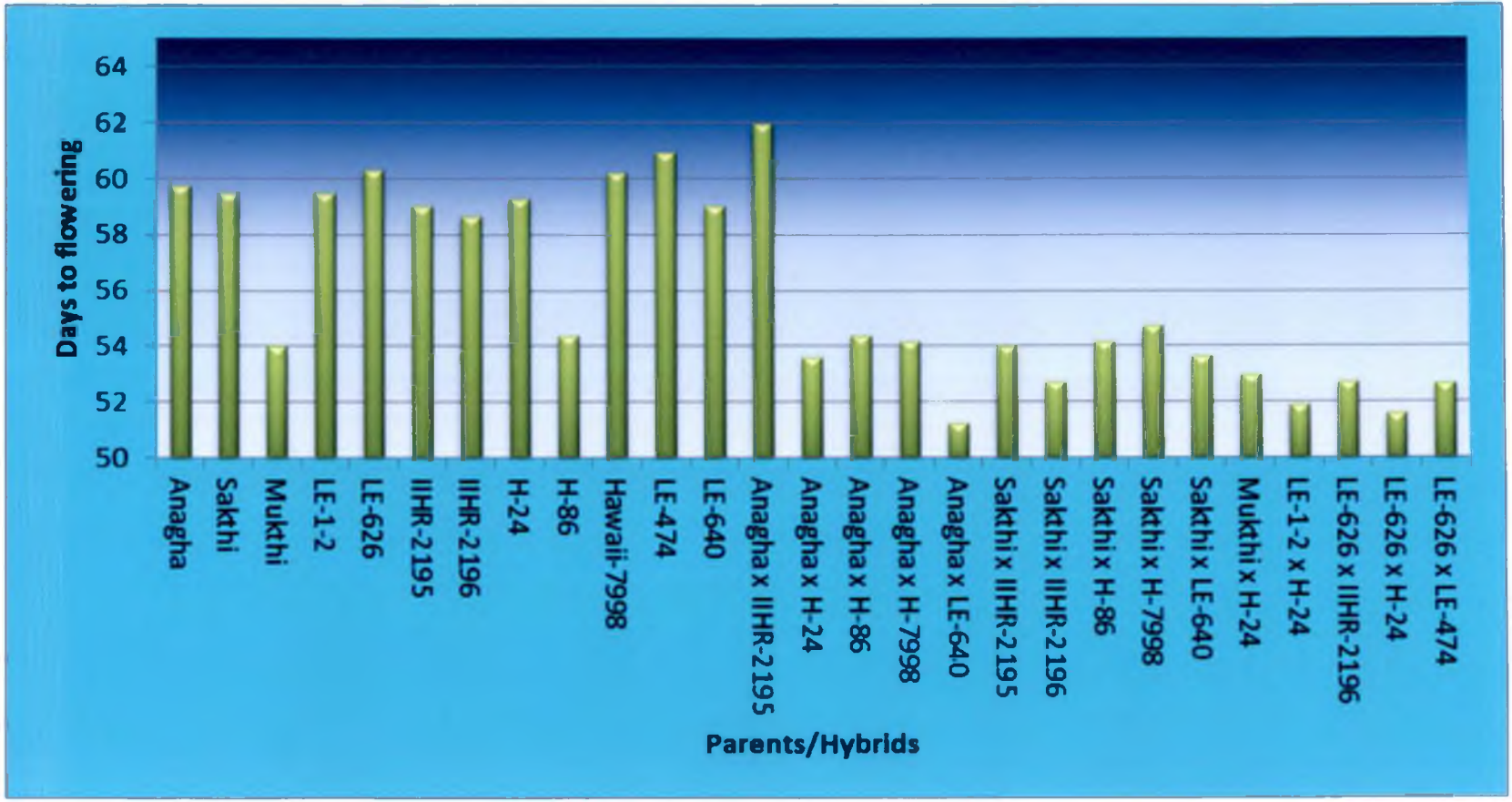



**Fig-2 Mean performance of parents and $F_1$ hybrids for days to flowering**

Number of days taken by a variety to put forth the first flower is generally indicative of its earliness. Among thirty five hybrids nine hybrids exhibited significant negative standard heterosis. Heterobeltiosis, relative heterosis and standard heterosis were highest in the negative direction in Anagha x LE-640. The same hybrid had maximum negative sca. Heterosis for days to flowering was reported by Dhaliwal *et al.* (2003) and Gaikwad *et al.* (2002).

### 5.3.3.3 Days to harvest

The genotypes H-24 (-1.75), IIHR-2196 (-0.83), Sakthi (-0.78), LE-640 (-0.43) and Mukthi (-0.27) were good general combiners for early harvesting also. This can be expected as the genotypes were earliest to flowering. Among the $F_1$ hybrids, Anagha x LE-640 (83.78 days) and LE-626 x H-24 (84.10 days) (Fig-3) were the earliest to harvest. Both hybrids were earlier than both the parents. This was closely followed by LE-626 x IIHR-2196 (84.53 days). This was also earlier than its parents. Earliness for yield is a desirable character in any crop. The preponderance of additive genetic variance over non-additive implies that days to harvest is governed by additive gene action.

Significant negative heterobeltiosis, relative heterosis and standard heterosis were found in Anagha x LE-640. The same hybrid had maximum negative sca. The present results concur with the findings of Sharma *et al.* (1999), Viredelwala *et al.* (1981) and Thakur *et al.* (2004).

### 5.3.3.4 Number of branches per plant

Mukthi, H-86 and LE-640 were good general combiners for number of branches/plant as evidenced by gca effects (8.02, 2.56 and 2.16 respectively). Mukthi x Hawaii-7998 (30.33) and Mukthi x LE-640 (28.69) produced more number of branches per plant which were higher than their respective parents. Significant heterosis were observed for this trait. Mukthi

