

**STUDIES ON LEAF CURL DISEASE OF TOMATO
CAUSED BY *TOMATO LEAF CURL VIRUS***

Ph. D. Thesis

by

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**DEPARTMENT OF PLANT PATHOLOGY
COLLEGE OF AGRICULTURE
FACULTY OF AGRICULTURE
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**STUDIES ON LEAF CURL DISEASE OF TOMATO
CAUSED BY *TOMATO LEAF CURL VIRUS***

Thesis

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CERTIFICATE – I

This is to certify that the thesis entitled “**Studies on leaf curl disease of tomato caused by *Tomato leaf curl virus***” submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Kamalnarayan Koshale** under my/our guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigations have been duly acknowledged.

Date: 20/07/2018


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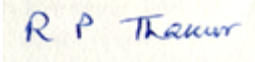


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LIST OF NOTATIONS/SYMBOLS

%	Percent	μM	Micromolar
@	At the rate of	$\sim$	Approximately, about, around
<	Less than	$\pm$	Tolerance or statistical margin of error
$\approx$	Approximately, about	$^{\circ}\text{C}$	Degree Celsius
μl	Microlitre	∞	Infinity
a.i.	Active ingredient	a.i. ha^{-1}	Active ingredient per hectare
anon.	Anonymus	bp	Base pair
cm	Centimetre	e.g.	For example
<i>et al</i>	And other people	Fig	Figure
g	Gram	g l^{-1}	Gram per litre
g mol^{-1}	Gram per mole	ha	Hectare
hr	Hour	i.e.	That is
kb	Kilo base	kDa	Kilo Dalton
kg	Kilogram	kg plot^{-1}	Kilogram per plot
kmph	Kilometre per hour	l	Litre
l ha^{-1}	Litre per ha	lb sq.in.^{-1}	Pound per square inch
M	Molar	m	Metre
mg	Milligram	min	Minute
ml	Millilitre	ml l^{-1}	Millilitre per litre
mm	Millimetre	mM	Millimolar
$\text{ng } \mu\text{l}^{-1}$	Nanogram per microlitre	nm	Nanometre
nt	Nucleotide	OD	Oil dispersion
pH	Power of hydrogen	q ha^{-1}	Quintal per hectare
SC	Suspension concentrate	sec	Second
SL	Soluble liquid	sq m	Square metre
$\text{U } \mu\text{l}^{-1}$	Unit per microlitre	viz.	Namely, that is to say, as follows
WG	Water dispersible granule		

LIST OF ABBREVIATIONS

AVT	Advanced varietal trail
BGCP	Begomovirus coat protein
cccdsDNA	covalently closed circular double strandedDNA
CP	Coat protein
cssDNA	circular single stranded DNA
CTAB	Cetyl trimethylammonium bromide
DNA	Deoxyribo nucleic acid
dNTPs	Deoxyribonucleotide triphosphate
EDTA	Ethylenediaminetetraacetic acid
IET	Initial evaluation trail
MP	Movement protein
NSP	Nuclear shuttle protein
ORF	Open reading frame
PAGE	Polyacrylamide gel electrophoresis
PCR	Polymerase chain reaction
PDI	Percent disease index
RBD	Randomized block design
RCA	Rolling circle amplification
REn	Replication enhancer
Rep	Replicase protein
RNA	Ribonucleic acid
TBE	Tris-borate-EDTA
TE	Tris EDTA
ToLCD	Tomato leaf curl disease
ToLCGV	<i>Tomato leaf curl Gujrat virus</i>
ToLCNDV	<i>Tomato leaf curl New Delhi virus</i>
ToLCV	<i>Tomato leaf curl virus</i>
TrAP	Transactivator protein
WTGs	Whitefly transmitted geminiviruses

THESIS ABSTRACT

-
a) Title of the Thesis	: Studies on leaf curl disease of tomato caused by <i>Tomato leaf curl virus</i>
b) Full Name of the Student	: Kamalnarayan Koshale
c) Major Subject	: Plant Pathology
d) Name and Address of the Major Advisor	: Dr. C. P. Khare, Professor, Department of Plant Pathology, College of Agriculture, IGKV, Raipur (Chhattisgarh)
e) Degree to be Awarded	: Ph. D. (Ag.) Plant Pathology
-

Signature of the Student

Signature of Major Advisor

Date: 20/07/2018

Signature of Head of the Department

ABSTRACT

The present study on “Studies on leaf curl disease of tomato caused by *Tomato leaf curl virus*” was carried out during 2014-2018. All the field experiments were Raipur during 2014-15 to 2017-2018. Polyhouse study was carried out at Centre of Excellence, IGKV, Raipur (C.G) in 2015-16 and 2016-17. A laboratory work was performed in Department of Plant Molecular Biology and Biotechnology, Dr. R.H. Richharia Research Laboratory, IGKV, Raipur (C.G). The seasonal occurrence of prevalent diseases of tomato was recorded under field and polyhouse conditions. In field condition the tomato crop was infected with five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot in both the seasons (*Rabi* and *Kharif*). In polyhouse conditions four diseases viz. leaf curl, mosaic, early blight and collar rot infected the tomato crop. Two samples (Raipur and Rasni) of leaf curl disease was found positive for virus and this was identified as *Tomato leaf curl virus* by PCR amplification with two primers viz., AV1 and ToLCV MP, which provided amplified

DNA fragments of approximately 800 bp and 200 bp, respectively. The activity of adult whitefly (*Bemisia tabaci*) and occurrence of disease was observed at 7 and 14 days after transplanting in *Rabi* and *Kharif*, respectively. In *Rabi* the correlation of leaf curl was significantly positive with whitefly population, T max, wind speed and T min and negative with RH max and RH gr. The weather parameters jointly contribute around 88.80 percent ($R^2 = 0.888$) impact on population of whitefly (*B. tabaci*). The change in whitefly population significantly influenced the percent incidence of leaf curl ($b = 9.200$). There was a significant positive correlation ($b = 0.719$) between percent incidence and PDI of leaf curl. In *Kharif* the correlation of leaf curl was significantly positive with whitefly population, T gr, RH gr and sun shine hour or intensity and negative with T min, rainfall, RH min and wind velocity. The weather parameters were found to contribute around 89.50 percent ($R^2 = 0.895$) impact on population of whitefly when acted together. The unit change in whitefly population significantly affect the incidence of leaf curl ($b = 8.064$). The percent leaf curl incidence, population of whitefly and weather parameters jointly contribute 95.30 percent ($R^2 = 0.953$) effect on percent disease index of leaf curl. The unit increase in percent leaf curl incidence showed significant positive increase ($b = 0.805$) of percent disease index. Among the nineteen ToLCVRES entries/ varieties evaluated only one entry (2016/ToLCVRES-1) was moderately resistant against ToLCD and the higher total yield ha^{-1} was recorded in 2015/ToLCVRES-5 (636.04 q), 2016/ToLCVRES-1 (631.81 q) and 2014/ToLCVRES-5 (565.35 q). Out of twenty three commercial varieties ten varieties viz. Bharani, Bhagyanwan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham and NS 962 showed constant resistant reaction, four varieties viz. MHTM 256, Anvitha, Nun 7610 and Kundan were moderately resistant one (Red Ruby) was was moderately susceptible against ToLCD. The maximum per ha yield (471.22 q) was recorded in cv. Arka Rakshak followed by Bharani (419.49 q), Abhilash (412.43 q), Bhagyanwan (386.11 q) and Priya-6636 (327.35 q). Among the determinate tomato two entries viz. 2016/ToDVAR-5 and 2016/ToDVAR-12 expressed resistant and one (2014/TODVAR-5) showed moderately resistant reaction against ToLCD. The higher yield was recorded from 2016/TODVAR-12 (344.08 q), H-86 (337.34 q) and 2016/TODVAR-5 (332.07 q) entries. In cherry tomato group, two entries (2015/TOCVAR-4 and 2015/TOCVAR-5) showed moderately resistant reaction and other two entries viz. 2015/TOCVAR-1 and 2015/TOCVAR-3 were moderately susceptible against the disease. The maximum total yield ha^{-1} (301.64 and

331.09 q) was noted in Swarna Ratan. Two entries (2015/TOINDVAR-4 and 2015/TOINDVAR-5) of indeterminate tomato showed moderately resistant reaction in both the years. The maximum yield ha^{-1} (384.41 q) was obtained from 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (321.65 q). Among the five insecticides evaluated the lowest disease incidence (8.84 %), disease index (5.35 %) and vector population (1.78 per ten leaves) with highest marketable yield (316.55 q ha^{-1}) and cost benefit ratio (1:2.62) was recorded in T5 (Thiamethoxam) followed by T₄ (Buprofezin) and T₃ (Cyantraniliprole / Cyazypyr).

शोधग्रन्थ सारांश

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विभागाध्यक्ष का हस्ताक्षर

सारांश

वर्तमान अध्ययन 2014–2018 के दौरान "टमाटर के पर्ण कुंचन विषाणु के कारण टमाटर की पत्ती की कुंचन रोग पर अध्ययन" पर किया गया। सभी क्षेत्र प्रयोग बागवानी निर्देश सह शोध फार्म, कृषि कॉलेज, रायपुर में 2014–15 से 2017–2018 के दौरान आयोजित किए गए। पॉली हाउस अध्ययन 2015–16 और 2016–17 में उत्कृष्टता केंद्र, आई जी के वी, रायपुर में किया गया। प्लांट आविष्क जीवविज्ञान और जैव प्रौद्योगिकी विभाग, डॉ आर एच रिचरिया रिसर्च लेबोरेटरी, आई जी के वी, रायपुर (सी.जी.) में एक प्रयोगशाला का काम किया गया। टमाटर की प्रचलित बीमारियों की मौसमी घटना क्षेत्र और पॉली हाउस की स्थितियों के तहत दर्ज की गई थी। क्षेत्र की स्थिति में टमाटर की फसल पांच बीमारियों से संक्रमित थी। पत्ते के कर्ल, मोजेक, टमाटर ने देखा मौसम, जल्दी ब्लाइट और कॉलर रोट दोनों मौसमों (रबी और खरीफ) में हुआ था। पॉली हाउस की स्थितियों में चार रोगों जैसे कि। पत्ती कर्ल, मोजेक, प्रारंभिक ब्लाइट और कॉलर रोट टमाटर की फसल को संक्रमित करता है। पत्ती कर्ल रोग के दो नमूने (रायपुर और रसनी) को वायरस के लिए सकारात्मक पाया गया था और पीसीआर एम्पलीफिकेशन द्वारा दो प्राइमर्स जैसे एवी 1 और टीओएलसीवी एमपी के साथ टमाटर के पत्ते के कर्ल वायरस के रूप में पहचाना गया था, जो लगभग 800 बीपी और 200 बीपी के एम्पलीफाइड डीएनए टुकड़े प्रदान किए गए थे। बी और खरीफ सीजन में क्रमशः प्रत्यारोपण के बाद 7 और 14 दिनों में वयस्क सफेद मक्खी आर बीमारी की घटना की गतिविधि देखी गई।

रबी सीजन में पत्ती के कर्ल का रिश्ता सफेद उड़ान आबादी, अधिकतम तापमान, हवा की गति और न्यूनतम तापमान और ऋणात्मक आर्द्रता और सापेक्ष आर्द्रता ढाल के साथ नकारात्मक के साथ काफी सकारात्मक था। मौसम पैरामीटर संयुक्त रूप से 88.80 प्रतिशत (आर 2 = 0.888) का योगदान करते हैं जो सफेद मक्खी की आबादी पर प्रभाव डालते हैं। सफेद मक्खी आबादी में बदलाव ने पत्ती के कर्ल (बी = 9.200) की प्रतिशत घटनाओं को काफी प्रभावित किया। प्रतिशत घटनाओं का प्रभाव पत्ती कर्ल के प्रतिशत रोग सूचकांक के साथ काफी सकारात्मक (बी = 0.71 9) था। खरीफ सीजन में पत्ती के कर्ल का रिश्ता सफेद उड़ान आबादी, तापमान ढाल, सापेक्ष आर्द्रता ढाल और सूर्य चमक और न्यूनतम तापमान, वर्षा, न्यूनतम सापेक्ष आर्द्रता (और हवा वेग) के साथ नकारात्मक के साथ काफी सकारात्मक था। मौसम पैरामीटर एक साथ काम करते समय व्हाइटपलाई (बी ताबासी) की आबादी पर लगभग 89.50 प्रतिशत (आर 2 = 0.8 9 5) प्रभाव का योगदान करने के लिए पाए गए थे। व्हाइटपलाई आबादी में इकाई परिवर्तन महत्वपूर्ण रूप से पत्ती कर्ल (बी = 8.064) की घटनाओं को प्रभावित करता है। प्रतिशत पत्ती कल घटनाएं, व्हाइटपलाई और मौसम मापदंडों की जनसंख्या संयुक्त रूप से पत्ती के कर्ल के प्रतिशत रोग सूचकांक पर 95.30 प्रतिशत (आर 2 = 0.953) प्रभाव का योगदान करती है। प्रतिशत पत्ती कर्ल घटनाओं में इकाई की वृद्धि ने प्रतिशत रोग सूचकांक में उल्लेखनीय सकारात्मक वृद्धि (बी = 0.805) दिखायी। उन्नीस TOLCVRES प्रविष्टियों / किस्मों में मूल्यांकन किया गया केवल एक प्रविष्टि (2016 / TOLCVRES-1) को TOLCD के खिलाफ मामूली प्रतिरोधी था और उच्च कुल उपज हेक्टेयर 2015 / TOLCVRES-5 (636.04 किंव), 2016 / TOLCVRES-1 में दर्ज किया गया था (631.81 किंव) और 2014 / TOLCVRES-5 (565.35 किंव)। तेईस व्यावसायिक किस्मों में से तीन किस्मों जैसे भारानी, भाग्यवान, अभिलाश, करण, करीना, करिश्मा, वीएनआर -3357, लक्ष्मी, साक्षम और एनएस 9 62 ने निरंतर प्रतिरोधी प्रतिक्रिया, चार किस्मों जैसे एमएचटीएम 256, अनविथा, नून 7610 और कुंदन मामूली प्रतिरोधी थे (लाल रूबी) को टीओएलसीडी के खिलाफ मामूली रूप से अतिसंवेदनशील था। अधिकतम (471.22 किंव) प्रति हेक्टेयर कुल उपज अर्का रक्षक में दर्ज की गई, इसके बाद भारणी (41 9.4 9 किंव), अभिलाश (412.43 किंव), भाग्यवान (386.11 किंव) और प्रिया -6636 (327.35 किंव)। स्थिर टमाटर में दो प्रविष्टियां जैसे कि। 2016 / TODVAR-5 और 2016 / TODVAR-12 प्रतिरोधी व्यक्त किया गया और एक (2014 / TODVAR-5) ने TOLCD के खिलाफ मामूली प्रतिरोधी प्रतिक्रिया दिखाई। उच्च उपज 2016 / TODVAR-12 (344.08 किंव), एच -86 (337.34 किंव) और 2016 / TODVAR-5 (332.07 किंव) प्रविष्टियों से दर्ज की गई थी। चेरी टमाटर समूह में, दो प्रविष्टियां (2015 / TOCVAR-4 और 2015 / TOCVAR-5) ने मामूली प्रतिरोधी प्रतिक्रिया और अन्य दो प्रविष्टियों जैसे कि दिखाया। 2015 / TOCVAR-1 और 2015 / TOCVAR-3 रोग के खिलाफ मामूली रूप से अतिसंवेदनशील थे। स्वर्ण रतन में अधिकतम कुल उपज हे -1 (301. 64 और 331.0 9 किंव) उल्लेख किया गया था। अनिश्चित टमाटर के दो प्रविष्टियां (2015 / TOINDVAR-4 और 2015 / TOINDVAR-5) दोनों वर्षों में मामूली प्रतिरोधी प्रतिक्रिया दिखाती हैं। 2015 / TOINDVAR-5 से 2015 / TOINDVAR-4 (321.65 किंव) के बाद अधिकतम कुल उपज हे -1 (384.41 किंव) प्राप्त किया गया था। पांच कीटनाशकों में से सबसे कम बीमारी की घटनाओं (8.84 प्रतिशत), प्रतिशत रोग सूचकांक (5.35 प्रतिशत) और वेक्टर आबादी (1.78 प्रति दस पत्तियों) का मूल्यांकन उच्चतम विपणन योग्य उपज (316.55 किंव / हे) और लागत लाभ अनुपात (1: 2.62) टी 5 (थियामेथॉक्सम) में दर्ज किया गया था जिसके बाद टी 4 (बुप्रोफेज़िन) और टी 3 (साइन्ट्रानिलिप्रोल / साइजोपीर) था।

CHAPTER- I

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), a member of the family Solanaceae, is one of the most popular and extensively grown vegetables (Chaudhary *et al.*, 2010 and Singh *et al.*, 2015) of both tropics and subtropics of the world (Govindappa *et al.*, 2013). It is a herbaceous, annual, subtropical (Bora *et al.*, 2012) fruiting plant which is originated in Latin America and has become one of the most widely grown vegetables with ability to survive in diverse environmental conditions (Ssekyewa, 2006). It is grown in small kitchen gardens, protected structures (greenhouse, glasshouse, polyhouse and walk-in tunnels) and open fields. The name tomato probably derived from the word “Tomat” in the Nahua tongue of Mexico (Manjunatha, 2008). In England, tomato is popularly known as “love of apple” while, in India, it is commonly referred as “poor man’s Orange” (Rai and Yadav, 2005 and Mihretu and Bhalekar, 2016). Worldwide, the tomato ranks second in importance after the potato (Pradhan *et al.*, 2015, Mihretu and Bhalekar, 2016) while it ranks third in priority after potato and onion in India (Anonymous, 2017 and Nadkarni *et al.*, 2017).