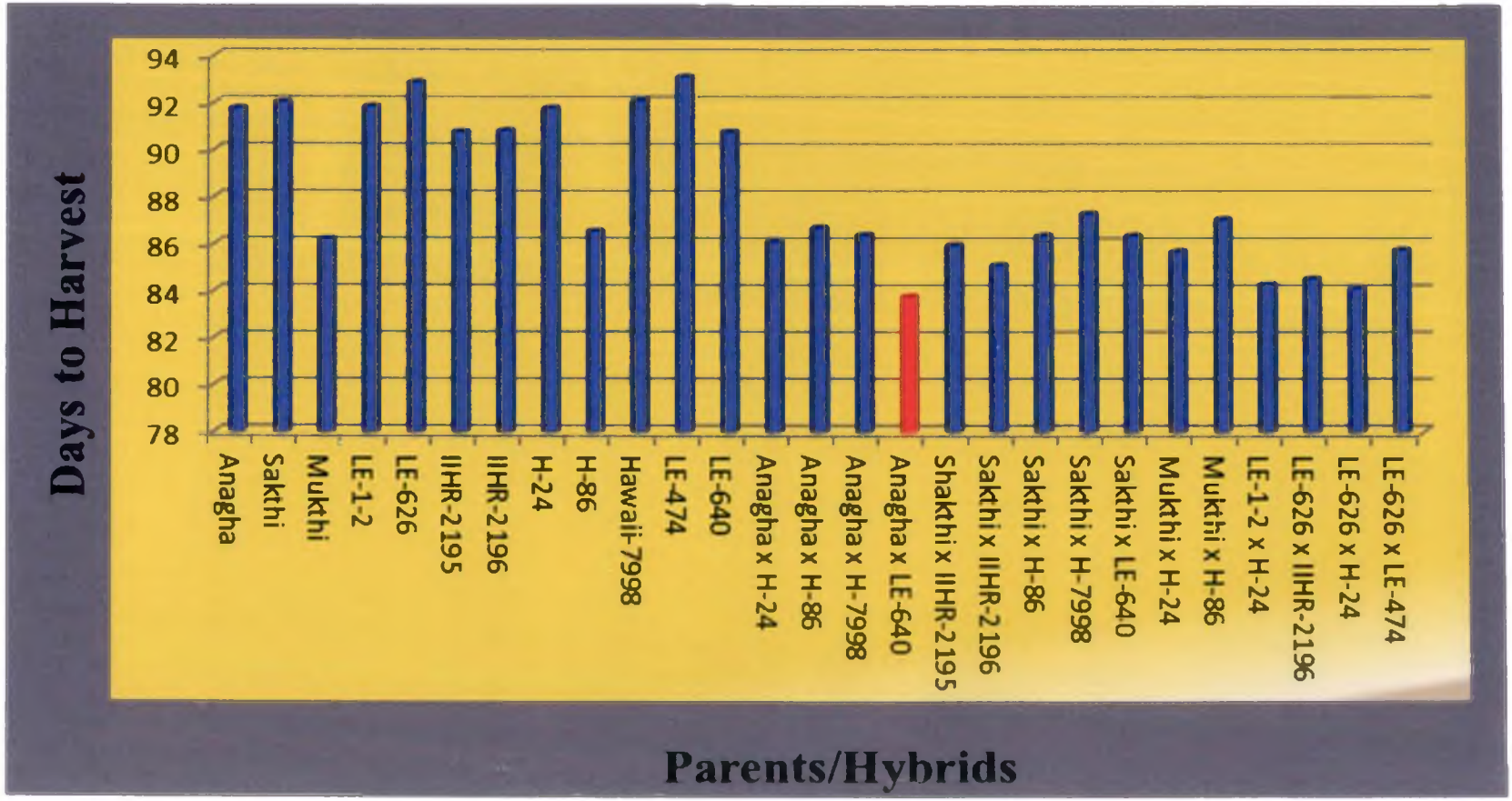



**Fig-3 Mean performance of parents and $F_1$ hybrids for days to harvest**

x LE-474 exhibited the highest heterobeltiosis of 21.52 per cent. Maximum relative heterosis was observed in the cross Mukthi x LE-474 (26.85 per cent). Standard heterosis was found maximum in the cross Mukthi x Hawaii-7998 (40.64 per cent). Heterosis for number of branches per plant was earlier reported by Nagaraja (1995) and Bhushana (2000).

### 5.3.3.5 Number of fruits per plant

Mukthi, LE-640 and Hawaii-7998 were good general combiners for number of fruits/plant as evidenced by gca effects (4.32, 3.21 and 3.12 respectively). Among the hybrids LE-1-2 x Hawaii-7998, Sakthi x LE-640 and Mukthi x H-86 showed significant positive sca effects (15.95, 11.58 and 7.19 respectively). Maximum number of fruits was produced by LE-1-2 x Hawaii-7998 (39.67) (Fig-4). Heterobeltiosis was 49.71 per cent, relative heterosis was 80.79 per cent and standard heterosis was 89.24 per cent for this hybrid. Heterosis for number of fruits per plant was earlier reported by Sadhankumar (1995), Rani (2000), Nagaraja (1995), Bhushana (2000) and Patil (2001).

### 5.3.3.6 Yield per plant

LE-640 and Mukthi were good general combiners for yield/plant as evidenced by gca effects (285.38 and 265.91 respectively). Sakthi x LE-640, LE-1-2 x Hawaii-7998, LE-626 x H-24, Mukthi x H-86, Mukthi x LE-474 and LE-1-2 x LE-640 showed significant positive sca effects (583.10, 497.76, 465.27, 387.82, 215.25 and 105.67 respectively). Highest yield was recorded by Sakthi x LE-640 (1405.45 g/plant) (Fig-5). This can be expected as this hybrid had maximum sca. Significant high heterobeltiosis and relative heterosis observed for fruit yield/plant in LE-1-2 x Hawaii-7998 (123.01 per cent and 139.53 per cent) Standard heterosis was found maximum in Sakthi x LE-640 (99.14 per cent). Sadhankumar (1995), Rani