In the world, tomato is cultivated over an area of 5.7 million ha with an annual production of 211.80 million metric tonnes with the productivity of 37.16 metric tonnes ha⁻¹ (Anonymous, 2016). In India, it occupies an area of about 0.80 million ha producing over 19.54 million metric tonnes with the productivity of 24.43 metric tonnes ha⁻¹ (Anonymous, 2017). In India, it is mainly grown in the states like Andhra Pradesh, Karnataka, Madhya Pradesh, Telangana, Odisha, Gujrat, Maharashtra, West Bengal, Bihar, and Chhattisgarh (Anonymous, 2015). In Chhattisgarh, approximately 50330 ha area is covered under tomato with a production of 0.81 million metric tonnes with an average productivity of 16.20 metric tonnes ha⁻¹ (Anonymous, 2015).

Importance of tomato is well established because of its nutritive value, high productivity, greater processing potentiality and wide ecological amplitude (Kakati and Nath, 2014). It is grown for its edible fruit, which can be consumed,

either raw as salads or cooked as a vegetable or in the form of various processed products such as juices, ketchups, paste, pickles, puree, sauces, etc (Bora *et al.*, 2012 and Sohrab *et al.*, 2016). The crop is grown for both fresh domestic and export market but there is increasing demand for processing (Bora *et al.*, 2012) and in India, tomato has been identified as a potential vegetable for export (Mihretu and Bhalekar, 2016).

It is an integral part of the daily human diet in many countries. Tomato and tomato-based products are considered as healthy foods for several reasons. They are very low in fat and calories, as well as being a good source of fibre. In addition, tomatoes are rich in carotenoids such as lycopene and β -carotene, vitamin C and other antioxidants including total phenols and provide micronutrients to supplement staple-based diets (Sain and Chadha, 2012, Govindappa *et al.*, 2013 and Shelat *et al.*, 2014).

There are many constraints that come in the way of tomato production (Mishra *et al.*, 2014). Among them diseases are the main constraints of tomato cultivation (Kakati and Nath, 2014). Tomato is known to be susceptible to more than 200 diseases (Shelat *et al.*, 2014), out of which buckeye rot (fruit rot)- *Phytophthora nicotianae* var. *parasitica* (Sharma and Dohroó, 2004), collar rot or Sclerotium wilt- *Sclerotium rolfsii* (Mahato *et al.*, 2017), damping off- *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii* (Rahman and Bhattiprolu, 2005 and Prasad *et al.*, 2017), early blight- *Alternaria solani* (Roopa, 2012), *Fusarium* wilt- *Fusarium oxysporum* f.sp. *lycopersici* (Manikandan and Raguchander, 2014), late blight (Olanya *et al.*, 2015), powdery mildew (Park *et al.*, 2010 and Cerkauskas and Brown, 2015), *Rhizoctonia* root rot- *Rhizoctonia solani* (Abdeljalil *et al.*, 2016 and Sumalatha *et al.*, 2017), *Septoria* leaf spot (Parker *et al.*, 1997 and Blum, 2000), bacterial fruit canker- *Clavibacter michiganensis* subsp. *michiganensis* (Ftayeh *et al.*, 2010 and Sharabani *et al.*, 2013), bacterial spot- *Xanthomonas campestris* pv. *vesicatoria* (Kavitha and Umesha, 2007), bacterial wilt- *Ralstonia solanacearum* (Ayana and Fininsa, 2016), bud blight- *Groundnut bud necrosis virus* (Manjunatha *et al.*, 2010), leaf curl disease- *Tomato leaf curl virus* (ToLCV) (Shelat *et al.*, 2014 and Yadav *et al.*, 2014), tomato mosaic- *Tomato mosaic virus* (Massumi *et al.*, 2009, Alishiri *et al.*, 2013 and

Imran *et al.*, 2013), tomato spotted wilt- *Tomato spotted wilt virus* (Massumi *et al.*, 2009 and Sevik and Arli-Sokmen, 2012), Root knot- *Meloidogyne* spp (Naz *et al.*, 2012 and Boroş *et al.*, 2015), little leaf- *Candidatus Phytoplasma trifolii* (Santos-Cervantes *et al.*, 2008 and Rathnamma, 2014) are major diseases of Tomato (Mahato *et al.*, 2017). However, 40 viruses from Alfamo, Luteo, Carla, Cucumo, Gemini, Poty, Illar, Nepo, Tombus, Tobamo and Tospovirus groups are known to infect tomato plants. Among all reported viral diseases, leaf curl disease caused by *Tomato leaf curl begomovirus* is the major limiting factors which causes substantial yield loss in India and worldwide (Govindappa *et al.*, 2013 and Mishra *et al.*, 2014).

In India occurrence of leaf curl virus disease was first observed in the northern plains by Pal and Tandon (1937) (Yadav *et al.*, 2014) and it was first reported in northern India by Vasudeva and Samraj (1948). In the 1950s, tomato leaf curl disease was reported to be present in central India (Varma, 1959 and Chowda Reddy *et al.*, 2005) and it has spread in all the tomato-growing regions of India (Varma and Malathi, 2003 and Saha *et al.*, 2014).

The incidence of ToLCV in tomato growing areas of Karnataka range from 17 to 53 per cent in July to November and 100 per cent in tomato cv. Pusa Ruby grown in February to May (Saikia and Muniyappa, 1989, Govindappa *et al.*, 2013 and Mishra *et al.*, 2014). The disease affects all stages of the plants causing 38-100 per cent yield loss, depending on the stage of the crop at the time of infection (Srivastav *et al.*, 2011). The tomato leaf curl virus disease (ToLCVD) is caused by 21 different types of ToLCV (Reddy *et al.*, 2008 and Shelat *et al.*, 2014) in the genus Begomovirus and family Geminiviridae (Polston and Anderson, 1997, Faquet and Stanely, 2003, Reddy *et al.*, 2008, Yadav *et al.*, 2014) and contain circular single stranded DNA (ssDNA) either in one component i.e. monopartite or in two components i.e. bipartite (Maruthi *et al.*, 2003, Reddy *et al.*, 2008). ToLCV is the most important and destructive viral pathogen in many parts of India (Saikia and Muniyappa, 1989, and Reddy *et al.*, 2008) which is transmitted by the sweet potato whitefly (*Bemisia tabaci* Gennadius) in persistent circulative non-propagative manner (Mishra *et al.*, 2014 and Zeshan *et al.*, 2016).

ToLCV epidemic is correlated with the size of the *B. tabaci* population (Govindappa *et al.*, 2013) climatic factors i.e. temperature, rainfall and relative humidity (Singh *et al.*, 2015), regional and seasonal variations (Ioannou and Iordanou, 1985 and Vijaya Lakshmi *et al.*, 2015). The incidence of ToLCV disease in the crop depends primarily on the immigration of vectors from alternative hosts, which act as reservoir of both virus and vector and the ease with which the vectors could acquire the virus from infected plants had little impact on disease incidence in the tomato crop (Alegbejo and Banwo, 2006 and Govindappa *et al.*, 2013).

The control of insect-transmitted viruses is always difficult because vectors are generally very mobile and small, and it is very hard to prevent colonisation of crops (Mason *et al.*, 2000). There are several strategies for management of ToLCV and its vector including cultural: early sowing, weed management, crop-free periods, virus-free transplants and the removal of infected plants (Loebenstein and Katis, 2014), physical: border crop, reflective mulches and UV-absorbing sheets (Legg *et al.*, 2014), mechanical: yellow sticky trap (Kakati and Nath 2014), biological: natural predators and parasitoids (Taylor, 2011, Legg *et al.*, 2014), host resistance and chemical methods. The most effective and widely used class of insecticides to reduce whitefly populations are the neonicotinoids of which at least three (Thiomethoxam, Imidacloprid, and Dinotefuran) and Diamides especially Cyantraniliprole (Cyazypyr) have been used to reduce incidence of ToLCV infected tomato plants in many tropical countries (Kodandaram *et al.*, 2010). Hence, pesticides play an important role in managing vector populations by reducing the number of individuals that can acquire and transmit a virus, thereby potentially lowering disease incidence (Kakati and Nath, 2014). Host plant resistance is most effective and economically cheap input of Integrated Pest Management. During the past twenty years, considerable efforts have been made to develop ToLCV resistant cultivars. Tomato cultivars, however, are not completely resistant to ToLCV. Nevertheless progress in breeding for ToLCV resistance has been slow because of the complex genetics of resistance. Identification of resistant genotypes/lines/ cultivars and exploration of resistant sources in tomato germplasm is very much important for the effective and ecofriendly management of ToLCV (Maruthi *et al.*, 2003 and Singh, 2014).

In view of the above facts and wide prevalence of this devastating disease the following objectives have been undertaken for study:

Objectives:

1. To observe the seasonal occurrence of prevalent viral diseases of tomato
2. To detect and identify the tomato leaf curl causing agent
3. To study the epidemiology of tomato leaf curl disease
4. To evaluate the performance of popular commercial varieties/ hybrids/ pipeline varieties against tomato leaf curl disease
5. To study the management of tomato leaf curl disease through vector control

CHAPTER – II

REVIEW OF LITERATURE

The literature pertaining to studies on several aspects including detection and identification of *Tomato leaf curl virus* (ToLCV), epidemiology and management are presented here under.

2.1 Tomato

Tomato, *Solanum lycopersicum* L. [syn. *Lycopersicon esculentum* Mill. *Lycopersicon lycopersicum* (L.) H. Karst] a member of the family Solanaceae (Singh, 2014). It is a herbaceous, annual, subtropical fruiting plant (Ssekyewa, 2006 and Bora *et al.*, 2012).

Scientific information indicates that cultivated tomato has originated in a wild form in the Peru-Ecuador-Bolivia area of the Andes (Gianessi *et al.*, 2003 and Rai and Yadav, 2005). Cultivated tomato originated in the New world, while the Andean Zone is likely to centre of origin of wild tomato. The most likely ancestor of cultivated tomato is the cherry type (*Lycopersicon esculentum* var *creasiforme*). The tomato was first domesticated in Mexico. In the early 16th century, Spanish conquistadors brought the tomato to Europe (Gianessi *et al.*, 2003). The first known record of tomato was the year to an Italian herbalist in 1554 and after 200 years it had gradually spread to other parts of the world. The Italians grew it in about 1550 and might have been the first European to eat it. The plant and its fruit were slow to gain acceptance in Europe except as an ornamental, a medicinal or a curiosity tomatoes were often hurled at unsatisfactory show business acts. Europeans knew it was related to poisonous members of the nightshade family they called it “mad apple” or “rage apple”, it was also considered a powerful aphrodisiac-the French named it pomme d’amour, “apple of love.” After 25 years, it was introduced to the English, Spanish and mid-European garden as a curiosity. But it didn't appear in American marketplaces until the 19th century. In the USA, Thomas Jefferson in Virginia first grew the plant in 1781 and made frequent references to the culinary uses of tomatoes at Monticello in the early 1800s. Later,

the French refugees spread it to Philadelphia in 1789 and to Massachusetts in 1802 by an Italian Painter (Gianessi *et al.*, 2003 and Rai and Yadav, 2005).

2.2 Diseases of tomato

There are many constraints that come in the way of tomato production (Mishra *et al.*, 2014). Among them diseases are the main constraints of tomato cultivation (Kakati and Nath, 2014). Tomato is known to be infected with more than 200 diseases (Shelat *et al.*, 2014), out of which buckeye rot (fruit rot), *Phytophthora nicotianae* var. *parasitica* (Sharma and Dohroó, 2004), collar rot or *Sclerotium* wilt, *Sclerotium rolfsii* (Mahato *et al.*, 2017), damping off, *Fusarium* spp. *Pythium* spp. *Rhizoctonia solani*, *Sclerotium rolfsii* (Rahman and Bhattiprolu, 2005 and Prasad *et al.*, 2017), early blight, *Alternaria solani* (Roopa, 2012), *Fusarium* wilt, *Fusarium oxysporum* f.sp. *lycopersici* (Manikandan and Raguchander, 2014), late blight (Olanya *et al.*, 2015), powdery mildew (Park, *et al.*, 2010 and Cerkauskas and Brown, 2015), *Rhizoctonia* root rot, *Rhizoctonia solani* (Abdeljalil *et al.*, 2016 and Sumalatha *et al.*, 2017), *Septoria* leaf spot (Parker *et al.*, 1997 and Blum, 2000), bacterial fruit canker, *Clavibacter michiganense* subsp. *Michiganense* (Ftayeh *et al.*, 2010 and Sharabani *et al.*, 2013), bacterial spot, *Xanthomonas campestris* pv. *vesicatoria* (Kavitha and Umesha, 2007), bacterial wilt, *Ralstonia solanacearum* (Ayana and Fininsa, 2016), bud blight, *Groundnut bud necrosis virus* (Manjunatha *et al.*, 2010), leaf curl disease, *Tomato leaf curl virus* (Shelat *et al.*, 2014 and Yadav *et al.*, 2014), tomato mosaic, *Tomato mosaic virus* (Massumi *et al.*, 2009, Alishiri *et al.*, 2013 and Imran *et al.*, 2013), tomato spotted wilt, *Tomato spotted wilt virus* (Massumi *et al.*, 2009 and Sevik and Arli-Sokmen, 2012), Root knot, *Meloidogyne* spp (Naz *et al.*, 2012 and Boroş *et al.*, 2015), little leaf, *Candidatus Phytoplasma trifolii* (Santos-Cervantes *et al.*, 2008 and Rathnamma, 2014) are major diseases of Tomato (Mahato *et al.*, 2017). However 40 viruses from Alfamo, Luteo, Carla, Cucumo, Gemini, Poty, Illar, Nepo, Tombus, Tobamo and Tospovirus groups are known to infect tomato plants. Among all the reported viral diseases, leaf curl disease caused by *Tomato leaf curl begomovirus* is the major limiting factor, which causes considerable yield loss in India and worldwide (Govindappa *et al.*, 2013 and Mishra *et al.*, 2014).

2.3 Occurrence of prevalent diseases of tomato

2.3.1 Fungal diseases

2.3.1.1 Collar rot

Collar rot or *Sclerotium* wilt the collar rot caused by *Sclerotium rolfsii* Sacc. is one of the important disease of tomato in India that may causes up to 30 percent loss to the crop (Thiribhuvanamala *et al.*, 1999 and Mahato *et al.*, 2017 and Mandal *et al.*, 2017). The disease is distributed in tropical and sub-tropical regions of the world where high temperatures prevail (Parvin *et al.*, 2016 and Mahato *et al.*, 2017). *S. rolfsii* is known to infect more than 500 species from various groups viz. cereals, pulses, oil crops, vegetables, ornamentals, and nursery seedlings of fruits and forest trees belonging to over 100 families (Agrios, 2006, Parvin *et al.*, 2016 and Billah *et al.*, 2017). Existence and occurrence of the disease has been reported in India by Sugha *et al.* (1990). The pathogen is a soil inhabitant, very aggressive nature, attacks the collar portion of plant at any growth stage of the plant, which ultimately leads to its death. The infection leads to the drying of lower leaves and eventually the whole plant dries with a typical symptom of severe rotting of the entire root system and dark lesions girdling the stem base (Begum *et al.*, 1985 and Billah *et al.*, 2017).

In field condition the incidence of collar rot was recorded 5 to 10 percent in Raipur, Chhattisgarh (Anon, 2013-14), 10-45 percent in Himachal Pradesh (Banyal *et al.*, 2008) and 7.61 to 21.79 percent in undulating red and lateritic zone of West Bengal (Mahato *et al.*, 2017).

Lievens *et al.* (2004) observed a severe collar/foot rot on two month old wilted tomato (*Lycopersicum esculentum*) plants in a large scale (2.5 ha) commercial greenhouse setting in Belgium. Amar and Banyal, 2011 conducted polyhouse surveys during the year 2008-09 and 2009-10 at different locations of Himachal Pradesh and observations were recorded on the occurrence of different diseases on *Capsicum*. The incidence of collar rot was recorded 10 to 20 percent.

2.3.1.2 Early blight

Early blight also called *Alternaria* leaf blight of tomato caused by *Alternaria solani*, is the most economically important disease of tomatoes in the USA, Australia, Israel, the UK and India, where significant reductions in yield (35-

78%) have been observed (Vloutoglou and Kalogerakis, 2000 and Bost, 2013). The fungus causes leaf blight and may cause seedling disease, collar rot, stem canker or fruit rot. Stem cankers are dark, sunken areas containing concentric rings and are usually restricted to one side of a stem. Collar rot is a dark, sunken lesion that girdles the stem at the base of a young plant. Leaf spots begin on the lower leaves as small, brownish-black lesions. As the spots enlarge up to 1/2 inch in diameter, concentric rings may be observed. Leaves turn yellow and dry up when only a few spots are present. Plants can be defoliated, causing low-quality tomatoes that are prone to sunscald. Fruit rots caused by this fungus are usually dark, sunken, leathery lesions around the fruit stems or growth cracks. Like stem and leaf lesions, the fruit lesion often shows a target pattern (Bost, 2013).