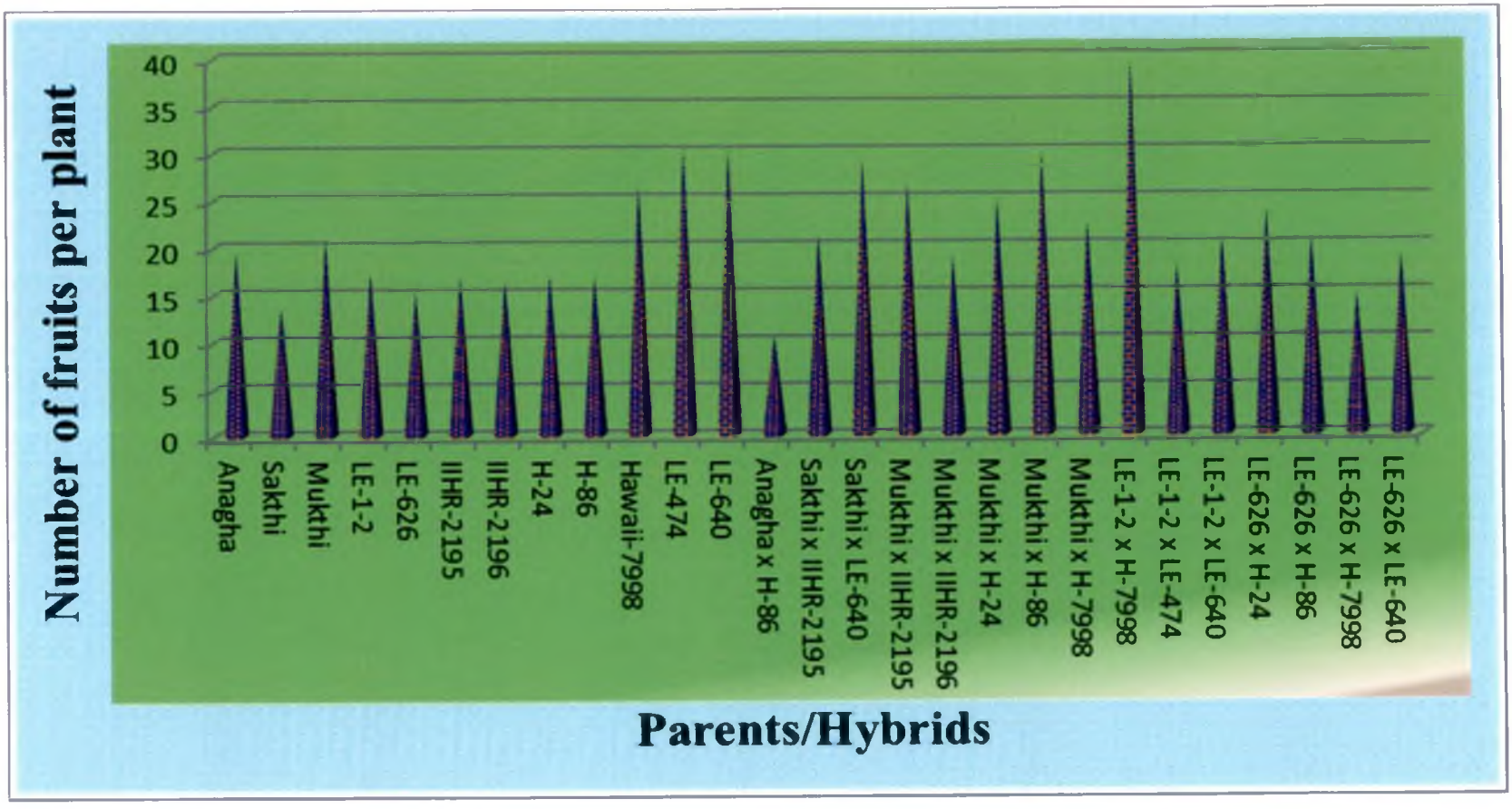



**Fig-4 Mean performance of parents and $F_1$ hybrids for Number of fruits per plant**

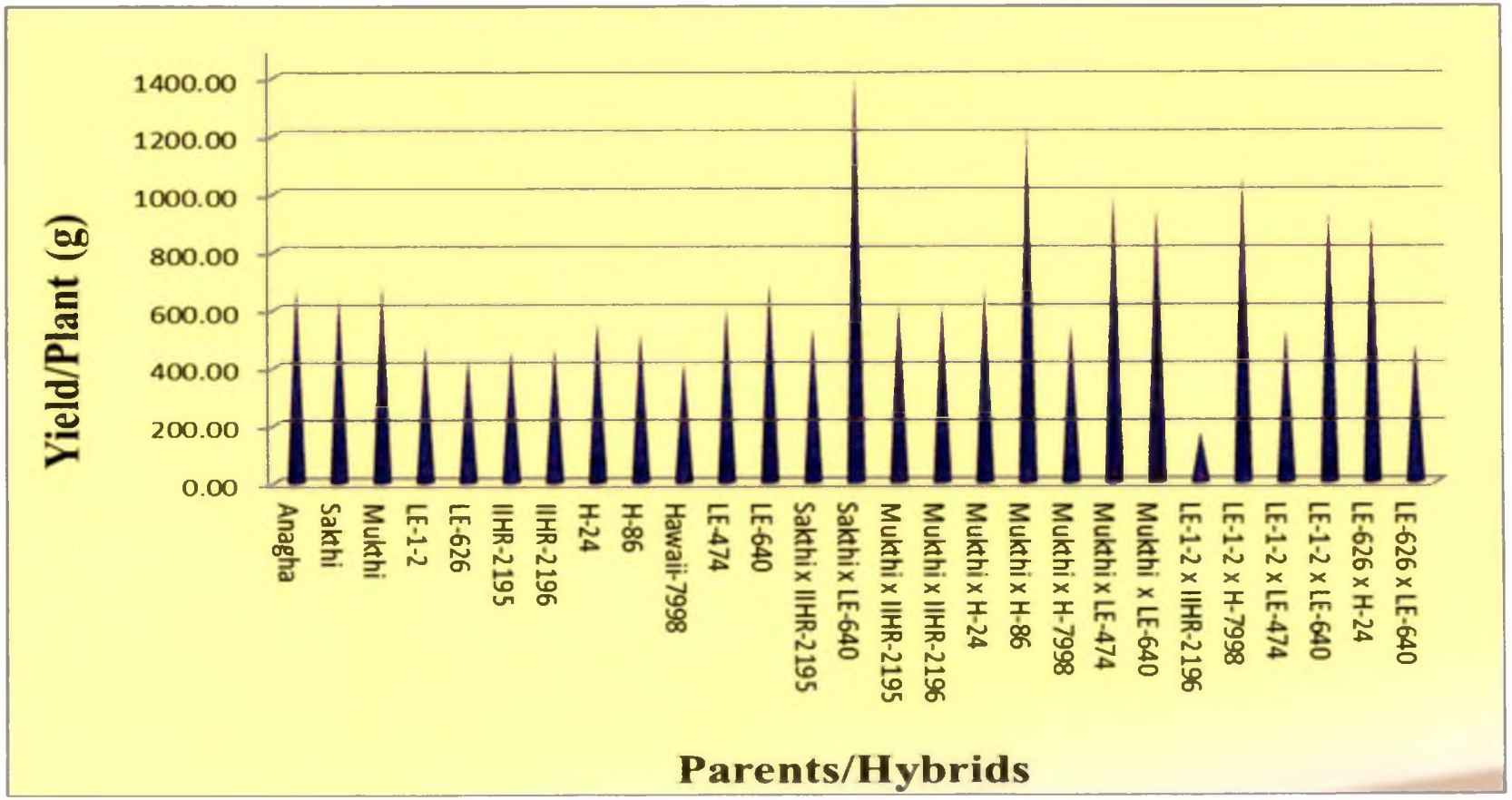



**Fig-5 Mean performance of parents and $F_1$ hybrids for Yield per plant (g)**

(2000), Bhushana (2000) and Patil (2001) reported significant positive heterosis for this trait.

### 5.3.3.7 Average fruit weight

Significant gca effects for average fruit weight were found maximum in Sakthi, LE-474 and LE-640 (7.05, 2.93 and 2.80 respectively). Anagha x IIHR-2195 (25.70), LE-1-2 x LE-474 (11.12), Anagha x LE-474 (9.71) and Mukthi x IIHR-2196 (8.18) hybrid combinations showed highly significant positive sca effects. The maximum sized fruits were produced by Anagha x IIHR-2195 (55.93 g) followed by Sakthi x LE-640 (55.78 g) and Sakthi x IIHR-2196 (55.09 g) (Fig-6). These hybrids also had maximum sca. Heterobeltiosis was found maximum in hybrid Sakthi x LE-640 (41.86 per cent). Relative heterosis was observed maximum in Sakthi x Hawaii-7998 (39.62 per cent). Standard heterosis was found maximum in the cross Anagha x IIHR-2195 (31.41 per cent). Tendulkar (1994), Sadhankumar (1995), Dharmatti (1995), Rani (2000) and Bhushana (2000) have reported significant positive heterosis for this trait.

### 5.3.3.8 Number of locules per fruit

Hawaii-7998 (0.52), LE-474 (0.39) and H-24 (0.23) showed significant gca effects for number of locules per fruit. LE-626 x H-86 (0.86), Sakthi x IIHR-2195 (0.83) and LE-1-2 x H-86 (0.56) hybrids showed significant positive sca effects. Maximum heterobeltiosis and relative heterosis was found in the cross Anagha x IIHR-2195. Standard heterosis was found maximum in the cross LE-626 x LE-474. Anbu *et al.* (1981), Dundi (1991) and Rai *et al.* (1996) reported increases number of locules per fruit in the $F_1$ hybrid.

### 5.3.3.9 Ascorbic acid (mg/100g)

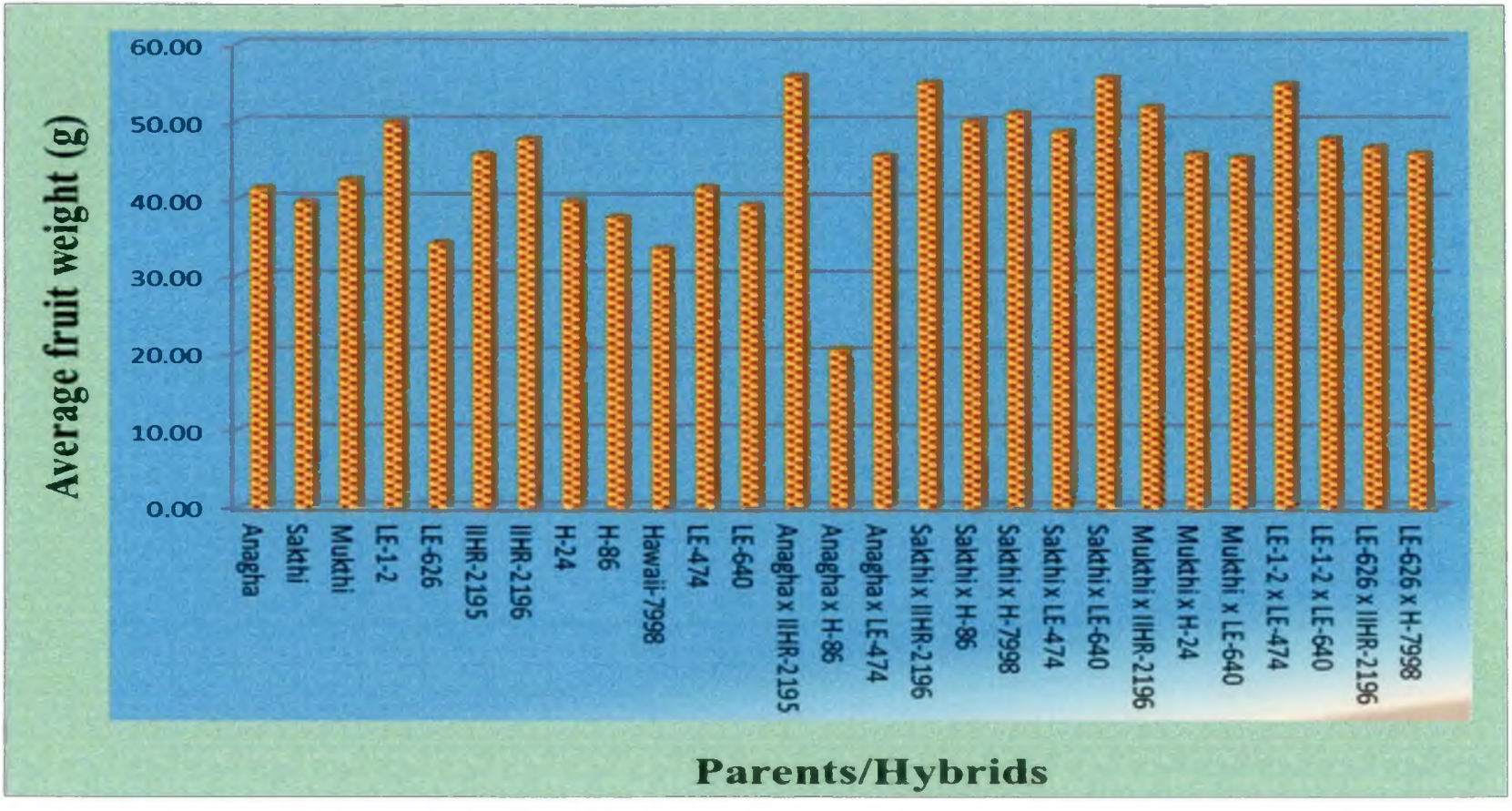



**Fig-6 Mean performance of parents and $F_1$ hybrids for Average fruit weight (g)**

Among the parents only LE-626 (2.36) and IIHR-2196 (0.98) and Anagha (0.78) showed highly significant positive gca effects. Among the hybrids Anagha x LE-640 has the maximum ascorbic acid content (28.44/100g$^{-1}$). Significant positive sca effects were expressed by LE-1-2 x LE-474 (3.45) and Sakthi x H-86 (3.34). Heterobeltiosis, relative heterosis and standard heterosis were positive, significant and maximum in the same hybrid Anagha x LE-640 (232.63 per cent, 243.69 per cent and 240.60 per cent respectively). Significant positive heterosis was observed by Nagaraja (1995) and Grace Sharon (2002).

High levels of ascorbic acid in tomato fruits provide health benefits for humans and also play an important role in several aspects of plant life. In plant, ascorbic acid is a co-factor for many enzymes, contributes to detoxify reactive oxygen species and is important for resistance against biotic and abiotic stress, senescence regulation and floral induction (Athar *et al.* 2008). Ascorbic acid is also implicated in biosynthesis and signalling of many plant hormones, controls stomata function and it is involved in photosynthesis, root development and nutrient uptake (Athar *et al.* 2008). The Ascorbic acid content in the plant will enhance the resistance to bacterial wilt (Sadhankumar, 1995).

**5.3.3.10 Acidity**

The mean square due to general combining ability was not significant for acidity. LE-1-2 x IIHR-2195 (0.07) hybrid combination exhibited considerable positive value for specific combing ability. Mukthi x IIHR-2196 has expressed the maximum acidity per cent (0.59). Positive, significant and maximum heterobeltiosis, relative heterosis and standard heterosis were observed in the same hybrid Mukthi x IIHR-2196 (58.11 per cent, 64.79 per cent and 72.06 per cent respectively). Bhushana (2000) and Patil (2001) observed significant negative heterosis.