Prasad (2002) recorded 28.60 to 65.36 percent disease index of early blight in northern districts of Karnataka during 2001. Roopa (2012) undertook a roving survey during 2011 to assess the severity of early blight of tomato in major tomato growing areas of Dharwad, Belgaum, Haveri, Gadag and Bagalkot districts. Disease severity was ranged from 17.30 to 37.25 percent and highest severity was recorded in Haveri (31.03%) and least in Dharwad (20.16%) districts. Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *Kharif* 2013 and *Rabi* 2013-14. The average severity of early blight was recorded from October 2013 to March 2014 in *kharif* and from November 2013 to March 2014 in *rabi* with increasing trend and average maximum disease severity of 23.33 and 5.96 percent (March 2014) was recorded in both *kharif* and *rabi* season respectively under open field condition (Anon, 2013-14).

Amar and Banyal (2011) reported that early blight is the major disease in polyhouse having light soils by conducting polyhouse surveys during the year 2008–09 and 2009–10 at various locations of Himachal Pradesh. Soni *et al.* (2017) carried out surveys to know the distribution and prevalence of early blight of tomato disease at farmer's fields and polyhouse units of Udaipur, Rajsamand and Chittorgarh districts of southern Rajasthan during the *kharif* season. The overall mean disease incidence recorded from 35.14 to 51.88 percent in open field and 33.94 to 69.28 percent in protected condition (Polyhouse) on different cultivars, respectively.

2.3.2 Viral diseases

2.3.2.1 Tomato leaf curl

Saikia and Muniyappa (1989) investigated the incidence of *Tomato leaf curl virus* infection of tomatoes during 1983-84 in Karnataka, India. From July to November the incidence ranged from 17 to 53 percent and from February to May up to 100 percent. In sequential sowings 90-100 percent of plants were infected in plots sown between the end of January and the end of May. The disease attains its peak in summer in South India (Sastry and Singh, 1973 and Muniyappa *et al.*, 1991b) and autumn in North India (Banerjee and Kalloo, 1987 and Muniyappa *et al.*, 1991b).

Kumar *et al.* (2004) conducted field surveys in the autumn of 1999-2000 and 2000-2001 in the rain-fed tomato growing belt of Akhnoor of Jammu and leaf curl incidence ranged between 80 to 98 percent in different villages. The *Tomato leaf curl virus* (ToLCV) was present in almost all fields of Belgaum, Dharwad and Haveri districts surveyed with the disease incidence ranged from 4 to 100 percent in rabi and was in severe form ranging from 60 to 100 percent during summer (Reddy, 2006 and Reddy *et al.*, 2011). Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *Kharif* 2013 and *Rabi* 2013-14. The average incidence of leaf curl was recorded from October 2013 to March 2014 in *kharif* and from November 2013 to March 2014 in *rabi* with increasing trend and average maximum disease incidence of 12.24 and 10.94 percent (March 2014) was recorded in both *kharif* and *rabi* season respectively under open field condition (Anon, 2013-14).

Ehsanullah (2014) conducted a survey during 2013-14 in major tomato growing districts of Karnataka and recorded 10.80 to 91.30 percent leaf curl incidence. Among the districts surveyed, highest disease incidence of 70.81 percent was recorded in Kolar and least incidence of 21.00 percent was recorded in Ramanagara districts.

Barboza *et al.* (2014) conducted a survey during 2012 in greenhouse as well as open fields. He reported 14.00 and 2.40 percent incidence of leaf curl in greenhouse and open fields respectively. In mid-October of 2005 tomato plants were found in a commercial greenhouse in Jefferson Co. KY, with symptoms

suggestive of virus infection. The plants had been seeded on-site in July and, at the time of these observations; disease incidence was greater than 90 percent (De Sá *et al.*, 2008). *Tomato yellow leaf curl virus* (TYLCV) with incidence of 28.9 percent was the most important restriction factor in greenhouse and field-grown tomato (Valizadeh *et al.*, 2011).

Saha *et al.* (2014) surveyed tomato leaf curl disease (ToLCD) in tomato in Sub-Himalayan Tarai region of West Bengal and Brahmaputra valley of Assam. The estimated incidence was 18 to 83 percent in sub-Himalayan West Bengal and 14 to 71 percent in Brahmaputra valley of Assam. Symptom of ToLCV has been encountered in many tomato fields in India and caused most devastating problem for its cultivation in all over the world, e.g. 23, 50, 55 to 90, 63, 90, and 100 percent in Nigeria, Sudan, Spain, Lebanon, India and Mediterranean, respectively (Maruthi *et al.*, 2003 and Singh *et al.*, 2015).

2.3.2.2 Tomato mosaic

Tomato mosaic is one of the most destructive diseases of tomato (Alonso *et al.*, 1989 and Alishiri *et al.*, 2013). It is a complex viral disease which is caused by four different viruses viz. *Cucumber mosaic virus* (CMV) (Massumi *et al.*, 2009 and Lamptey, 2013), *Tomato mosaic virus* (ToMV) (Massumi *et al.*, 2009 and Alishiri *et al.*, 2013), *Tobacco mosaic virus* (TMV) (Alishiri *et al.*, 2013 and Lamptey, 2013), and *Potato virus Y* (PVY) (Aramburu *et al.*, 2006 and Massumi *et al.*, 2009). It can cause stunting and reduced yields and also affects fruit quality. The symptoms depend on the strain of the virus and the environmental conditions. Mosaic symptoms appear on leaves as dark green islands surrounded by light green areas with reduced leaf size. The dark green areas of the mottle often appear thicker and somewhat elevated giving the leaves a blister like appearance. Leaves sometimes look fern like and sharply pointed. Early infections cause flower drop, reduce fruit set and occasionally cause blemishes and distortions of the fruits. Fruit may develop necrotic blotches and patches on cultivars with some resistance to tomato mosaic. These blotches are restricted to the skin tissue and often only one or two trusses will be affected (Elmhirst, 2006 and Bambawale *et al.*, 2012).

Alishiri *et al.* (2013) reported 16.89 percent infection of mosaic in major tomato growing areas of Iran. Ten fields of Raipur (Chhattisgarh) were selected for

the pest surveillance of tomato in *Kharif* 2013 and *Rabi* 2013-14. The average incidence of mosaic was recorded from October 2013 to March 2014 in *kharif* and from December 2013 to March 2014 in *rabi* with increasing trend and average maximum disease incidence of 17.03 percent was recorded in February 2014 (*kharif*) and 12.61 percent in March 2014 (*rabi*) in open field condition (Anon, 2013-14). Jalender *et al.* (2017) conducted survey in tomato growing areas of Ranga Reddy district during *kharif* 2013 and in Guntur district during *rabi* 2013-14 and recorded natural occurrence of disease incidence with an percent ranged from 6.9 to 15.7 among different Mandals.

Kaya *et al.* (2009) performed a study to find out the virus diseases in tomato plants growing at the protected production areas in Mugla province between 2002 and 2004. The incidence of TMV and CMV in the leaf samples were 30.00 and 2.56 percent respectively. Massumi *et al.* (2009) recorded the incidence of *Tobacco mosaic virus*, *Potato virus Y*, *Tomato mosaic virus* and *Cucumber mosaic virus* were 5.6, 5.0, 4.8 and 23.4 percent respectively in greenhouses in Kerman, Hormozgan, Sistan-Baluchestan, Yazd and Boushehr provinces of Iran.

2.3.2.3 Tomato spotted wilt

Tomato spotted wilt virus (TSWV) is one of the most important viruses affecting tomatoes, occasionally leading to losses of up to 100% (Rosello *et al.*, 1996). TSWV belongs to the genus *Tospovirus* within the family *Bunyaviridae* (van Regenmort *et al.*, 2000). TSWV was first reported in tomato by Brittlebank in Australia (1919). The economic impact of TSWV is huge mainly due to its extremely broad host range, with over 1,090 plant species within 100 families (Parrella *et al.*, 2003 and Peters, 2003). The virus causes severe yield losses (producing less valuable or unmarketable plants, fruits or flowers) in many economically important crops (Ramkat *et al.*, 2006). It is transmitted exclusively by at least nine species of thrips (Jones, 2005) in a propagative-circulative manner (Wijkamp and Peters, 1993). TSWV virions have spherical enveloped particles, about 80–110 nm in diameter (Adkins, 2000 and Sevik and Arli-Sokmen, 2012).

Pattaiya (2006) carried out survey and surveillance of tomato spotted wilt virus disease at open fields of three locations viz. Panagar, Jabalpur and Indrana to determine the incidence of virus. He observed overall 18 to 34, 15 to 30 and 16 to

24 percent infection was observed in Panagar, Jabalpur and Indrana respectively in different varieties. Bòzdogan and Kamberoglu (2015) conducted a survey in Center (Antalya) district of Turkey and reported 74.28 to 92.30 percent (average 78.57 %) infection of tomato spotted wilt virus in tomato crop during 2007-2009.

Kaya *et al.* (2009) performed a study to find out the virus diseases in tomato plants growing at the protected production areas in Mugla province between 2002 and 2004 and recorded tomato spotted wilt incidence of 3.85 percent.

2.4 Tomao leaf curl disease (ToLCD)

2.4.1 First report and geographical distribution

The occurrence of leaf curl virus disease was first observed from northern plains of India by Pal and Tandon (1937) (Yadav *et al.*, 2014) and it was first reported in northern India by Vasudeva and Samraj (1948). In the 1950s, tomato leaf curl disease was reported to be present in central India (Varma, 1959 and Chowda Reddy *et al.*, 2005) and it has spread in all the tomato growing regions of India (Varma and Malathi, 2003, Praveen *et al.*, 2004 and Saha *et al.*, 2014). Tomato leaf curl disease (ToLCD) is threatening commercial cultivation of tomato crop in India and the worldwide (Padidam *et al.*, 1995, Varma and Malathi, 2003 and Saha *et al.*, 2014). It has been also reported in the Philippines in 1971 (Shi *et al.*, 1998a), Bangladesh in 1974 (Talukdar, 1974 and Akanda, 1991), Middle East (Abu-Gharbieh *et al.*, 1978 and Maruthi *et al.*, 2003), Thailand in 1980 (Giatgong, 1980 and Thanapas *et al.*, 1983), Africa (Martelli and Quacquarelli, 1982 and Maruthi *et al.*, 2003), Taiwan in 1981 (Anon, 1984 and Green *et al.*, 1987), Pakistan in 1982 (Solangi *et al.*, 1983, Anon, 1984 and Rana *et al.*, 1992), Indonesia in 1985 (Anon, 1985), Malaysia in 1986 (Abu Kassim and Abu Bakar, 1986), Cambodia in 1989 (Rowell *et al.*, 1989 and Marom, 1993), Nepal in 1990 (Dahal *et al.*, 1993 and Ghimire and Pradhanang, 1996), China in 1992 (Liu *et al.*, 1997), Caribbean region (Nakhla *et al.*, 1994 and Maruthi *et al.*, 2003), Northern states of Nigeria (Alegbejo 1995 and Maruthi *et al.*, 2003), Sri Lanka in 1995 (Zeidan *et al.*, 1998), Western Hemisphere (Polston and Anderson, 1997 and Maruthi *et al.*, 2003) and Mexico (Momol *et al.*, 1999 and Maruthi *et al.*, 2003). The virus has long been known in the other part of world viz. Middle East, North,

Central, East and West Africa, South East Asia, and Southern Europe (Alegbejo, 1995, Antignus, 2003, Czosnek *et al.*, 1990, Navas-Castello *et al.*, 1999, Moriones and Navas-Castello, 2000, Muniyappa *et al.*, 2000, Ladipot *et al.*, 2001, Kashina *et al.*, 2002, Rybicki *et al.*, 2000, Alegbejo and Banwo, 2006, Moriones *et al.*, 2017 and Zaidi *et al.*, 2017).

2.4.2 Symptoms of ToLCD

Affected tomato plants are stunted and their branches and petioles tend to assume an erect position. Leaflets are smaller than those of healthy plants, puckered, and often show an accentuated upward curling of their margins with or without yellowing. Growth of the plants is inhibited (Green and Kalloo, 1994).

Infected plants show a variety of symptoms including leaf curling, shrinking of tomato leaves, vein clearing, shape abnormalities, chlorosis, stunting and partial or complete sterility if infection occurs at an early stage of plant development (Ramappa *et al.*, 1998, Chakraborty *et al.*, 2003 and Williams, 2007).

Symptoms of ToLCD include curling of leaf lamina, vein clearing and stunting, even yellowing in severe cases and if infection occurs at the seedling stage, plants can become sterile (Kumar *et al.*, 2004 and Chowda Reddy *et al.*, 2005).

Infected plants are stunted, flower shedding may occur and few harvestable fruits of small size are produced (Kisha, 1981), leaves are rolled upwards and inwards, internodes are shortened and proliferation of lateral branches occurs (Moustafa, 1991 and Alegbejo and Banwo, 2006).

The predominant symptoms of the disease are vein clearing, vein banding, reduction in leaf size, stunting, marginal and severe curling of leaves. Puckering of leaf is also common (Chaudhary *et al.*, 2010). Begomoviruses are known to induce distinct types of symptoms of leaf curl, including vein yellowing, severe reduction in leaf size, downward curling, crinkling of interveinal areas, interveinal and marginal chlorosis, purple discoloration of the abaxial surface of leaves, shortening of internodes, development of small branches and reduced fruiting. Therefore, the diseases caused by begomoviruses have been collectively described as either leaf curl or yellow leaf curl or yellow vein mosaic based on their biological properties and subtle differences in symptoms (Arora *et al.*, 2011).

The disease is marked by symptoms such as yellowing of leaf lamina with upward leaf curl as well as distortion, reduction in internodes and new leave's size, wrinkle facade, stunted growth, and dissemination of flower from plant before onset of fruiting (Kumar *et al.*, 2012). The disease induces severe stunting, bushy growth and partial or complete sterility depending on the stage at which infection has taken place. Infected plants bear few or no fruit (Rajasri and Vijayalakshmi, 2013).

The symptoms of disease become visible in tomato two to three weeks after infection and consist of upward curling of leaflet margins, yellowing of young leaves and abortion of flowers. Those leaflets that appear soon after inoculation are cupped down and inwards. Infected plants are severely stunted and resulting decrease of plant growth reduces total yield (Gafni, 2003, Crescenzi *et al.*, 2004 and Mishra *et al.*, 2014). Tomato leaf curl disease is manifested by yellowing of leaves, upward leaf curling, bushy growth, leaf distortion, shrinking of leaf surface, stunted plant growth, excessive branching, abnormal growth of plants and flower and fruit abscission (Shelat *et al.*, 2014).

The disease 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 (Saikia and Muniyappa, 1989 and Yadav *et al.*, 2014).

In tomato, plants infected with *Tomato leaf curl New Delhi virus* (ToLCNDV) exhibit typical symptoms including upward or downward curling and crinkling of leaves, vein clearing, yellow mottling, leaf puckering and blistering of leaves. At the later stages of the infection, plants appear stunted with shortened internodes and show impaired fruit setting, leading to complete crop loss (Chakraborty, 2008 and Moriones *et al.*, 2017). Typical symptoms of ToLCNDV infection in its various hosts include leaf curling, vein thickening, puckering, purpling/darkening of leaf margins, leaf area reduction, internode shortening and severe stunting (Zaidi *et al.*, 2017).

2.4.3 Losses due to ToLCD

Tomato leaf curl disease (ToLCD) is a serious and threatening disease of tomato, causing losses of up to 100 percent in various parts of the world (Varma and Malathi, 2003). Yield losses of 23, 50, 63, and 100 percent have been reported in Nigeria, Sudan, Lebanon, and the Mediterranean, respectively (Yassin and Abu 1972, Makkouk *et al.*, 1976, Alegbejo and Ogunlana 1995, Lapidot *et al.*, 2001 and Alegbejo and Banwo, 2006). In Israel, the disease affects tomato during the summer and autumn seasons causing up to 100 percent yield loss in susceptible cultivars (Lapidot *et al.*, 1997 and Maruthi *et al.*, 2003).

Affected plants produce either no fruit or few small-sized fruits depending on the stage of development at which the viral attack occurs. In Uttar Pradesh this disease is widely prevalent and estimated to cause 27 to 40 percent loss (Ansari *et al.*, 2005 and Chaudhary *et al.*, 2010). Yield loss is greatest when *Tomato leaf curl virus* (ToLCV) infection occurs during the early stages of plant growth and Saikia and Muniyappa (1989) reported 95 percent yield reduction in a susceptible variety that was infected at two weeks after planting (Nagaraju *et al.*, 2010 and Govindappa *et al.*, 2013).