In Kerala and other South Indian states, acidic tomatoes are preferred by many consumers. In the present study Sakthi (0.58 per cent), IIHR-2195 (0.40 per cent) and LE-474 (0.39 per cent) were found to have high acidity per cent. Among hybrids Mukthi x IIHR-2196 (0.58), Mukthi x H-24 (0.55) and Sakthi x LE-640 (0.53) recorded high acidity per cent.

### 5.3.3.11 Total sugars and reducing sugars

As evidenced by gca effects H-86, LE-626 and IIHR-2195 were good general combiners for total sugars. LE-1-2 x H-24 and Anagha x H-86 showed significant positive sca effects (0.83 and 0.82 respectively). Maximum heterobeltiosis and relative heterosis were observed in Anagha x H-86 (41.92 and 48.92 per cent respectively). Standard heterosis were found maximum in the cross LE-1-2 x H-24 (23.58 per cent).

Among the parent LE-626 (0.21) exhibited high positive gca effect apart from the other parents. The hybrids with high sca effects for reducing sugars were Sakthi x LE-474 (0.33) and LE-1-2 x IIHR-2195 (0.29). Maximum heterobeltiosis of 70.03 per cent was found in LE-626 x H-86. Maximum relative heterosis was observed in the cross LE-626 x H-24 (87.59 per cent). Standard heterosis was found maximum in the cross LE-626 x IIHR-2196 (13.36 per cent).

The flavour of tomato is determined by the amount of sugar and acid present. Sugars, acids and their interactions are important to sweetness, sourness and overall flavour intensity in tomatoes (Stevens *et al.*, 1977). High sugars and relatively high acids are required for the best flavour. High acids and low sugars will produce a tart tomato while high sugars and low acids will result in a bland taste, insipid tomato (Kader, 1986). Soluble solid content and titratable acidity, the main components responsible for tomato flavour (Flores *et al.*, 2008), are properties of the tomato most likely to match the consumer perception of the internal quality (Arazuri *et al.*, 2007).

### 5.3.3.12 Total soluble solids (TSS)

Mukthi (0.62) and Anagha (0.31) exhibited significant positive general combining ability. Significant high positive specific combing ability effects were exhibited by LE-626 x LE-640 (0.75) and Mukthi x IIHR-2196 (0.62) hybrid combinations. Among the parents and hybrids tested Mukthi x IIHR-2196 hybrid (6.40 per cent) has the highest per cent of total soluble solids. Maximum heterobeltiosis and standard heterosis were observed in the cross Mukthi x IIHR-2196 (5.79 per cent and 5.44 respectively). Maximum relative heterosis of 18.81 per cent was found in Anagha x Hawaii-7998. The present results concur with the findings of Tendulkar (1994), Nagaraja (1995) and Patil (2001).

According to Mizrahi *et al.* (1988), total soluble solids (TSS) content is the most important quality criterion for tomato paste processing and serves as the base for fixing the price to be paid to the producer. High soluble solids content is a desirable characteristic for the canned tomatoes industry since at improves the quality of the processed product (DePascale *et al.*, 2001). Higher solid content in fruits is a target characteristic, as this would reduce the cost for processing. The sugars are mostly glucose and fructose and constitute about 65% of total soluble solid in expressed fruit juice (Winsor *et al.*, 1962).

### 5.3.3.13 Shelf life

Shelf life is the most important criteria in transport of vegetables. Tomatoes with good shelf life are preferred for transport. As the tomato is a highly perishable vegetable, post-harvest losses will be less in genotypes with more shelf life. In the present study IIHR-2196 had the maximum shelf life (24.47 days). $F_1$ hybrids exceed this. Among the hybrids Mukthi x H-86 has the maximum shelf life (28.28 days) (Fig-7). Mukthi (3.49), LE-1-2 (1.37) and LE-626 (1.33) recorded significant high positive gca effects for

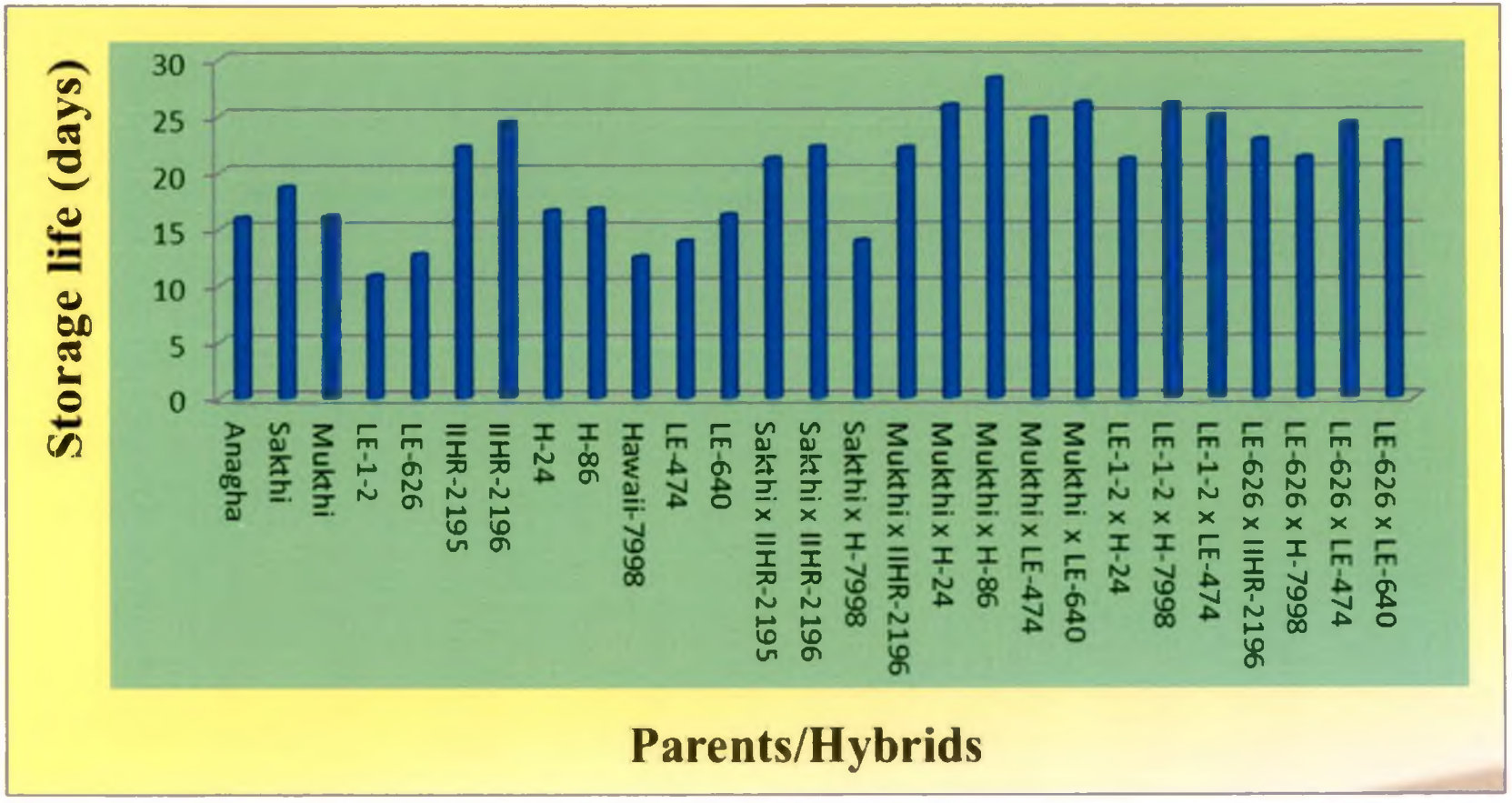



**Fig-7 Mean performance of parents and $F_1$ hybrids for storage life in days**

shelf life. Hybrids LE-1-2 x Hawaii-7998 (4.87), Sakthi x IIHR-2195 (4.40), Sakthi x IIHR-2196 (4.38) and Mukthi x H-86 (4.28) showed significant positive specific combining ability effects for shelf life. Maximum heterobeltiosis and relative heterosis were found in LE-1-2 x Hawaii-7998 (107.55 and 122.14 respectively). Standard heterosis was found maximum in the cross Mukthi x H-86 (75.84 per cent).

### 5.3.3.14 Fruit shape index

LE-626 (0.07), LE-1-2 (0.06), LE-474 (0.06) and H-24 (0.05) expressed significant positive gca effects for fruit shape index. The crosses with high positive specific combining ability effects for fruit shape index were Anagha x H-24 (0.18) and Sakthi x H-86 (0.16). Maximum heterobeltiosis of 15.68 per cent was found in Sakthi x H-86. Maximum relative heterosis was observed in the cross LE-626 x IIHR-2196 (15.09 per cent). Standard heterosis was found maximum in the cross Anagha x H-24 (21.90 per cent). Reddy and Reddy (1994), Tendulkar (1994) and Kulkarni (1999) have reported significant positive heterosis for this trait.

Fruit shape index has a direct positive effect on insoluble solids. With increased insoluble solids, other fruit qualities such as total solids, consistency, lycopene, pH and pericarp thickness were enhanced but the levels of acidity, reducing sugar, and number of locules/fruit decrease.

### 5.3.3.15 Fruit cracking

Significant high negative gca effects were observed for fruit cracking in Anagha (-0.65), IIHR-2195 (-0.65) and IIHR-2196 (-0.65). No fruit cracking was observed in most of the hybrids. Hybrid combination Anagha x LE-640 showed the highest negative value for sca effect (-2.18) followed by Mukthi x LE-640 (-1.19) and LE-1-2 x LE-640 (-1.09). Standard heterosis was not observed in all 35 hybrids. Heterobeltiosis and relative heterosis were negative, significant and maximum for fruit cracking in

hybrid LE-626 x H-24 (-100.00 per cent and -100.00 per cent respectively) followed by LE-1-2 x H-7998 (-100.00 per cent and -100.00 per cent respectively).

### 5.3.4 Evaluation of $F_2$ progenies for combined resistance to bacterial wilt and ToLCV disease

The $F_2$ population was screened for bacterial wilt and ToLCV and selections were made based on average fruit weight, number of fruits per plant, total yield per plant and earliness to harvest. The $F_2$ segregants of Mukthi x IIHR-2195, Mukthi x IIHR-2196, Mukthi x H-24, Mukthi x H-86, Sakthi x IIHR-2195, Sakthi x IIHR-2196, Sakthi x H-86 and Sakthi x Hawaii-7998 were found resistant to both bacterial wilt and ToLCV disease.

$F_2$ progenies of Anagha x Hawaii-7998, Mukthi x H-86 recorded the maximum plant height. And the minimum plant height was observed in the $F_2$ progenies of LE-1-2 x H-24 and LE-1-2 x IIHR-2195.

The $F_2$ segregants of Sakthi x IIHR-2196, LE-626 x IIHR-2195, Sakthi x H-24, Sakthi x H-86, Mukthi x Hawaii-7998 and LE-626 x IIHR-2196 recorded the highest value for number of branches per plant.

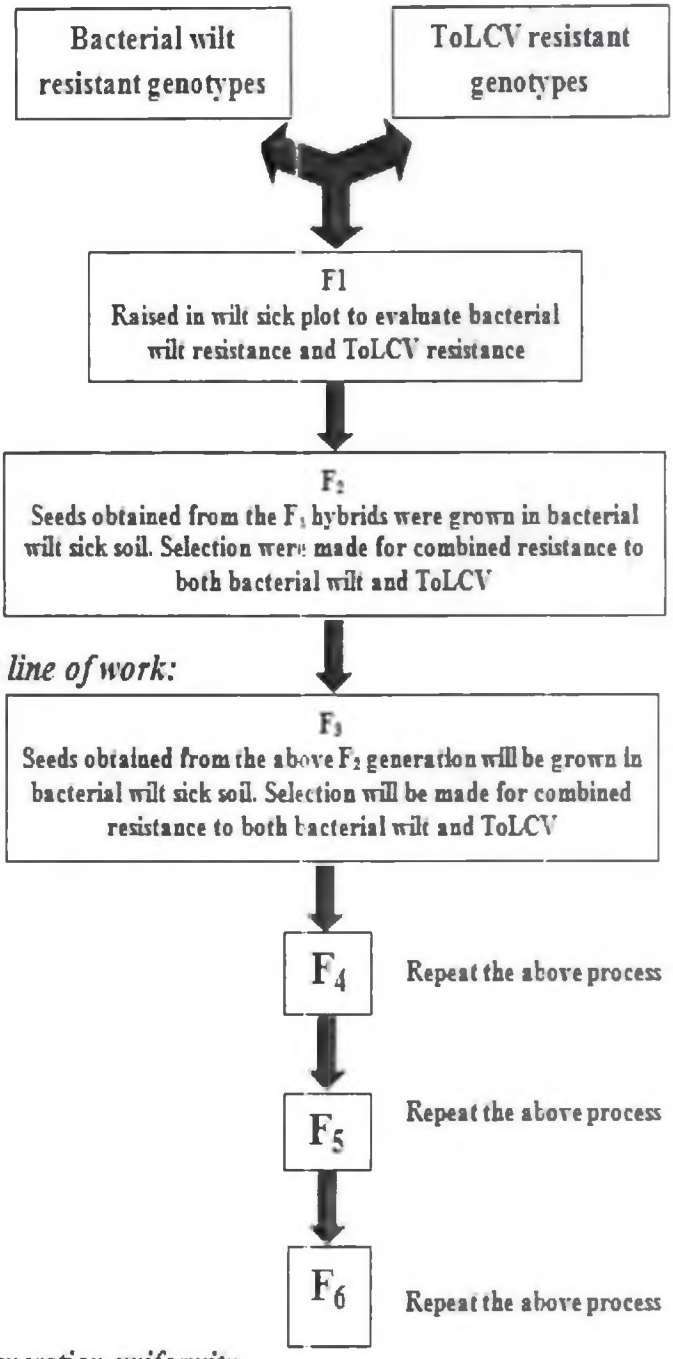
The earliness can be evaluated from the factors like days to flowering and days to first harvest. $F_2$ progenies of Anagha x IIHR-2195 were the earliest to flower followed by Anagha x IIHR-2196. The same hybrids were also earliest for days to harvest.