Reddy *et al.* (2010) conducted an experiment under natural conditions to study growth and yield loss in tomato due to ToLCV using a variety 'Megha'. He reported that tomato crop is susceptible to ToLCV at all stages of the growth but plants are more prone to infection at early stage, 30 to 40 days after transplanting (DAT) and also the disease severity and loss is more in the plants infected at early stages. He observed highest reduction in plant height (44.93 %) with number of fruits (3.00) and fruit weight (3.83 g) per plant and yield reduction (98.68 %) in the plants infected at 30 DAT. The disease affects all stages of the plants causing 38 to 100 percent yield loss, depending on the stage of the crop at the time of infection (Das Gupta *et al.*, 2003, Ansari, 2007 and Srivastav *et al.*, 2011). Since ages, *Tomato leaf curl* disease (ToLCD) has been a severe problem in tomato production causing up to 100% yield losses in India and worldwide, especially in those areas where tomato is grown commercially (Banerjee and Kalloo 1987, Kalloo, 1988, Singh *et al.*, 2010, Rajasri and Vijayalakshmi, 2013 and Singh *et al.*, 2014).

2.5 The causal agent of ToLCD

Tomato leaf curl disease (ToLCD) is caused by either monopartite (Navot *et al.*, 1991 and Hong and Harrison, 1995) or bipartite (Padidam *et al.*, 1995 and Srivastava *et al.*, 1995) *Tomato leaf curl virus* (ToLCV) from geminiviruses (more than 20 species) group of the genus Begomovirus, family Geminiviridae (Maruthi *et al.*, 2003 and Reddy *et al.*, 2008). Despite the great variability in viral genomes, both bipartite and monopartite viruses cause similar symptoms and substantial yield losses (Saikia and Muniyappa, 1989, Czosnek *et al.*, 1990, Muniyappa *et al.*, 1991b, Maruthi *et al.*, 2003, Reddy *et al.*, 2008 and Kumar *et al.*, 2012).

2.5.1 Taxonomy of *Tomato leaf curl virus* (ToLCV)

All Viruses have been classified into 8 orders viz. Bunyavirales (9 families), Caudovirales (3 families), Herpesvirales (3 families), Ligamenvirales (2 families), Mononegavirales (9 families), Nidovirales (4 families), Picornavirales (6 families) and Tymovirales (4 families) with 40 families and 85 unassigned families. Among eight orders four orders i.e. Bunyavirales (*Fimoviridae*, *Phenuiviridae* and *Tospoviridae*), Mononegavirales (*Rhabdoviridae*), Picornavirales (*Secoviridae*) and Tymovirales (*Alphaflexiviridae*, *Betaflexiviridae* and *Tymoviridae*) with 8 families and an unassigned order having 18 families viz. *Amalgaviridae*, *Benyviridae*, *Bromoviridae*, *Caulimoviridae*, *Closteroviridae*, *Endornaviridae*, *Geminiviridae*, *Genomoviridae*, *Luteoviridae*, *Nanoviridae*, *Ophioviridae*, *Partitiviridae*, *Potyviridae*, *Pseudoviridae*, *Reoviridae*, *Tolecusatellitidae*, *Tombusviridae*, *Virgaviridae* and an Unassigned family) include viruses that infect plants (Anon, 2017). Of the 26 families, fifteen families include viruses that infect tomato, i.e. families *Tospoviridae* (Dong *et al.*, 2010, Yin *et al.*, 2014 and Anon, 2017), *Secoviridae* (Cohen and Harpaz, 1964, Hanssen *et al.*, 2010 and Anon, 2017), *Alphaflexiviridae* (Anon, 2017 and Hussein and Kamberoglu, 2017), *Betaflexiviridae* (Massumi *et al.*, 2009 and Anon, 2017) *Tymoviridae* (Ferrand *et al.*, 2015 and Anon, 2017) *Amalgaviridae* (Candresse *et al.*, 2013, Padmanabhan *et al.*, 2015 and Anon, 2017) *Bromoviridae* (Batuman *et al.*, 2009, Hanssen *et al.*, 2010 and Anon, 2017) *Closteroviridae*, (Duffus, *et al.*, 1996, Hanssen *et al.*, 2010 and Anon, 2017), *Geminiviridae* (Cohen and Harpaz

1964, Hanssen *et al.*, 2010 and Anon, 2017), *Luteoviridae* (Thomas and Hassan, 2002, Warren, *et al.*, 2005 and Anon, 2017) *Potyviridae* (Li *et al.*, 2014 and Anon, 2017), *Pseudoviridae* (King *et al.*, 2012 and Anon, 2017), *Tolecusatellitidae* (Kumar *et al.*, 2015 and Anon, 2017), *Tombusviridae* (Massumi *et al.*, 2009 and Anon, 2017) and *Virgaviridae* (Massumi *et al.*, 2009 and Anon, 2017).

2.5.1.1 Geminiviridae

The family *Geminiviridae* includes a large number of viruses that infect plants and produce in many cases very significant reductions in economically important crops of both monocotyledonous and dicotyledonous plants. They are, basically, characterized by two distinctive features: (1) the morphology of the virion particle, which is geminate (consists of two incomplete paired or twin particles), $\sim 22 \times 38$ nm in size and has the appearance of two quasi-icosahedral moieties with a total of 22 pentameric capsomers, and (2) the nature of their genetic material, they possess small one or two single stranded DNA (ssDNA) molecules of 2.5–3.0 kb size (Gutierrez, 1999, Fauquet *et al.*, 2005, Andrew *et al.*, 2012 and King *et al.*, 2012). Their genome also has an intergenic region of around 300 bases in the intergenic region the conserved sequence ‘TAATATTAC’ is the starting point of the bi-directional transcription, which occurs either in the viral sense (v) or in the complementary sense (c). The virus is replicated in the nucleus by utilizing host enzymes by a rolling circle (or concatamer) mechanism on a double stranded (ds) replicative form (Fauquet *et al.*, 2005 and Andrew *et al.*, 2012).

The geminivirus replication cycle can be subdivided in several functionally distinct stages characterized by specific events. Early during the infection process, viral particles are injected by the insect vector, presumably uncoated, and the viral genome is transported into the host cell nucleus by mechanisms whose molecular details are largely unknown (Lazarowitz, 1992, Palmer *et al.*, 1998 and Gutierrez, 1999). Once within the nucleus, amplification of the viral genome, which involves an efficient DNA replication process, occurs in three distinct stages (Stanley and Townsend, 1985, Saunders *et al.*, 1992 and Gutierrez, 1999). First, stage A, involves the conversion of the genomic circular ssDNA [(c)ssDNA] into supercoiled covalently closed circular dsDNA intermediates or replicative form I

[(ccc)dsDNA(RFI)]. Second, or stage B, is the amplification of the dsDNA intermediates by a rolling-circle mechanism. Third, or stage C, is the production and encapsidation of mature genomic circular ssDNA into viral particles. This strategy is remarkably similar to that of many prokaryotic replicons (Baas and Jansz, 1988, Novick, 1998, Gutierrez, 1999).

Geminivirus centers of diversification were identified from the phylogenetic tree constructed from all available sequences (Fauquet *et al.*, 2008) as the areas from where the maximum number of geminiviruses has been identified. On the basis of all available data about geminiviruses Nawaz-ul-Rehman and Fauquet (2009) identified eight distinct geographical centers of diversification for geminiviruses. These are Australia, Japan, South China, Indian sub-continent, Sub-Saharan Africa, Mediterranean-European region, South America and Central America. (Sattar, 2012).

Geminiviruses are transmitted by either leafhopper, plant hopper, treehopper or whitefly (King *et al.*, 2012, Leke *et al.*, 2015, Basak, 2016, Sohrab *et al.*, 2016, Ruiz *et al.*, 2017 and Zaidi *et al.*, 2017) and few are also reported to be transmitted by aphids (Roumagnac *et al.*, 2015). They infect a wide range of monocotyledonous and dicotyledonous plants but each member of the *Geminiviridae* family has its own limited host range (Pratap *et al.*, 2011).

Geminiviruses have been classified into seven genera based on their genome organization, hosts, and insect vectors (Leke *et al.*, 2001). Genus *Becurtovirus*, type species: *Beet curly top Iran virus*, transmitted by leafhoppers to dicotyledonous plants. Genus *begomovirus*, type species: *Bean golden mosaic virus*, *Tomato leaf curl virus*, transmitted by whiteflies (*Bemisia* spp.) to dicotyledonous plants. Genus *Curtovirus*, type species: *Beet curly top virus*, transmitted by leafhoppers or treehoppers to dicotyledonous plants. Genus *Eragrovirus*, type species: *Eragrostis curvulastreak virus*, infects monocotyledonous plants. Genus *Mastrevirus*, type species: *Maize streak virus*, transmitted by leafhoppers usually to monocotyledonous plants. Genus *Topocuvirus*, type species: *Tomato pseudo-curly top virus*, transmitted by treehoppers to dicotyledonous plants. Genus *Turncurtovirus*, type species: *Beet curly top virus*, transmitted by leafhoppers or treehoppers to dicotyledonous plants

(King *et al.*, 2012, Leke *et al.*, 2015, Basak, 2016, Sohrab *et al.*, 2016, Ruiz *et al.*, 2017 and Zaidi *et al.*, 2017). Recently in the 10th report of ICTV (Anon, 2017) the family *Geminiviridae* has been classified into nine genera viz. *Becurtovirus*, *begomovirus*, *Capulavirus*: *Alfalfa leaf curl virus*, transmitted by *Aphis craccivora* (Roumagnac *et al.*, 2015), *Curtovirus*, *Eragrovirus*, *Grablovirus*: *Grapevine red blotch virus*, transmitted by three cornered alfalfa hopper, *Spissistilus festinus*, Hemiptera: Membracidae (Bahder *et al.*, 2016), *Mastrevirus*, *Topocuvirus* and *Turncurtovirus*.

2.5.1.2 Begomovirus

The genus, *Begomovirus* under the family, *Geminiviridae* comprises 322 species (Zaidi *et al.*, 2017 and Anon, 2017). They are transmitted by whitefly (*Bemisia* spp.) in a circulative, persistent manner (Khan *et al.*, 2013). *Geminiviruses* have unique twin particles of 18 × 30 nm size and infect only dicotyledonous plants (Chakraborty *et al.*, 2003, Tsai *et al.*, 2011 and Jeevalatha *et al.*, 2017). *Begomoviruses* cause severe damage in several economically important crops, including beans, cassava, cotton, cucurbits, legumes, okra, papaya, pepper, potato and tomato in the tropical and subtropical regions of the world (Varma and Malathi, 2003, Shih *et al.*, 2007, Arora *et al.*, 2011, Pratap *et al.*, 2011, and Tsai *et al.*, 2011).

The majority of the *begomoviruses* are bipartite and the genomic components are referred as DNA-A and DNA-B (Fauquet *et al.*, 2008, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017), each of these being approximately 2.6 to 2.8 kb in size (Dry *et al.*, 1993, Reddy *et al.*, 2005 and Khan *et al.*, 2013). However, a few Old World *begomoviruses* such as *Tomato leaf curl virus* (ToLCV) and *Tomato yellow leaf curl virus* (TYLCV) are monopartite and have single genomic component, homologous to DNA-A of the bipartite *begomoviruses* (Pratap *et al.*, 2011). DNA-A encodes two proteins in the virion sense viz. the coat protein (AV1, CP) for encapsidation and insect transmission and AV2, a pathogenicity determinant, believed to be involved in virus movement in plants (Rojas, *et al.*, 2005) and/or act as a suppressor of RNA silencing (Czosnek *et al.*, 2002, Yadava, *et al.*, 2010, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017). In the complementary sense, it encodes the replication associated protein (AC1, Rep) which is essential

for viral replication (Czosnek *et al.*, 2002, Nash *et al.*, 2011, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017), the transcriptional activator protein (AC2, TrAP) that controls late gene expression and involved in RNAi suppression (Czosnek *et al.*, 2002, Trinks, *et al.*, 2005, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017), the replication enhancer protein (AC3, REn), a stimulator of viral DNA replication (Czosnek *et al.*, 2002, Pasumathy, *et al.*, 2011, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017), AC4 and AC5 for which the function is still remain unclear (Jeevalatha *et al.*, 2017). The DNA B component possesses two ORFs (BV1 and BC1) that encode for two proteins, movement protein (BC1, MP) and nuclear shuttle protein (BV1, NSP), involved in cell-to-cell movement within the plant, host range and symptom modulation (Czosnek *et al.*, 2002, Ribeiro *et al.*, 2003, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017). Although not directly involved in interaction with the whitefly vector, DNA B sequences affect the efficiency of virus acquisition by the insect by determining the location of begomoviruses in plant tissues (Liu *et al.*, 1997 and Czosnek *et al.*, 2002,). The two genomic components (DNA-A and DNA-B) of a given begomovirus share a “common region” (CR) of ~200 nucleotides, which is very similar or identical in the two DNA components (Czosnek *et al.*, 2002, Ribeiro *et al.*, 2003, Rojas *et al.*, 2005, Pratap *et al.*, 2011 and Jeevalatha *et al.*, 2017). CR has conserved reiterated motifs and a putative stem-loop structure containing the highly conserved nonanucleotide sequence (TAATATT↓AC), which is nicked (indicated by arrow) by the Rep protein to initiate the rolling circle replication (Hanley-Bowdoin, 1999 and Pant *et al.*, 2001, Rojas *et al.*, 2005, Pratap *et al.*, 2011, and Jeevalatha *et al.*, 2017). However, a few Old World begomoviruses such as *Tomato leaf curl virus* (ToLCV) and *Tomato yellow leaf curl virus* (TYLCV) are monopartite and have single genomic component, homologous to DNA-A of the bipartite begomoviruses. These monopartite viruses require only DNA-A to cause systemic infection (Dry *et al.*, 1993, Kheyr-Pour *et al.*, 1991 Navot *et al.*, 1991 and Pratap *et al.*, 2011). On rare occasions, betasatellites have been reported along with bipartite begomoviruses like ToLCNDV (Sivalingam *et al.*, 2010 and Jyothsna *et al.*, 2013). The association of these satellite molecules are found to enhance the symptom severity (Kumari *et al.*, 2010 and Jeevalatha *et al.*, 2017).

Several species of tomato infecting begomoviruses have been reported from India (Chakraborty *et al.*, 2003, Kumar *et al.*, 2008, Tiwari, *et al.*, 2010, 2013, Kumari *et al.*, 2011, Kumar *et al.*, 2012, Saha *et al.*, 2014, Singh, 2014 and Zaidi *et al.*, 2017). Among begomoviruses, *Tomato leaf curl virus* (ToLCV) is one of the most important viruses causing major loss to tomato production (Kumar *et al.*, 2012, Saha *et al.*, 2014, Singh, 2014 and Zaidi *et al.*, 2017).

2.5.2 *Tomato leaf curl virus* (ToLCV)

Tomato leaf curl virus (ToLCV) is one of the most devastating and economically significant pathogen of cultivated tomatoes (*Solanum lycopersicum*) in tropical and subtropical regions (Alegbejo and Banwo, 2006, Reddy *et al.*, 2008, Kumar *et al.*, 2012 and Ruiz *et al.*, 2017). Particles of *Tomato leaf curl virus* (ToLCV) are 20 nm in size (Mall *et al.*, 2014). Species status for begomoviruses, however, cannot be conferred based on symptom type or epitope profile. The most definitive method utilises nucleotide sequences and genome organisation (Fauquet *et al.*, 2003 and Chowda Reddy *et al.*, 2005). There are several reports of species or strains of tomato leaf curl geminiviruses causing TLCD in India. The species from Northern India, such as *Tomato leaf curl New Delhi virus* from New Delhi (ToLCNDV) (GenBank Accession Nos. U15015 and U15016) (Padidam *et al.*, 1995, Chakraborty *et al.*, 2003 and Reddy *et al.*, 2011) and from Lucknow (ToLCNDV-[Luc], GenBank Accession Nos. Y16421 and X89653) (Srivastava *et al.*, 1995), are bipartite in nature and both genomic components are required for infection to occur (Padidam *et al.*, 1995, Srivastava *et al.*, 1993 and Chakraborty *et al.*, 2003). Isolates reported from Southern India apparently possess only the DNA-A component (Chatchawankanphanich and Maxwell, 2002, Muniyappa *et al.*, 2000, Chakraborty *et al.*, 2003 and Reddy *et al.*, 2011).

On the Indian subcontinent, at least 13 distinct virus species have been associated with ToLCD (Brown *et al.*, 2015 and Zaidi *et al.*, 2017). Out of which 9 are monopartite and 4 are bipartite (Table 2.1).