Average fruit weight and number of fruits per plant are two important characters which directly correlate to the yield per plant. Average fruit weight was found maximum in $F_2$ progenies of Mukthi x IIHR-2196, LE-1-2 x LE-640 and Mukthi x LE-640. Maximum number of fruits per plant was observed in Mukthi x H-24, Mukthi x H-86 and Mukthi x IIHR-2195.

Yield per plant, which is one of the important consideration in any breeding programme is mainly determined by the number of fruits per plant and average fruit weight. High values for yield per plant was recorded for the $F_2$ progenies of Mukthi x IIHR-2195, Mukthi x IIHR-2196, Sakthi x Hawaii-7998 and Sakthi x H-86.

The primary objective of the present study was to develop tomato genotypes with combined resistance to bacterial wilt and ToLCV. In the study 30 such $F_2$ segregants could be identified. One disadvantage with respect to many of the bacterial wilt is their small fruit size. In the present study 11segregants could be identified which have an average fruit weight of more than 45 g. These segregants can be further improved by advancing generations up to $F_6$ for evolving varieties with combined resistance to bacterial wilt and ToLCV. Schematic representation of the breeding technology to be followed is given below.

Schematic representation of breeding technology



### 5.3.5 Genetics of ToLCV resistance

To formulate breeding strategies for evolving disease resistant varieties, knowledge of inheritance pattern of disease resistance is considered as a pre-requisite.

Resistance to ToLCV was evaluated in two parents Pusa Ruby and IIHR-2195 their $F_1$, $F_2$, $B_1$, and $B_2$ generations.

In the $F_1$ 16 plants out of 20 showed resistance. This points to the dominance of resistance over susceptibility. The $F_2$ segregation ratio was in agreement with the Mendelian genetic ratio of 3:1 (Resistant : Susceptible). The reactions of the test cross $B_1$ ($F_1$ back crossed to Pusa Ruby) confirmed this with a genetic ratio of 1:1 (Resistant : Susceptible) and the $B_2$ ($F_1$ back crossed to IIHR-2195) generation reaction to ToLCV fits into a genetic ratio of 1:0 (Fig-8).

The inheritance studies in six generations of cross combination Pusa Ruby x IIHR-2195 clearly revealed that the resistance to ToLCV in IIHR-2195 is controlled by a single dominant gene. Kasrawi (1989) noted single dominant gene governing the ToLCV resistance in *L. pimpinellifolium*. The resistance gene to ToLCV in tomato is incompletely dominant (Chomdej *et al.*, 2007). Singh *et al.* (2008) observed that the gene action for resistance to ToLCV in tomato variety H-24 is single completely dominant gene.

As the gene governing the resistance to ToLCV in IIHR-2195 is single dominant, hybridization followed by selection for yield and desirable horticultural attributes will be required to incorporate ToLCV resistance in commercially superior varieties. As the resistance is governed by single dominant gene, it can be easily incorporated in $F_1$ hybrids.

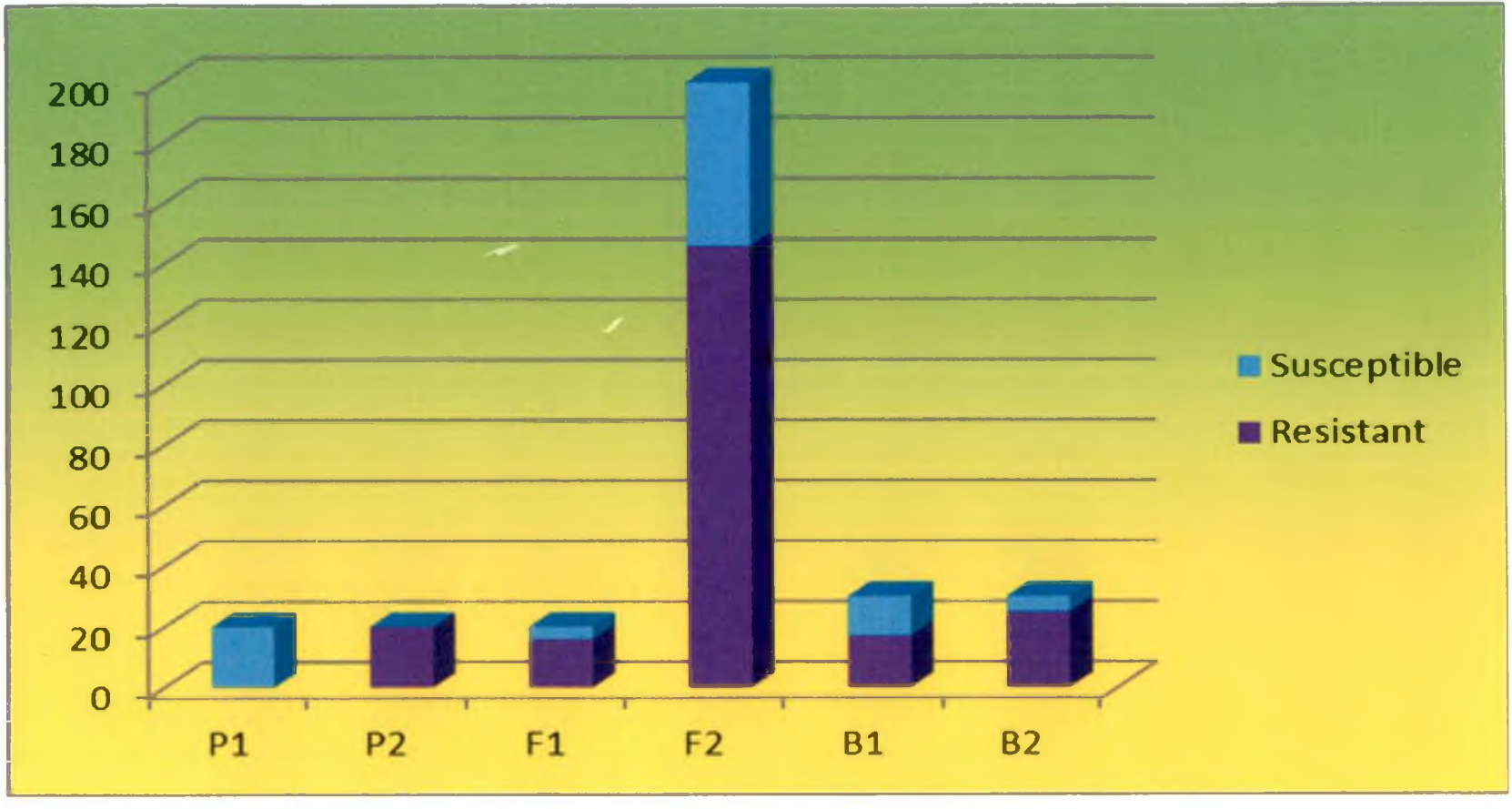



Fig-8 All generations reaction to ToLCV comparison

# *Summary*

## 5. SUMMARY

The investigations on "Incorporation of Tomato Leaf Curl Virus (ToLCV) resistance in bacterial wilt resistant tomato" were carried out during January, 2009 to June, 2011 at the Department of Olericulture, College of Horticulture, Vellanikkara.

1. Eighty tomato genotypes were screened for ToLCV resistance. Of these 26 (LE-474, LE-635, LE-640, LE-641, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2199, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998, Rani, TTI-11, TTI-18, TTI-21 and TTI-29) were highly resistant to ToLCV.

2. Twenty six genotypes which were highly resistant in natural screening were artificially inoculated by cleft grafting transmission to confirm the resistance to ToLCV. In these genotypes. 20 genotypes (LE-474, LE-635, LE-640, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998 and Rani) remained highly resistant after the graft transmission and remaining six genotypes (LE-641, IIHR-2199, TTI-11, TTI-18, TTI-21 and TTI-29) showed symptoms of tomato leaf curl virus disease.

3. Twenty genotypes which were highly resistant in graft transmission along with known susceptible Pusa Ruby were artificially inoculated by whitefly transmission to confirm their resistance to ToLCV. All 20 genotypes (LE-474, LE-635, LE-640, LE-658, LE-666, LE-667, Arka Ananya, IIHR-2195, IIHR-2196, IIHR-2197, IIHR-2198, IIHR-2202, IIHR-2747, TLBRH-1, TLBRH-6, Cherry Tomato, H-24, H-86, Hawaii-7998 and Rani) remained highly resistant after the whitefly transmission while Pusa

Ruby showed typical symptoms of tomato leaf curl virus disease. This confirms the resistance reaction of these 20 genotypes to ToLCV.

4. Among the seventy six tomato genotypes screened for bacterial wilt resistance, Anagha, LE-1-2, LE-474, Sakthi, LE-626 and Mukthi were resistant to bacterial wilt with a PDI of 10.0, 13.3, 13.3, 16.7, 16.7 and 19.0 respectively. Additional sources of resistance to bacterial wilt were identified in LE-628, LE-640 and LE-649 which were resistant to bacterial wilt with PDI of 13.3, 16.7 and 20.0 respectively.

5. Five selected bacterial wilt resistant lines (Anagha, Shakti, Mukthi, LE-1-2 and LE-626) were crossed with seven ToLCV resistant lines (IIHR-2195, IIHR-2196, H-24, H-86, Hawaii-7998, LE-474 and LE-640) in a line x tester fashion to evolve 35 $F_1$ hybrids. Parental combinations which resulted in heterotic $F_1$ hybrids were identified for different characters.

6. The thirty five $F_1$ hybrids developed were screened for both ToLCV and bacterial wilt resistance.

7. Among the 35 hybrids, 16 hybrids possessed combined resistance to ToLCV and bacterial wilt.

8. Among the 35 hybrids, 30 hybrids displayed resistance to ToLCV disease.

9. Among the 35 hybrids, Mukthi x Hawaii-7998, Mukthi x LE-474, Mukthi x LE-640, LE-1-2 x IIHR-2195, LE-626 x LE-474, LE-1-2 x LE-474, Sakthi x LE-640, LE-1-2 x Hawaii-7998, LE-1-2 x IIHR-2196, LE-626 x IIHR-2196, Anagha x Hawaii-7998, LE-626 x LE-640, Anagha x LE-474, Anagha x LE-640, Sakthi x Hawaii-7998 and Sakthi x LE-474 were resistant to bacterial wilt.

10. $F_1$ hybrids which had highest *per se* performance were LE-1-2 x Hawaii-7998 (39.67 fruits/plant) for fruits per plant, Sakthi x LE-640 (1.4 kg/plant) for fruit yield per plant, Anagha x IIHR-2195 (55.93 g) for

average fruit weight and Mukthi x H-86 for maximum shelf life (28.28 days).

11. Good general combiners for different characters were identified. Good general combiners were Hawaii-7998 for plant height, LE-474 (for dwarfness), H-24 (for days to flowering and days to harvest), Mukthi for number of branches per plant, number of fruits per plant, total soluble solids and increased shelf life. Sakthi was the best general combiner for average fruit weight and LE-640 for yield per plant.

12. The $F_2$ population was screened for combined resistance to ToLCV and bacterial wilt.

13. Among the $F_2$ segregants Mukthi x IIHR-2195-$F_2$-24, Mukthi x IIHR-2195- $F_2$-25, Mukthi x IIHR-2195- $F_2$-31, Mukthi x IIHR-2195- $F_2$-34, Mukthi x IIHR-2195- $F_2$-36, Mukthi x IIHR-2195- $F_2$-38, Mukthi x IIHR-2195- $F_2$-40, Mukthi x IIHR-2195- $F_2$-41, Mukthi x IIHR-2195-F2-47, Mukthi x IIHR-2195- $F_2$-54, Mukthi x IIHR-2195- $F_2$-58, Mukthi x IIHR-2196- $F_2$-16, Mukthi x IIHR-2196- $F_2$-43, Mukthi x IIHR-2196- $F_2$-45, Mukthi x IIHR-2196- $F_2$-57, Mukthi x IIHR-2196- $F_2$-66, Mukthi x IIHR-2196- $F_2$-71, Mukthi x IIHR-2196- $F_2$-72, Mukthi x IIHR-2196- $F_2$-73, Mukthi x IIHR-2196- $F_2$-78, Mukthi x IIHR-2196- $F_2$-80, Mukthi x H-24- $F_2$-10, Mukthi x H-86- $F_2$-32, Sakthi x IIHR-2195- $F_2$-58, Sakthi x IIHR-2196- $F_2$-6, Sakthi x IIHR-2196- $F_2$-18, Sakthi x IIHR-2196- $F_2$-20, Sakthi x H-86- $F_2$-75, Sakthi x Hawaii-7998- $F_2$-81and Sakthi x Hawaii-7998- $F_2$-91 which were found promising and resistant to both ToLCV and bacterial wilt. These segregants can be further improved by advancing generations for evolving varieties with combined resistance to bacterial wilt and ToLCV.

14. Segregation pattern in $F_1$, $F_2$, $B_1$ and $B_2$ revealed that the resistance to ToLCV in IIHR-2195 is controlled by a single dominant gene.

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