Chakraborty *et al.* (2003) characterized the biological and molecular properties of *Tomato leaf curl Gujarat virus* from Varanasi, India (ToLCGV-[Var]). He cloned the full-length genome of DNA-A and DNA-B of ToLCGV-[Var] in pUC18. Sequence analysis showed that DNA-A (AY190290) is 2,757 bp

Table 2.1: Tomato leaf curl viruses infecting tomato in India

Acronomy	Virus name	Location	Reference
Monopartite			
ToLCBV	<i>Tomato leaf curl Bangalore virus</i>	Southern India	Hong <i>et al.</i> , 1995; Muniyappa <i>et al.</i> , 2000; Kirthi <i>et al.</i> , 2004; Fadil, 2012; Snehi <i>et al.</i> , 2016
ToLCV-Dh	<i>Tomato leaf curl Dharwad virus</i> (ToLCV-Dh)	Southern India	Sinha <i>et al.</i> , 2004; Verma <i>et al.</i> , 2016
ToLCJoV	<i>Tomato leaf curl Joydebpur virus</i>	Northern India	Shih <i>et al.</i> , 2007; Paul <i>et al.</i> , 2009; King <i>et al.</i> , 2012; Venkataravanappa <i>et al.</i> , 2014
ToLCKV	<i>Tomato leaf curl Karnataka virus</i>	Southern India	Chatchawankanphanich and Maxwell, 2002; Fadil, 2012, Snehi <i>et al.</i> , 2016
ToLCKeV	<i>Tomato leaf curl Kerala virus</i>	Southern India	Pandey <i>et al.</i> , 2010 Pasumarthy <i>et al.</i> , 2010; Fadil, 2012; Paul, 2014
ToLCPaV	<i>Tomato leaf curl Patna virus</i>	Northern India	Kumari <i>et al.</i> , 2010; Fadil, 2012; King <i>et al.</i> , 2012
ToLCPV	<i>Tomato leaf curl Pune virus</i>	Western India	Chowda Reddy <i>et al.</i> , 2005; Fadil, 2012, King <i>et al.</i> , 2012; Vanitha <i>et al.</i> , 2013
ToLCRajV	<i>Tomato leaf curl Rajasthan virus</i>	Northern India	Sivalingam <i>et al.</i> , 2010; Fadil, 2012; King <i>et al.</i> , 2012; Snehi <i>et al.</i> , 2016
ToLCRnV	<i>Tomato leaf curl Ranchi virus</i>	Northern India	Kumari <i>et al.</i> , 2011; Fadil, 2012; Swarnalatha <i>et al.</i> , 2013; Saha <i>et al.</i> , 2014
Bipartite			
ToLCGV	<i>Tomato leaf curl Gujarat virus</i>	Northern India	Chakraborty <i>et al.</i> , 2003; King <i>et al.</i> , 2012, Jyothsna <i>et al.</i> , 2013; Snehi <i>et al.</i> , 2016
ToLCLuV	<i>Tomato leaf curl Lucknow virus</i>	Northern India	Sinha <i>et al.</i> , 2004; Kumar <i>et al.</i> , 2012
ToLCNDV	<i>Tomato leaf curl New Delhi virus</i>	Northern India	Padidam, <i>et al.</i> , 1995; Srivastava <i>et al.</i> , 1995; Chakraborty <i>et al.</i> , 2003; Reddy <i>et al.</i> , 2011; Zaidi <i>et al.</i> , 2017
ToLCPMV	<i>Tomato leaf curl Palampur virus</i>	Northern India	Kumar <i>et al.</i> , 2008, Heydarnejad <i>et al.</i> , 2009; Malik <i>et al.</i> , 2011; Fadil, 2012, Snehi <i>et al.</i> , 2016

and DNA-B (AY190291) is 2,688 bp in length. Open reading frames (ORFs) in both DNA-A and DNA-B are organized similarly to those in other begomoviruses.

ToLCNDV is a bipartite begomovirus in that it has two genome components, named DNA-A and DNA-B (Padidam *et al.*, 1995 and Zaidi *et al.*, 2017). DNA-A contains six partially overlapping open reading frames (ORFs) two (AV1 and AV2) in the virion sense, and four (AC1, AC2, AC3 and AC4) in the complementary sense (Padidam *et al.*, 1996, Akbar Behjatnia *et al.*, 1998, Selth *et al.*, 2006 and Zaidi *et al.*, 2017). ToLCNDV DNA-B contains two ORFs one (BV1) gene in the virion sense orientation, and another (BC1) gene in the complementary sense orientation (Zaidi *et al.*, 2017). The genes in the virion and complementary sense orientations on DNA-A and DNA-B are interspaced by an intergenic region containing a common region (CR) comprising sequences that are conserved between DNA-A and DNA-B. The main topological feature of the CR is a hairpin structure with a conserved nonanucleotide (5'-TAATATT↓AC-3') that spans the virion strand origin of replication (*v-ori*, indicated by '↓') which is common to all geminiviruses (Padidam *et al.*, 1995 and Zaidi *et al.*, 2017). The intergenic region is also the site of the origin of DNA replication (*ori*) in geminiviruses (Akbar Behjatnia *et al.*, 1998 and Selth *et al.*, 2006). Iterated ~5–7 nucleotide-long sequences (called iterons) that are present 50 of the hairpin form binding sites for the virus replication-associated protein, Rep (encoded by AC1). In addition to a Rep protein, the ToLCNDV DNA-A encodes a replication enhancer protein [REn, from AC2 open reading frame (ORF)], a transcriptional activator protein (TrAP, from AC3), a coat protein (CP, from AV1), an AV2 protein and an AC4 protein. DNA-B encodes a movement protein (MP, from BC1) and a nuclear shuttle protein (NSP, from BV1) (Fondong, 2013 and Zaidi *et al.*, 2017).

DNA-A encodes two proteins in the virion sense *viz.* the coat protein (CP) of ~29.9 to 30.3 kDa, ~260 amino acids from ORF AV1 (nt 315-1091) for encapsidation and insect transmission and a pathogenicity determinant (pre-coat protein) of ~13.4 kDa, 116 amino acids from ORF AV2 (nt 155-505). Believed to be involved in virus movement in plants and/or act as a suppressor of RNA silencing (Czosnek *et al.*, 2002, Rojas *et al.*, 2005, Boukhatem *et al.*, 2008, Glick *et al.*, 2009, Pratap *et al.*, 2011, Fadil, 2012 and Jeevalatha *et al.*, 2017). Amino

acid sequences of V1 and V2 polypeptides and the position of these genes were similar to those of the coat protein and the movement protein of other geminiviruses infecting dicotyledonous hosts (Boukhatem *et al.*, 2008). In the complementary sense, it encodes the replication associated protein (Rep) of 40.6 kDa, 357 amino acids from ORF AC1 (nt 2622-1549), which is essential for viral replication (Czosnek *et al.*, 2002, Boukhatem *et al.*, 2008, Glick *et al.*, 2009, Pratap *et al.*, 2011, Fadil, 2012 and Jeevalatha *et al.*, 2017), the transcriptional activator protein (TrAP) of ~15.4 kDa, 135 amino acids from AC2 (nt 1640-1233), that controls late gene expression and involved in RNAi suppression (Czosnek *et al.*, 2002, Boukhatem *et al.*, 2008, Glick *et al.*, 2009, Pratap *et al.*, 2011, Fadil, 2012 and Jeevalatha *et al.*, 2017), the replication enhancer protein (REn) of 16.0 kDa, 134 amino acids from ORF AC3 (nt 1492-1088), a stimulator of viral DNA replication (Czosnek *et al.*, 2002, Boukhatem *et al.*, 2008, Glick, *et al.*, 2009, Pratap *et al.*, 2011, Fadil, 2012 and Jeevalatha *et al.*, 2017) and RNAi Suppressor of ~11.0 kDa, 98 amino acids from ORF AC4 (nt 2471-2178) for which the function is still remain unclear (Boukhatem *et al.*, 2008, Glick *et al.*, 2009, Fadil, 2012, Jeevalatha *et al.*, 2017). DNA-A is capable of autonomous replication in protoplasts. The DNA-B component possesses two ORFs (BV1 and BC1) that encode for two proteins, movement protein of ~29.0 kDa (BC1, MP) involved in cell-to-cell movement within the plant, host range and symptom modulation *i.e.* pathogenicity determinant and nuclear shuttle protein of ~32.0 kDa (BV1, NSP), (Czosnek *et al.*, 2002, Ribeiro *et al.*, 2003, Pratap *et al.*, 2011, Fadil, 2012 and Jeevalatha *et al.*, 2017).

2.5.3 Replication of ToLCV

The replication of geminivirus genome/s in plant cells take/s place through the formation of double stranded (ds) DNA intermediates via a rolling circle (concatamer) mechanism (Agrios, 2005, Fauquet *et al.*, 2005 and Andrew *et al.*, 2012). Virions are inoculated into the phloem by viruliferous whiteflies during feeding and transported to the phloem-associated cells. The viral single-stranded DNA (ssDNA) genome is then freed from the capsid (Gorovits and Czosnek, 2017). In the first stage of multiplication, the uncoated ssDNA migrates to nucleus where the cellular RNA primer anneals or start complementary DNA synthesis at

intergenic region. Host DNA dependent DNA polymerase (DdDp) synthesizes complementary (-) sense DNA. The primer is displaced and gap in the second strand DNA is sealed. Now the ds DNA is assembled in the nucleus into nucleosome *i.e.* groups of eight histone protein molecules wrapped about by two coils of DNA and form “transcriptionally active minichromosome” (TAMC). Transcription takes place in the nucleus. Some of the ds DNA (TAMC) transcribed in two mRNAs from opposite directions from divergent promoters located in the intergenic region by using host DNA dependent RNA polymerase-II (Bidirectional transcription occurs). These mRNAs are transported into cytoplasm where they (mRNAs) translate into proteins in “Bidirectional manner *i.e.* ambisense” in cytoplasm. In translation process first trans-activator protein is synthesized by using host’s protein synthesis machinery which stimulates the expression of other ORFs for production of other proteins. Now replicase, replication enhancer and nuclear shuttle proteins imported from cytoplasm into nucleus. Stem loop structure forms on remaining ds DNA in the nucleus. The geminivirus Replicase protein is site specific endonuclease that binds at ‘TAATATTAC’ region on stem-loop structure of (+) sense DNA and cause nick for allowing free 3' end for addition of new nucleotides. The new (+) sense DNA synthesizes by addition of new nucleotides at 3' end with displacement of proportionate (equal) number of nucleotides at 5' end (e.g. for addition of one nucleotide at 3' end, same (one) number of nucleotide displaces from 5' end). When synthesis of new DNA strand is completed the Rep protein nicks just after the last nucleotide of new strand (*i.e.* at stem loop) to release the original DNA fragment [(+) DNA] and continued to be synthesized. After completion of synthesis the DNA strand either new or original is religated by the Rep protein. The circular ssDNA is either encapsidated by coat protein or systematically spread within the plant with the help of movement protein. Geminivirus particles usually accumulate in the nuclei of infected cells either in random aggregates or in crystalline arrays. In some cases, one or more dark-staining fibrillar rings appear in the nuclei of infected plants (Hull, 2002, Agrios, 2005, Astier *et al.*, 2008 and Hull, 2009).

2.5.4 Host rang of ToLCV

It has been documented that *Tomato leaf curl virus* infects different plant species from various families in the world (Table 2.2a and 2.2b).

2.6 Molecular detection and identification of tomato leaf curl causing agent

Polymerase chain reaction (PCR) is the most sensitive approach to detect a minute amount of viral nucleic acid. It is the most ideal method to amplify geminiviruses as they replicate via a double- stranded, circular DNA form.

Hong and Harrison (1995) extracted total DNA from young leaves of tomato plants that had recently developed systemic symptoms and carried out PCR amplification by using degenerate primers (P1 and P2) of CP gene. The coat protein fragment exhibited the virus infection in symptomatic samples. After electrophoresis of the PCR products in a 1 % LMP agarose (Gibco BRL) gel, the required fragment was recovered and cloned into the *Bam*HI site of pUCI9. They sequenced coat protein (CP) gene-containing circular DNA molecule of an isolate of tomato leaf curl geminivirns (ITmLCV, 2749 nt) obtained from southern India, and the CP genes of tomato yellow leaf curl geminivirus isolates from Nigeria and two regions of Saudi Arabia. ITmLCV DNA had the same arrangement of ORFs, and the same pattern of repeats in the large intergenic region as is found in DNA-A of other whitefly-transmitted geminiviruses (WTGs) from the Old World.

Padidam *et al.* (1995) sequenced genomes of two isolates of *Tomato leaf curl geminivirus* from India (ToLCV-India). ToLCV-India contains A and B components, both of which are required for systemic movement and symptom development. The two isolates have 94% sequence identity but one isolate gave mild symptoms in *Nicotiana benthamiana* and tomato. The genome organization of ToLCV-India is similar to other whitefly-transmitted geminiviruses (WTGs) with bipartite genomes. However, it contains an additional ORF, AV3 that has not been reported for other WTGs. Its coat protein (CP) sequence is highly homologous to that of *Indian cassava mosaic virus* (90 %).

Zeidan *et al.* (1998) cloned the genome of TYLCV and ToLCV isolates from infected tomato plants from Bangladesh, China, India, Malaysia, Sri Lanka, Taiwan, The Philippines and Thailand, and sequenced partially or entirely. DNA

Table 2.2a: Host plants of tomato leaf curl virus

Family	Host species	Reference
Acanthacea	<i>Acanthospermum hispidum</i>	Ansari <i>et al.</i> , 2006
Amaranthaceae	<i>Amaranthus retroflexus</i>	Smith <i>et al.</i> , 2015
Apocyanaceae	<i>Lochnera pusilla</i>	Reddy, 2006
Asteraceae	<i>Ageratum conyzoides</i>	Reddy, 2006
	<i>Bidens biternata</i>	Paul, 2014
	<i>Blainvillea rhomboidea</i>	Reddy, 2006
	<i>Conyza stricta</i>	Paul, 2014
	<i>Galinsoga parviflora</i>	Paul, 2014
	<i>Helianthus annuus</i>	Vanitha <i>et al.</i> , 2013
	<i>Parthenium hysterophorus</i>	Reddy, 2006
	<i>Sonchus arvensis</i>	Ansari <i>et al.</i> , 2006
	<i>Sonchus asper</i>	Ansari <i>et al.</i> , 2006
	<i>Sonchus brachyotis</i>	Paul, 2014
	<i>Synedrella nodiflora</i>	Paul, 2014
	<i>Vernonia cinerea</i>	Ansari <i>et al.</i> , 2006
	<i>Xanthium strumarium</i>	Ansari <i>et al.</i> , 2006
	<i>Zinnia elegans</i>	Ansari <i>et al.</i> , 2006
Capparaceae	<i>Gynandropsis pentaphylla</i>	Paul, 2014
Caricaceae	<i>Carica papaya</i>	Raj <i>et al.</i> , 2008
Chenopodiaceae	<i>Chenopodium anthelmintium</i>	Saikia and Muniyappa, 1989
	<i>Chenopodium</i> spp.	Heydarnejad <i>et al.</i> , 2013
Cruciferae	<i>Benincasa hispida</i>	Roy <i>et al.</i> , 2013
	<i>Citrullus lanatus</i> var. <i>lanatus</i>	Ruiz <i>et al.</i> , 2017
	<i>Cucumis melo</i> L.	Ito <i>et al.</i> , 2008
	<i>Cucumis melo</i> var. <i>reliculatus</i>	Samretwanich <i>et al.</i> , 2000
	<i>Cucurbita pepo</i>	Ruiz <i>et al.</i> , 2015
	<i>Cucumis sativus</i> L.	Ruiz <i>et al.</i> , 2017
	<i>Lagenaria siceraria</i>	Ito <i>et al.</i> , 2008
	<i>Luffa aegyptiaca</i>	Sorab <i>et al.</i> , 2013
	<i>Luffa cylindrical</i>	Sohrab <i>et al.</i> , 2003
	<i>Momordica charantia</i>	Tahir and Haider, 2005 and Tiwari <i>et al.</i> , 2010
	<i>Sechium edule</i>	Nagendran <i>et al.</i> , 2017
Euphorbiaceae	<i>Croton bonplandianum</i>	Ansari <i>et al.</i> , 2006
	<i>Euphorbia geniculata</i>	Ansari <i>et al.</i> , 2006
	<i>Euphorbia hirta</i>	Ansari <i>et al.</i> , 2006
	<i>Jatropha curcas</i>	Ansari <i>et al.</i> , 2006

Table 2.2b: Host plants of tomato leaf curl virus

Family	Host species	Reference
Fabaceae	<i>Cassia tora</i>	Sohrab, 2016
	<i>Crotalaria juncea</i>	Ansari <i>et al.</i> , 2006
	<i>Glycine max</i>	Raj <i>et al.</i> , 2006
	<i>Lens esculenta</i>	Ansari <i>et al.</i> , 2006
	<i>Phaseolus vulgaris</i>	Ansari <i>et al.</i> , 2006
	<i>Physalis virginiana</i>	Stonor <i>et al.</i> , 2003,
Lamiaceae	<i>Salvia plebia</i>	Paul, 2014
	<i>Calceolaria uniflora</i>	Paul, 2014
Malvaceae	<i>Abelmoschus esculentus</i>	Ansari <i>et al.</i> , 2006
	<i>Abutilon indicum</i>	Ansari <i>et al.</i> , 2006
	<i>Althea rosea</i>	Ansari <i>et al.</i> , 2006
	<i>Gossypium hirsutum</i>	Ansari <i>et al.</i> , 2006
	<i>Hibiscus rosa-sinensis</i>	Ansari <i>et al.</i> , 2006
	<i>Sida mysoriansis</i>	Ansari <i>et al.</i> , 2006
Polygonaceae	<i>Walteria Americana</i>	Paul, 2014
	<i>Rumex dentatus</i>	Ansari <i>et al.</i> , 2006
Oxalidaceae	<i>Oxalis acetosella</i>	Paul, 2014
	<i>Oxalis corniculata</i>	Paul, 2014
Solanaceae	<i>Capsicum annum</i>	Ansari <i>et al.</i> , 2006
	<i>Capsicum chinense</i>	Ruiz <i>et al.</i> , 2017
	<i>Capsicum fruitiscence</i>	Ansari <i>et al.</i> , 2006
	<i>Cyphomandra betacea</i>	Stonor <i>et al.</i> , 2003
	<i>Datura stramonium</i>	Ansari <i>et al.</i> , 2006
	<i>Lycopersicon chilense</i>	Vidavski <i>et al.</i> , 1998
	<i>Lycopersicon esculentum</i>	Ruiz <i>et al.</i> , 2017
	<i>Lycopersicon glandulosum</i>	Paul, 2014
	<i>Lycopersicon hirsutum</i>	Vidavski <i>et al.</i> , 1998
	<i>Lycopersicon peruvianum</i>	Vidavski <i>et al.</i> , 1998
	<i>L. pimpinellifolium</i>	Vidavski <i>et al.</i> , 1998
	<i>Nicandra physalodes</i>	Ansari <i>et al.</i> , 2006
	<i>Nicotiana benthamiana</i>	Usharani <i>et al.</i> , 2004
	<i>Nicotiana glutinosa</i>	Ansari <i>et al.</i> , 2006
	<i>N. plumbaginifolia</i>	Ansari <i>et al.</i> , 2006
	<i>N. sylvestris</i>	Paul, 2014
	<i>N. tabacum</i>	Ansari <i>et al.</i> , 2006
	<i>Petunia hybrid</i>	Stonor <i>et al.</i> , 2003
	<i>Physalis minima</i>	Ansari <i>et al.</i> , 2006
	<i>Solanum melongena</i>	Ruiz <i>et al.</i> , 2017
	<i>Solanum nigrum</i>	Ansari <i>et al.</i> , 2006
	<i>Solanum pseudocapsicum</i>	Stonor <i>et al.</i> , 2003
	<i>Solanum seaforthianum</i>	Stonor <i>et al.</i> , 2003
	<i>Solanum tuberosum</i>	Gawande <i>et al.</i> , 2007

and protein sequence comparisons indicate that many TYLCV and ToLCV isolates analyzed so far constitute distinct virus species and are not strains of the same species.

Khan (2000) employed geminivirus specific degenerated primers to detect TLCV occurring in its vector whitefly *Bemisia tabaci* by PCR based approach. One primer pair (PAL1v1978/PAR1c496), amplified TLCV DNA fragment of about 1.1 Kb representing partly replicase gene, intergenic region and partly coat protein gene was used. When a set of primer (AV494/AC1048) targeted to the core region of the coat protein gene of geminivirus was used, a PCR amplified fragment of about 0.5 Kb was obtained.

Muniyappa *et al.* (2000) used polymerase chain reaction for detection of ToLCV using degeneated primers both in infected tomato plants and viruliferous *B. tabaci*.

Banks *et al.* (2001) collected thirty five symptomatic tomato leaf samples within the epidemic region and extracted DNAs from all gave the expected 500 to 600 bp amplicon with begomovirus-specific primers A/B. These primers amplify from the conserved nonanucleotide TAATATTAC in the common region of DNA-A to the conserved amino acid sequence CEGPCKYG within the coat protein gene. *AluI* and *TaqI* restriction patterns of all 35 polymerase chain reaction (PCR) products were identical. One PCR product from an epidemic (GenBank no. AF321929) and a non-epidemic (AF321930) site (Bangalore) were cloned and sequenced. The two 531-bp inserts showed 96% nucleotide identity to each other and 94% nucleotide identity to the equivalent region of *Tomato leaf curl Bangalore virus* (ToLCBV-Ban-4) (AF165098), suggesting that the epidemic was caused by an indigenous ToLCBV strain.

Chakraborty *et al.* (2003) collected tomato plants (cv. Punjab Chuhara) showing typical leaf curl symptoms 12 days postinoculation (dpi). The total DNA from infected tomato leaves was isolated by the cetyl trimethyl ammonium bromide (CTAB) method followed by concentration of super-coiled DNA by the alkaline lysis method. They detected, begomovirus infection in samples initially by PCR using degenerate primers i.e. DNA-A specific oligonucleotide primers (GAv50/ GAc1122) and DNA-B specific primer combinations (GBv74/ GBc1280)

for general detection of begomoviruses. They characterized molecular properties of *Tomato leaf curl Gujarat virus* from Varanasi, India (ToLCGV-[Var]) and cloned the full-length genome of DNA-A and DNA-B of ToLCGV-[Var] in pUC18. Sequence analysis displayed that DNA-A (AY190290) is 2,757 bp and DNA-B (AY190291) is 2,688 bp in length. Open reading frames (ORFs) in both DNA-A and DNA-B are organized similarly to those in other begomoviruses. DNA-A and DNA-B share a common region of 155 bp with only 60% sequence identity. DNA-B of ToLCGV-[Var] shares overall 80% identity with DNA-B of *Tomato leaf curl New Delhi virus-Severe* (ToLCNDV-Svr) and 75% with ToLCNDV-[Lucknow] (ToLCNDV[Luc]). Comparison of DNA-A sequence with different begomoviruses indicates that ToLCGV-[Var] shares 84% identity with *Tomato leaf curl Karnataka virus* (ToLCKV) and 66% with ToLCNDV-Svr. ToLCGV[Var] shares a maximum of 98% identity with another isolate of the same region (ToLCGV-[Mir], AF449999) and 97% identity with one isolate from Gujarat (ToLCGV-[Vad], AF413671). All three viruses belong to the same species that is distinct from all the other geminivirus species described so far in the genus Begomovirus of the family Geminiviridae. The name “*Tomato leaf curl Gujarat virus*” is proposed because the first sequence was taken from an isolate of Gujarat, India.

Sinha *et al.* (2004) collected *Tomato leaf curl virus* (ToLCV) infected samples from four different ecological zones of India: Northern zone, NewDelhi (IARI) [ToLCNDV-IARI], Central zone, Jabalpur [ToLCV-Jb], Raipur [ToLCV-Rp] and Southern zone, Dharwad [ToLCV-Dh] and maintained by whitefly transmission into tomato cv. Pusa Early Dwarf. Replicase gene coding for replication initiator protein (Rep) was amplified by PCR using gene specific primers, yielding an amplicon of 1086 bp for all the isolates. Sequence analysis of the *rep* amplicons of all the Indian isolates of ToLCV causing the disease clearly shows the presence of two subgroups irrespective of their geographical evolution. Isolates belonging to subgroup I comprising of *Tomato leaf curl virus-New Delhi* (ToLCV-NDe) having bipartite genome are conserved within themselves and showed 94–95% nucleotide sequence homology. Second subgroup comprising of *Tomato leaf curl virus-Bangalore* (ToLCBV) having monopartite genome and conserved among themselves, but showed only 73-75% homology with the

subgroup I. In phylogenetic tree analysis, ToLCV-NDe appeared in a different cluster than ToLCV-Ban. All the four isolates used in this study fall in ToLCV-NDe group based on their replicase gene sequences. The specificity determinant located at N terminal suggests ToLCV-NDe and ToLCV-Rp as mild isolates.

Chowda Reddy *et al.* (2005) done phylogenetic analyses of the CP sequences which revealed five different *Tomato leaf curl begomovirus* (TLCB) clusters each <88% identity to the others. Four clusters represented known Indian TLCBs, whereas one cluster contained sequences originating from Haryana State with most identity (89%) to the provisional Begomovirus species *Croton yellow vein mosaic virus*. They characterised sixty five begomovirus positive samples further by PCR with DNA-beta, DNA-B, four Indian TLCB species, PALIc1960/PARIV722 (universal begomovirus primers), and by sequencing. The majority of samples represented monopartite TLCBs associated with DNA-beta components. All four known TLCBs appeared to be present throughout India.

Reddy (2006) amplified *Tomato leaf curl virus* DNA from the collected samples in PCR using *Tomato leaf curl virus* specific primers (ToLCBV 33 F and ToLCBV B 1070 R), a thick band was observed at 1000 base pairs. Thus he confirmed the presence of ToLCV in all the collected symptomatic tomato plants from different regions of North Karnataka. Further, the amplified product was eluted from the gel and cloned into a plasmid (cloning vector) to facilitate its sequencing. The results of the cloning and nucleotide sequencing of the coat protein gene revealed that isolates from Belgaum, Dharwad and Haveri showed 95.10 to 99.60 percent homology indicating they are closely related to each other. However, these isolates showed wide variation of upto 46.50 percent divergence with some of the isolates of North Western Indian ToLCV 17 Nasik (AJ 10356) and North Indian ToLCV 19.Patna (AJ 810358).

Shih *et al.* (2006) reported that the genome organization of the chilli begomovirus from Punjab is similar to that of *Tomato leaf curl Joydebpur virus* (ToLCJV, AJ875159) from Bangladesh (Maruthi *et al.*, 2006), with which it shares 90.3% sequence identity. Both of these viruses contain the V1, V2, C1, C2, C3 and C4 predicted opening reading frames (ORFs), and an additional predicted ORF C5

of 849 nt (282 amino acids) on the complementary strand which is absent in DQ629103.

Bela-ong and Bajet (2007) detected whitefly-transmissible geminiviruses by the polymerase chain reaction (PCR) in total nucleic acid preparations of tomato and squash leaf samples from different areas in the country. Begomovirus DNA fragments were detected by PCR using 3 sets of degenerate primers that amplify different regions of the genomic A DNA component of begomoviruses. The core coat protein primer pair gave the diagnostic ~560 bp amplicons, the top half primers produced ~1.6 kb PCR products, and the bottom half primers yielded ~1.2 kb amplicons. Not all samples produced amplicons of the expected sizes in PCR. Some samples produced bands in all 3 primer sets, some in only 2 of the 3 sets of primers, while some produced PCR fragments in only 1 of the 3 primer pairs, which suggests variation in the virus DNA sequence in terms of the presence or absence of primer annealing sites. Southern blot analysis using as probe the PCR product amplified from a top half clone of the genomic A DNA component of the Philippine isolate of *Tomato leaf curl geminivirus* (ToLCVPh), confirmed the Begomovirus identity of the top half primer pair-generated amplicons. Results confirmed that begomoviruses are responsible for some tomato and squash leaf curl diseases and the prevalence of these diseases threatens sustainable production of tomato and squash in the country.

Pandey *et al.* (2010) collected leaves of infected tomato plants from two different regions of Indian subcontinent viz. central region of New Delhi and from the fields of Kerala in the middle of February 2006. The coat protein fragment was detected from infected, symptomatic samples using the Begomovirus coat protein primers (BGCP). They performed rolling circle amplification (RCA) for both the samples using TempliPhi 100 Amplification kit (Amersham Biosciences, USA). Complete nucleotide sequences of the full length (~2.7 kb) genomes of the two isolates amplified by the RCA technique were found to be monopartite. The rolling circle amplification (RCA) products obtained from symptomatic samples were digested with *BamH I* enzyme, cloned in cloning vector pCAMBIA1391Z and sequenced. The genomes are 2751-2769 nucleotides in length and are referred to as DNA A since they show maximum homology to the DNA A of previously

characterized begomoviruses. The viruses were identified and named as ToLCV-CTM and ToLCV-K3/K5 and the sequences are submitted to NCBI under accession numbers DQ629102 and EU910141/EU910140 respectively.

Tiwari *et al.* (2010) collected samples from plants showing yellow mosaic accompanied with slight curling on leaves including few healthy plants. PCR was carried out using the total DNA isolated from infected leaf samples and a pair of begomovirus specific primers which resulted in the expected size (~800 bp) amplicon in 3/6 samples indicating presence of begomovirus. For further identification of the begomovirus, the PCR amplicons were cloned and sequenced (GenBank accession no. EU439260). The sequence data analysis revealed highest 98-93% similarities with several isolates of *Tomato leaf curl New Delhi virus* (ToLCNDV) at both nucleotide and amino acid levels. The phylogenetic analysis also showed closest relationships of the isolate (EU439260) with various variant of ToLCNDV. Based on highest sequence similarities and closest relationships with ToLCNDV the virus isolated from bitter melon was considered as an isolate of *Tomato leaf curl New Delhi virus*.

Pratap *et al.* (2011) collected leaf samples of eggplant showing yellow mosaic symptoms from various locations of Nagpur in Central India during a field survey and isolated total genomic DNA by Cetyl trimethyl ammonium bromide (CTAB) method leaf samples of infected plants as well as from healthy eggplants (as negative control). RCA of isolated DNA was performed and the RCA products were digested with different restriction enzymes (*HindIII*, *EcoRI*, *BamHI*, *SacI* and *EcoRV*). The appearance of ~2.7 kb amplified DNA suggested the presence of a begomovirus in the infected leaves, while no such band appeared on digestion with negative control. The 2.7 kb fragments were directly cloned into the respective sites of pGreen0029 vector and sequenced. The end sequences (about 700 bases in total), obtained from each of the positive samples, showed the presence of a bipartite (DNA-A and DNA-B) begomovirus. Nucleotide sequence analysis of DNA-A showed that it shared highest 97.6% identity with *Tomato leaf curl New Delhi virus*-India [India:Udaipur:Okra:2007] and lowest 87.9% identity with *Tomato leaf curl New Delhi virus*-India [India:NewDelhi:Papaya:2005], while DNA-B showed highest 94.1% identity with ToLCNDV-IN [IN:UD:Ok:07] and

lowest 76.2% identity with ToLCNDV-India [India:Lucknow]. Thus, it appears that this begomovirus is a variant of ubiquitous ToLCNDV and hence, they suggested the name ToLCNDV-India [India:Nagpur:Eggplant:2009] for this variant.

Rajasri and Vijayalakshmi (2011) carried out PCR to identify the Gemini virus infection in ToLCV infected tomato plants. Further the derived products were cloned and sequenced. The ToLCV sample of Hyderabad shared a maximum identity of 93% with *Tomato leaf curl New Delhi virus* (ToLCV) strain when compared with known sequences in NCBI Genbank

Reddy *et al.* (2011) collected leaves and twigs samples exhibiting typical symptoms of ToLCV from all the tomato fields surveyed in Belgaum, Dharwad, Gadag and Haveri districts of North Karnataka during rabi 2005 and summer 2006. They extracted total DNA from all the representative field samples, by Cetyl trimethyl ammonium bromide method (CTAB) and carried out their PCR amplification with ToLCV specific primers i.e. *Tomato leaf curl Bangalore virus* (ToLCBV33F / ToLCBV1070R). All the samples were found positive for PCR amplification with specific primers for DNA 'A' component of ToLCBV. These primers amplified a $\approx$ 1040 bp product. They generated phylogenetic trees to examine the diversity of the sequences for the four CP sequences together with representative sequences available in gene Bank. The isolates under study clustered into two groups. The Dharwad isolate and Belgaum- 2 isolate were closely related (99.4% nucleotide similarity) and formed in to one cluster in which Haveri and Belgaum-1 isolates had comparatively less homology (97.30% nucleotide homology) between themselves and clustered into another sub group. The isolates under study had lowest nucleotide sequence homology of 53.50 to 53.90% with ToLCV 19. Patna (AJ 810358) followed by ToLCV 18. *Malvastrum*.Pa (AJ 810357) (53.50-54.00%), ToLCV 17. Nasik (AJ 810356) (53.90-54.30%), while they had highest homology of 92.40-96.00% with ToLCBV-AVT 1 (AY 428770). The results showed that these isolates are entirely different from North Indian isolates and there is some variability within the isolates collected from a geographical location, indicating that there will be continuous variability in gemini viruses.

Vanitha *et al.* (2013) conducted a study to characterize the begomovirus causing sunflower leaf curl disease by cloning and sequencing the major genomic components. They cloned and sequenced the complete DNA-A components of begomovirus isolated from sunflower leaf tissue infected with leaf curl virus collected from Main Agricultural Research Station, Raichur, Karnataka, India. The virus contained the DNA-A components of 2761 nucleotides (nt) in length. They reported that DNA-A molecule shared maximum identity with *Tomato leaf curl Karnataka virus* clone IKH12 (ToLCKV-[IKH12] (HM803118) (97.13%) and clone IKB3 (ToLCKV-[IKB3]) (HM851186) (96.95) from India.

Saha *et al.* (2014) characterized five tomato leaf curl disease (TLCD) causing virus isolates COB-2, COB-5, GUW-1, RAI-1 and SILIGURI-2 from Sub-Himalayan Tarai region of West Bengal and Brahmaputra valley of Assam based on sequencing of coat protein (CP) gene of begomovirus genomes. The sequence analysis showed that the present isolates shared 79-98% nt identity among them and 79-99% nt identities with other tomato infecting begomoviruses available in database. The isolates COB2, RAI-1 and SILIGURI-2 were similar to each other and related by 94-99% sequence identity with the isolates of *Tomato leaf curl New Delhi virus* (ToLCNDV, EU375489, EF043230, JN676054, HM007113, U15016, AM849548, JX232220, AM286434). The isolate COB-5 and GUW-1 are similar and are related with the *Tobacco curly shoot virus* (TbCSV, GU001879, JX467693), *Tomato leaf curl Ranchi virus* (ToLCRnV, GQ994095) and *Tomato leaf curl Bangladesh virus* (ToLCBnV, AF188481) by 95-98% sequence identity. In phylogenetic analysis, the present isolates formed two clades among them, COB2, RAI-1 and SILIGURI-2 in one and COB-6 and GUW-1 into another clade. The present data suggest that the TLCD in tomato in these regions is caused by a combination of begomoviruses.

Kamal *et al.* (2015) collected tomato leaf curl samples from six major tomato cultivating areas of Bangladesh. They isolated total DNA from symptomatic leaves and subjected to rolling circle amplification (RCA). Restriction digestion, polymerase chain reaction (PCR) and sequencing was performed using the RCA products. The coat protein of ToLCV was sequenced by the begomovirus specific “BGCP” forward and reverse primers. The partial

sequences of all the six isolates showed more than 90 percent nucleotide (nt) identities with *Tomato leaf curl virus* coat protein (CP) gene.

Jeevalatha et al. (2017) determined the complete coat protein (cp) gene sequence of eighty *Tomato leaf curl New Delhi virus*-[potato] (ToLCNDV-[potato]) isolates collected from eleven states. Phylogenetic analysis based on CP gene grouped the isolates into two major clades (I & II) and they shared 95.9–100.0% identity. The DNA A and DNA B of eight representative isolates (six from clade I and two from clade II) were 2739–2740 and 2692–2694 nts long and shared 94.6–99.4% and 97.2–99.5% homology within the isolates, respectively. Among the eight isolates, the DNA A of two isolates (Clade II), GWA-5 and FAI-19 had 94.6–95.3% sequence identity to other six isolates and formed a subclade within the ToLCNDV-[potato] isolates. Similar grouping was also revealed with AC1 and AC4 genes of these eight isolates. The DNA A components shared more than 90.0% identity with the DNA A of ToLCNDV isolates from cucurbitaceous crops, tomato, bhendi, 89.0–90.0% with ToLCNDV-papaya isolates and 70.4–74.0% with other *Tomato leaf curl viruses*.

Ruiz et al. (2017) reported that new full-length sequences from zucchini squash and tomato indicated a high genetic homogeneity (>99% sequence identity) in the ToLCNDV populations in Spain, pointing to a single recent introduction event.

Zaidi et al. (2017) found that nevertheless, partial ToLCNDV genome sequences from Tunisia and Italy share high degrees of nucleotide identity (97.6%–99.2%) with the Spanish isolates, such that it is very likely that the Italian and Tunisian isolates are monophyletic with the Spanish isolates.

2.7 The vector

Among the 1100 recognized species of whiteflies in the world, only four viz. *Bemisia tabaci* Gennadius (Sweetpotato whitefly), *Trialeurodes vaporariorum* Westwood (greenhouse / glasshouse whitefly), *T. abutiloneus* Haldeman (banded-wing whitefly) and *T. ricini* Misra (castor whitefly) are recognized as vectors of plant viruses (Jones, 2003 and Dalmon et al., 2009). *Bemisia tabaci* is considered the most common and important whitefly vector of plant viruses worldwide (Mau

and Kessing, 2007). It is responsible for transmitting >150 virus species, the majority of which are begomoviruses (Polston, *et al.*, 2014 and Smith *et al.*, 2015). *Bemisia tabaci* (Gennadius) is classified under order Hemiptera, family Aleyrodidae and sub family Aleyrodinae (Mohanty and Basu, 1986 and Martin, 1987), reported as the only known vector of *Tomato leaf curl virus* (Kumar *et al.*, 2012, Mishra *et al.*, 2014 and Mandali *et al.*, 2016). Mound and Halsey (1978) listed 22 synonyms for *B. tabaci*. To date, over 30 'biotypes' of *B. tabaci* have been named (Banks and Markham 2000, Perring 2001 and Liu, *et al.*, 2012) based on esterase profiles (Brown *et al.*, 1995) and biological assays such as mating compatibility and virus transmission ability (Shankarappa, *et al.*, 2007 and Chowda-Reddy *et al.*, 2012). Out of them two biotype viz. *B. tabaci* biotypes B (Banks, 2001, Kumar *et al.*, 2012 and Czosnek *et al.*, 2017) and Q (Ning *et al.*, 2015), are vectors of *Tomato leaf curl virus*. *B. tabaci* biotypes B is also known as the silver leaf whitefly Biotype B, [*B. argentifolii* (Bellows and Perring)] (Kumar *et al.*, 2012).

Three types of damage may be caused by the Sweetpotato whitefly: 1) direct damage, 2) indirect damage and 3) virus transmission (Berlinger, 1986). Direct feeding damage is caused by the piercing and sucking sap from the foliage of plants. This feeding causes weakening and early wilting of the plant and reduces the plant growth rate and yield (Berlinger, 1986). It may also cause leaf chlorosis, leaf withering, premature dropping of leaves and plant death. Infestations of Sweetpotato whitefly nymphs are associated with the occurrence of irregular ripening of tomatoes and silver leaf of squash. Indirect damage results by the accumulation of honeydew produced by the whiteflies. This honeydew serves as a substrate for the growth of black sooty mold on leaves and fruit. The mold reduces photosynthesis and lessens the market value of the plant or yields it unmarketable (Berlinger, 1986). The third type of damage is caused by the vectoring of plant viruses by this insect. A small population of whiteflies is sufficient to cause considerable damage (Cohen and Berlinger, 1986 and Mau and Kessing, 2007).

B. tabaci has a host range of over 600 plant species (Mound and Halsey 1978, Greathead 1986, Secker, *et al.*, 1998, Evans 2007 and Taylor, 2011). It has been suggested that *B. tabaci* has a much wider host range than other *Bemisia*

biotypes indicating its success as a cosmopolitan pest is due to a large host range (Brown *et al.*, 1995, Perring 2001 and Taylor, 2011).

2.8 Epidemiology of ToLCD

In Ludhina, Punjab, whitefly was most active when the temperature ranged 33 °C to 39 °C (Butter Rataul, 1978). Naresh and Nene (1980) reported that in Nainital condition (terai region of UP), the fly remained active from October to May on tomato.

Bhutani and Jotwani (1984) have noted that the activity of adult fly decreased with the onset of rain. Bharadwaj and Kushwaha (1984) noted that whitefly population had negative correlation with relative humidity (RH) and positive correlation with temperature in Rajasthan condition. Horowitz *et al.* (1984) reported from Israel that the high mortality of first instar larvae of *B. tabaci* in cotton fields was mainly due to maximum humidity and temperature. Gerling (1986) observed that extreme relative humidity, both high and low, adversely affect the survival rate of immature stages.

Banerjee and Kalloo (1989) recorded that the incidence of ToLCD was high in rainy season rather than winter season crop in all tomato growing states of India. Due to climate change, the incidence pattern has been changed.

Ioannou and Iordanou (1985) said that the incidence of TYLCV was generally characterized by great regional and seasonal variations which were usually attributed to respective fluctuations in the population density of the whitefly vector.

Saikia and Muniyappa (1989a and 1989b) observed a positive correlation between the incidence of TLCV disease and whitefly population is well documented and attempts were made to prevent the spread of the virus by controlling whitefly populations.

Green and Kalloo (1994) reported that the epidemiology of whitefly-transmitted geminiviruses is characterized by a close correlation between disease incidence and whitefly populations which often show strong seasonal fluctuations.

Holt *et al.* (1999) emphasized that the incidence of disease in the crop depends primarily on the immigration of vectors from alternative hosts which act

as a reservoir of both the virus and vector. A very low rate of simulated vector immigration into a tomato crop sufficed to cause almost total infection. Disease incidence was sensitive to vector mortality only when vector numbers were low. In most cases, the immigration of viruliferous vectors made disease incidence insensitive to the mortality of vectors within the tomato crop.

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 and ToLCVD incidence is positively correlated with it. From September to October, which is also the period of low temperatures and high rainfall, numbers fall to approximately a tenth of their summer levels. Tomato leaf curl virus disease (ToLCVD) incidence in South India is highly correlated with the size of the *B. tabaci* population. ToLCVD symptoms can appear as early as 2 week after planting (WAP) in susceptible tomato, planted in March which later increases rapidly to 100 percent by 11 WAP and leading to complete crop failure (Saikia and Muniyappa, 1989, Ramappa *et al.*, 1998 and Nagaraju *et al.*, 2002).

Reddy (2006) found that tomato planted during August 2005 and November 2005 showed slow progress of the disease and less incidence as there was high humidity and high rainfall, which suppress the vector activities whereas the May-2005 and February-2006 planted crops had early onset of the disease and rapid spread of the disease and higher vector population. The crops planted between June to September found to be better in reducing the disease incidence, as there was high humidity and high rainfall.

Konet *et al.* (2008) found that the whitefly population was more in December to February when the temperature was low. Both whitefly and disease pressure was more in *rabi* season (Singh *et al.*, 2015) whereas the role of *B. tabaci* population size in relation to ToLCV incidence has also been recorded by Cohen and Antignus (1994) in the Jordan Valley. However, in Tanzania, ToLCV disease incidence was very low but its peak of symptoms and whitefly population occurred between the first week of September to Mid October and November to February when minimum and maximum temperature ranged from 15 °C to 32.5 °C, respectively (Nono-Womdim, *et al.*, 1996). It was also recorded that the disease

incidence was more in winter season transplanted crop than rainy season at eastern part of Uttar Pradesh in Varanasi (Singh *et al.*, 2010 and Singh *et al.*, 2015).

Chakraborty (2012) observed the first appearance of *B. tabaci* and TYLCV incidence at about 48 and 50 SMW. He noted a significant negative correlation ($R = -0.573$, $p = 0.005$) between number of whiteflies counted by visual observation and TYLCV incidence. He observed that the population of whitefly steadily declined with the maturity of plant because whiteflies basically preferred young tender tomato leaves than old tomato plants. He recorded significant negative correlation of *B. tabaci* population with the maximum temperature (T_{max}), minimum temperature (T_{min}), temperature gradient (T_{gr}), average temperature (T_{avg}), persistent maximum relative humidity (RH_{max}) (83 - 91 %), minimum relative humidity (RH_{min}) and bright sunshine hour ($8.10 \text{ hrs day}^{-1}$). He observed significant positive relations between the relative humidity gradient (RH_{gr}) and the field flies population. He also observed that the drizzling rainfall (R_{fall}) had an insignificant positive effect on the pest structure. But heavy rainfall within a short period had imparted significant negative effect on white fly incidence.

The incidence of ToLCD in the crop depends primarily on the immigration of vectors from alternative hosts, which act as reservoir of both virus and vector and the ease with which the vectors could acquire the virus from infected plants had little impact on disease incidence in the tomato crop (Ramappa, 1998 and Kakati and Nath, 2014). It is also appeared that very low rate of vector immigration into tomato crop would suffice to cause almost total infection (Holt, 1998 and Govindappa *et al.*, 2013). Though it is an evident that in the infectivity test, 4 to 46 percent of the whiteflies (*B. tabaci*) collected from ToLCV infected fields were found viruliferous (Ramappa, 1993 and Kakati and Nath, 2014). *B. tabaci* trapped on cylindrical sticky yellow traps on the day of tomato transplanting in the main field, the migration of *B. tabaci* increased in subsequent days of planting, indicating that only the migrating *B. tabaci* are highly responsible for the ToLCV spread (Venkatesh, 2000 and Govindappa *et al.*, 2013).

Singh *et al.* (2015) observed positive relation of ToLCD incidence with coefficient of infection (CI %) and climatic factors (temperature, rainfall and humidity). In rainy season of three years (2007-2010), average rainfall was 75.50

mm, minimum and maximum temperature ranged from 24.86 °C to 40.00 °C, respectively with relative humidity of 74.82 % and CI (%) of ToLCD reached on 32.5%. Whereas, in winter season, rainfall was minimum and static on 1.78 mm, minimum and maximum temperature ranged from 7.14°C to 28.70°C, respectively coupled with 62.39% relative humidity and CI (%) of ToLCD increased and reached up to 42.62%. In present investigation, ToLCD incidence increased in winter season (October - February) than rainy season (July -September) grown crop. This may be population of vector whiteflies did not survived and multiplied in rainy season due to high temperature whereas, winter season was more favourable for faster multiplication of whitefly population.

Vijaya Lakshmi *et al.*, (2015) undertook a study at Horticultural Research Station Lam during 2013-14 & 2014-15 with an objective of investigating the impact of climate change on the development of tomato leaf curl disease and vector. From the correlation and regression of the two years data, the incidence indicated significant positive correlation with maximum temperature (2013, $r = 0.77$. 2014, $r = 0.81$) and minimum temperature (2013, $r = 0.62$. 2014, $r = 0.74$). However it showed significant negative correlation with afternoon relative humidity (2013, $r = -0.66$. 2014, $r = -0.65$) in both the years. The disease initiated during the third week of November and gradually increased and reached maximum up to 100% by March second week where high maximum temperatures prevailed. Coefficient of multiple determination (R^2) was also significant (R^2 for 2013 = 0.731. 2014 = 0.777.) and implies that 75.4 (mean of two years) of the variation in the development of the *Tomato leaf curl virus* was explained by the five independent variables minimum and maximum temperature, morning and afternoon relative humidity, rainfall and one dependent variable (whitefly population).

Bemisia tabaci populations are highly influenced by climatic conditions viz. extreme temperatures, low relative humidity (<60%), and heavy and persistent rainfall. Consequently, the climatic conditions of the Mediterranean, with mild temperatures and high humidity, together with the presence of large areas of overlapping monocultures grown in greenhouses, such as in south eastern areas of

Spain, favour the presence of high populations of whiteflies and the introduction of new viruses (Janssen *et al.*, 2005 and Ruiz *et al.*, 2017).

2.9 Evaluation of the performance of popular commercial varieties / hybrids and others (entries) against tomato leaf curl disease

None of the methods available for the management of the ToLCD are as effective as the use of ToLCV resistant cultivars and no variety can be always resistant or tolerant to disease. Thus there is a need to develop ToLCV resistant cultivars continuously for effective and environmentally safer management of ToLCD. The success of disease resistance breeding solely depends on the evaluation tests employed. It is important to employ most reliable tests of resistance when dealing with destructive diseases like ToLCD.

Muniyappa *et al.* (1991a) screened 1201 tomato cultivars, breeding lines and accessions of *Lycopersicon* species for *Tomato leaf curl virus* (ToLCV) under field and laboratory conditions during summer of 1986 to 1989. Two lines of *L. hirsutum* (P1390658 and P1390659) and 2 lines of *L. peruvianum* (P1127830 and P1127831) were resistant to TLCV infection.

Channarayappa *et al.* (1992) screened more than 1200 cultivars, breeding lines, and wild species of *Lycopersicon* for resistance to the ToLCV under field conditions. All accessions of *Lycopersicon esculentum* were found susceptible to ToLCV. Three lines of *Lycopersicon hirsutum* and one of *Lycopersicon peruvianum* accessions showed apparent resistance to the ToLCV.

Tripathi and Varma (2002) evaluated 38 cultivars and 11 breeding lines of *L. esculentum* Mill. against ToLCV. None was highly resistant or resistant while three and seven were moderately resistant when exposed to the cloned virus DNAs by agroinoculation and whitefly inoculation respectively.

Dharmatti *et al.* (2004) screened 102 genotypes of tomato against ToLCV in summer season of 1997 and found only 5 lines viz. 20/2, 20/4, 20/5, 20/6 and AVRDC Alcobasa as resistance.

Alegbejo and Banwo (2006) screened 16 tomato cultivars obtained from the Institute for Agricultural Research (IAR), Samaru, Nigeria for resistance to local strains of ToLCV at Samaru, over a two year period, 1998-1999 and 1999-2000 dry seasons. They reported that five cultivars were moderately resistant, nine

were moderately susceptible, while two were highly susceptible and most of the cultivars were high yielding (46–55 t ha⁻¹) with good fruit size (4.8-6.0 cm × 2.8-4.1 cm).

Reddy *et al.* (2008) screened 50 genotypes of tomato for ToLCV during summer 2005-06 under field conditions and found one of the lines as resistant, however, six (Alcobasa-B, Vybhav, L-32, S-21, Sankranti and Nandi) and nine genotypes had mild and moderate infection respectively. He also noted that in the second season, *i.e.* 2006 only Nandi and Vybhav were moderate resistant, along with the new commercial hybrids Hy-558, Hy-530, NS-563 and NS-719. The variety Vybhav was superior over other varieties against the disease. He observed that the plant height of the genotypes contributes to maximum extent (52.21 %) to the divergence followed by yield per plant and percent disease incidence (10.86 % each), but the vector population contributed least (0.97 %). As a result of D² clustering, the commercial hybrids possessing lot of diversity fall in to four different clusters, cluster II had got six entries, cluster III 3 entries, cluster IV 6 entries and cluster V only one entry whereas cluster I had 50 entries.

Arora *et al.* (2011) undertook an investigation to screen 12 tomato genotypes including two resistant checks (56-14-7 and 58-11-1-1), two susceptible checks (Punjab Upma and Punjab Chhuhara) and eight advanced lines (11-22, 2-20-2, 6-2-3, 4-4-1-1, 7-4-5, 8-3-2, 8-5-2-1 and 1-2-3), against tomato leaf curl disease (ToLCD). He found that all eight advanced lines were resistant to ToLCV with zero percent infection whereas Punjab Upma and Punjab Chhuhara were susceptible. He observed that stomatal size, frequency and index on adaxial and abaxial phyloplanes were significantly higher in susceptible as compared to the resistant checks and advanced lines. However, trichome size and frequency on both phyloplanes were significantly higher in resistant checks and advanced lines as compared to the susceptible checks. SEM studies also exhibited differences in size and number of stomata, trichomes and epidermal thickenings in resistant and susceptible tomato leaves. He detected the presence of virus in susceptible checks but not in resistant checks and advanced lines by molecular studied. Zero percentage of disease incidence, smaller and lesser stomata, larger and higher

number of trichomes and absence of virus in advanced lines through molecular studies proved that the advanced lines were resistant to ToLCV.

Gaikwad *et al.* (2011) evaluated 11 accessions of tomato including two susceptible checks (Punjab Upma and Punjab Chhuhara) in autumn season (July-December, 2009) against ToLCD under natural epiphytotic conditions. He noticed that five lines did not show any disease symptoms, whereas both the susceptible checks had 100 percent disease infection.

Shekhawat and Srivastava (2011) crossed 10 parents including four ToLCV resistant and six ToLCV susceptible genotypes in a half diallel fashion and evaluated the resultant 45 each of F1 and F2 along with their parents for yield, its components characters and tolerant to ToLCV. They reported that among all the genotypes, H-24, H-86, H-36, DVRT-1, Azad T-6 and IIVR Sel-2 gave promising results.

Bora *et al.* (2012) tested a total of 18 tomato (*Lycopersicon esculentum* Mill.) genotypes, received under All India Coordinated Research Project (AICRP) on Vegetable Crops, for resistance against leaf curl virus under natural condition during 2007-08 to 2009-10 in different agro-climatic zones of Assam particularly Lower Brahmaputra Valley Zone (LBVZ) and Hill Zone (HZ). He pooled the data and said that tomato genotype 'H-24' exhibited lowest incidence of leaf curl virus of 9.6 percent up to flowering and fruiting stage as against 20.4 percent in the susceptible check 'Punjab Chhuhara'. He observed that genotype 'H-24' had the highest fruit yield of 33.7 t ha⁻¹ at Jorhat location which was 35.3 percent higher than the susceptible check. He also reported that tomato cultivar 'H-24' showed the highest benefit: cost ratio of 4.77 as against 3.60 in the 'Punjab Chhuhara'.

Sain and Chadha (2012) conducted field experiments in 2007 and 2008 at AVRDC – The World Vegetable Center's-Regional Center for South Asia in Hyderabad, India to evaluate 30 improved lines of tomato for yield performance and field tolerance/ resistance against *Tomato leaf curl virus*. In 2007, yield ranged from 27.92 to 83.74 t ha⁻¹, while in 2008 it ranged from 62 to 80 t ha⁻¹. They found that lines DR2-1 (BL1173), DR-4 (BL1176), and NC 3220 × 57-27-3 were high yielding and stable throughout the two-year period. They reported significant negative correlation between disease severity index and yield.

Rajasri and Vijayalakshmi (2013) screened 29 tomato genotypes including 15 hybrids, 13 varieties and one exotic wild accession against ToLCD under greenhouse conditions at National Bureau of Plant Genetic Resources Regional Station, Rajendranagar, Hyderabad during 2007-2009. They found that among the screened genotypes, one wild accession, EC251672 was immune without any symptoms whereas ten genotypes comprising of 9 hybrids viz. Akash-918, NS-539, NS-515, Siri-9005, STH-803, STH-807, To-1827, US-1196, US-2175 and one cv. Vybhav were resistant to ToLCV.

Most of the genotypes were found in category of moderately susceptible, susceptible, and highly susceptible disease reaction, it may be due to changing of viral strain and not stable to any genotypes for ToLCV resistance till long duration (Singh *et al.*, 2010, 2015). A classical example is that H 24 line of tomato is being used as donor parent for resistance to ToLCV in many parts of the world but today this line has become moderately resistant and susceptible may be due to climate change (Singh *et al.*, 2010, 2015).

Ehsanullah (2014) tested 100 tomato lines for resistance against ToLCV (Ban4) out of them seven lines viz. EC-077160, EC -771615, L-00887, EC-676730, EC-608443, EC- 771590 and LA- 0369 showed immune reaction and 32 genotypes showed moderately resistant reaction. He also confirmed that all the seven field resistant genotypes viz. EC-771607, EC-771615, L-00887, EC- 676730, EC608443, EC-771590 and LA-0369 exhibited resistant reaction to ToLCV when inoculated using viruliferous whitefly vector under glasshouse conditions.

Singh (2014) screened 32 tomato genotypes for its resistance/ susceptible reaction against ToLCD under greenhouse condition during winter cropping seasons (*Rabi*) 2009-10 and 2010-11. He observed that among the screened genotypes, one wild accession, H-88-78-1 was immune against ToLCV without producing any symptoms of leaf curl disease. However, three genotypes (Hissar Lalima, TLBRH-6 and NS-515) were resistant and eight genotypes (Hissar Anmol, Kishi Vishesh, Kashi Amrit, Kashi showed resistant Sharad, KS-17, KS-118, Avinash-2 and US-1008) were moderately resistant to ToLCV.

Yadav *et al.* (2014) screened the total 80 genotypes in pot culture under natural conditions during February, 2009 at Department of Olericulture, College of

Horticulture, Kerala Agricultural University, Thrissur. He found that out of 80 genotypes under pot culture experiment 26 were Highly resistant, 1 Moderately resistant, 2 Resistant, 9 Moderately Susceptible, 18 Susceptible, 24 Highly Susceptible.

Singh *et al.*, (2015) screened 153 tomato genotypes for three consecutive years (2006–09) under glasshouse and field conditions for ToLCV resistance. They observed higher incidence of disease during the *Rabi* season as compared to the *Kharif* season trials. They studied the reactions of different genotypes by artificial inoculation. Based on the coefficient of infection they found nine genotypes (EC-520049 (*Solanum chmielewskii*), EC-520058, EC-520060 and EC-520061 (*S. habrochaites*), EC520070, EC-520071, EC-520077, EC-520079 (*S. pimpinellifolium*) and H-88-78-1(*S. lycopersicum*, a derivative of *S. habrochaites* f. *glabratum*) as highly resistant in both environments.

Singh *et al.* (2015) conducted a study on 83 morphologically diverse tomato genotypes grown at Indian Institute of Vegetable Research, Varanasi for three years (2007-08, 2008-09 and 2009-10) in both rainy (June-October) and winter (November-March) seasons. He observed that among the 83 genotypes none was resistant, however, 3 were resistant and 14 moderately resistant, while 49, 12 and 5 were moderately susceptible, susceptible and highly susceptible, respectively in rainy season 2007-08. But in winter season they found that none of genotypes was highly resistant and resistant, however, 6, 39, 25 and 13 were moderately resistant, moderately susceptible, susceptible and highly susceptible respectively. In 2008-2009 none of the genotype was highly resistant in both rainy and winter seasons. While, tomato genotypes in both rainy and winter seasons were 3 and 0 resistant, 16 and 7 moderately resistant, 42 and 38 moderately susceptible, 17 and 31 susceptible and 5 and 7 highly susceptible, respectively. They also found similar results in year, 2009-2010, none genotype showed highly resistant reaction during both rainy and winter seasons. The disease reaction of tomato genotypes in rainy season was 4 resistant and 8 moderately resistant while 45, 20 and 5 genotypes were moderately susceptible, susceptible and highly susceptible, respectively. But in winter season, none of genotypes was found resistant, only 3 were moderately resistant, whereas moderately susceptible,

susceptible and highly susceptible were 27, 34 and 19, respectively. However, in response of these three years 2007-08, 2008-09 and 2009-10, resistant genotypes were more in rainy season (3, 3 and 4) than winter season (0) indicating more disease pressure was in winter season than rainy season. On the basis of overall mean of three years data, out of 83 genotypes no genotype recorded as highly resistant or resistant to ToLCV disease. However, six genotypes, viz. EC 519730, F 6021, F 60501, LA 3969, LA 4012 and LA 4040-1 expressed moderately resistant disease reaction with CI % ranged from 12.3% to 16.2%.

Mihretu and Bhalekar (2016) undertook an investigation to evaluate F5 and F6 generations of tomato genotypes for yield potential during spring-summer 2009/10 and 2010/11. They evaluated tomato genotypes of F5 and F6 generations of two crosses ($M-3-1 \times H-24$ and $872 \times 18-1-1$) and two standard checks ('Bhagyashree' and 'Dhanashree'). They recored highest plant height, 92.67 and 81.4 cm in T27 (cross $87-2 \times 18-1-1$) in F5 and F6 generations respectively, number of branches per plant, 6.2 (T6, cross $M-3-1 \times H-24$) in F5 and 5.33 (T32, cross $87-2 \times 181-1$) in F6, days to first harvesting ranged from 66 (T9, cross $M-3-1 \times H-24$) to 75.33 days in F5 and 71.33 to 80 days in F6, harvest duration, 62.67 to 69 days in F5 and 52 to 70 days in F6. They observed significant differences in all yield and yield contributing characters in both generations. Maximum number of fruits per plant was 45.3 (T8, cross $M-3-1 \times H-24$) in F5 and 50.13 (T25) in F6, average fruit weight, 74.55 and 77.24 g (T29, cross $87-2 \times 18-1-1$) in F5 and F6 progeny generations, respectively, fruit yield per plant, 1.94 kg (T26, cross $87-2 \times 18-1-1$) in F5 and 1.94 kg (T8 and T25) in F6 generation, yield, 56.56 t/ha (T26) in F5 and 57.35 t/ha (T25) in F6 generation. Percent mean disease incidence of *Tomato leaf curl virus* was 2.26 in F5 and 2.4 percent in F6 progenies.

The leaf curl disease affected all fifteen tested varieties of tomato during the years 2014-2015 in Tripura. The disease was most severe in BT-1 variety with mean disease 80.9%, while, that was significantly less in the varieties, like, Tura Local, Type-1 and H-24 as well as a hybrid, All-Rounder (Syngenta), with TLCV incidences, 37.5%, 43.3%, 48% and 47.9%, respectively. The disease incidence was recorded more in 2015 than 2014. Similarly, the number of fruits and fruit weight of all tested varieties were less in 2015 (Ranebennur *et al.*, 2016).

Zeshan *et al.* (2016) screened 27 tomato varieties/lines (Roker, Big Beef, 09079, Uovo Roseo, Naqeeb, Caldera, Sitara-TS-101, Pakit, Riogrande, Nuyt-9-11, Nagina, Lyp#1, Roma, Nuyt-25- 11, Carmen, BL-1176-Riostone-1-1, Libnan Arif, Nuyt - 04-11, Salma, PO-02, 09088, 09080, 10127, 10113, 09091, 10125 and 014276) for the source of resistance against ToLCD in field condition. They reported that out of twenty seven varieties/lines, three were highly susceptible, six were susceptible, four were moderately susceptible, six were moderately resistant and eight cultivars were resistant. No variety/line was highly resistant or immune against TLCVD.

Nadkarni *et al.* (2017) screened 35 tomato genotypes including wild accessions against tomato leaf curl disease in field condition during summer 2015. They found that among the 35 screened genotypes, seven genotypes Vaibhav, EC541109 (*Solanum pimpinellifolium* L.), EC168283 (*Solanum pimpinellifolium* L.), IIHR2372 (*Solanum lycopersicum* L.), IIHR1970 (*Solanum peruvianum* L.), IIHR2200 (*Solanum lycopersicum* L.) and LA2805 (*Solanum lycopersicum* var. *cerasiforme* L.) showed high resistance against ToLCV without producing any symptoms of leaf curl disease. One genotype viz. EC165751 showed resistant reaction and two genotypes viz. Nandi and EC620545 showed moderately resistant reaction to ToLCV, Twelve genotypes showed moderately susceptible reaction, seven genotypes showed susceptible reaction and six genotypes were identified as highly susceptible to ToLCV.

2.10 Management of tomato leaf curl disease through vector control

Mulching is most effective in seedbeds and at early stages of growth giving a 2 week delay in virus spread. With yellow polyethylene mulch, virus spread can be delayed by 4 weeks. The whiteflies are attracted to the yellow plastic where they are then killed by the heat (Cohen, 1981, Keren *et al.*, 1991 and Green and Kalloo, 1994). The objective for using mulches to manage whiteflies is to reduce the insect's ability to find the crop. The mode of action of inert ground covers such as plastics, sawdust, straw and rice husk mulches, has been attributed to interference with visual hostfinding or suicidal attraction to the sun-heated mulch (Cohen, 1982 and Cohen and Berlinger, 1986). Coloured plastic mulches in a

variety of colours, including aluminium, silver, transparent, white and yellow have proven to be effective for reducing whitefly numbers and/ or the incidence of whitefly transmitted viruses (Suwwan *et al.*, 1988, Orozco-Santos *et al.*, 1994, 1995, Csizinszky *et al.*, 1995, 1997, 1999 and Smith *et al.*, 2000). For example, the incidence of *tomato mottle virus* in Florida (Csizinszky *et al.*, 1995), and TYLCV in tomato in Jordan (Suwwan *et al.*, 1988) was reduced using aluminum or silver reflective mulches. Coloured or reflective mulches are most effective early in the crop cycle, before the developing plant canopy covers the mulch (Hilje *et al.*, 2001).

Living barriers trap crops and mulches intended to manage whiteflies in a single field would be classified as local. Earlier work suggested that the majority of *B. tabaci* adults normally fly <2 m from the ground (Gerling and Horowitz, 1984). Thus, in theory, the placement of a tall physical barrier around a crop field could impede or delay whitefly movement into the crop. Barriers can be constructed of various materials including screening, polyethylene plastic, or wood. In some cases, the barrier can consist of a relatively tall species that is planted around the perimeter of a primary crop. Examples of plants commonly used as living barriers include graminaceous species, like sorghum (*Sorghum bicolor*), Johnson grass (*Sorghum halepense*), corn (*Zea mays*) and elephant grass (*Pennisetum purpureum*). In contrast, whitefly transmitted viruses are persistent or semi-persistent in nature (Nault, 1997), so infectious whiteflies will remain infectious for hours to days, or for life, depending on the type of virus, regardless of how many hosts they feed on before finding a susceptible plant species. With whiteflies, barrier plants probably function by reducing the overall numbers of insects migrating into the crop, rather than reducing the percentage of vectors that are infectious. Thus, it is expected that barrier plants would not be as effective in managing most whitefly transmitted viruses as they are with non-persistent aphid viruses (Hilje *et al.*, 2001).

Rajasri *et al.* (2011) used six different types of mulches (white polythene sheet mulch, black polythene sheet mulch, UV reflective mulch, paddy straw mulch, saw dust mulch and paddy husk mulch) for the management of ToLCV.

Whitefly behavioural modifications with varying levels of control can be achieved by mulches (Simmons *et al.*, 2010 and Taylor, 2011)

Buprofezin was the first selective insect growth regulators (IGR) introduced for control of *B. tabaci* in cotton (Horowitz and Ishaaya, 1992). This compound acts specifically on immature developmental stages through its vapour phase activity (vapour pressure, 9.4106 mm Hg), where it acts through inhalation by nymphs, and through direct contact adsorption by the integument (De Cock *et al.*, 1990) resulting in nymphal mortality during ecdysis (Yasui *et al.*, 1987 and Ishaaya *et al.*, 1988). Buprofezin is most toxic to whitefly crawlers and 2nd instar nymphs, and population regulation occurs primarily by rapidly preventing the developmental transition of individuals to the 2nd to 4th nymphal instars (Beevi and Balasubramanian, 1991). Although buprofezin has no direct effect on *B. tabaci* adult longevity or oviposition, it has been suggested that the compound may reduce the fecundity and egg hatch of female whiteflies exposed to treated leaves under some conditions (Ishaaya *et al.*, 1988 and Beevi and Balasubramanian, 1991, 1995). However, buprofezin does not possess any soil systemic activity, and has very little translaminar movement in cotton foliage.

Palumbo *et al.* (2001) suggested that the imidacloprid and thiamethoxam are the most effective insecticide for the control of *B. tabaci*.

Ali *et al.* (2005) performed an experiment to evaluate the efficacy of insect growth regulators (IGR), Neonicotinoid and other insecticides against the whitefly. Buprofezin was proved to be effective against nymphs and acetamiprid, diafenthiuron and imidacloprid were effective against the whitefly adults during the year 2003 and 2004.

Ahmed (2006) conducted a study in Elrahad area, Kordofan state, in 2005/06 to evaluate the effect of twelve treatments on the control of TLCV disease. The results of this study have shown that covering of the tomato seedlings in combination with Actara (thiamethoxam), Confider (imidacloprid) insecticides application have significantly decreased whitefly population by 22.4 percent and 44.3 percent, respectively.

Reddy (2006) found that the sequential application of Imidachloprid (0.005%)- Triazophos (0.15%) - Thiamethaxam (0.05%) - Econeem (0.5%) was effective for disease management of tomato leaf curl disease and better yield.

Neonicotinoids or Chloronicotinyl insecticides (CNIs) represent a novel and distinct chemical class of insecticide with remarkable chemical and biological properties. Imidacloprid and Thiamethaxam is important member of Neonicotinoids which are widely used for controlling whiteflies, aphids and leafhoppers, thrips and small lepidopteran and coleopteran pests in most of the vegetable crops like tomato, chilli, okra, capsicum, cucurbits, melons, leaf vegetables etc. Neonicotinoids are flexible insecticides that can be used as foliar, drench or seed dressing treatments (Elbert and Nauen, 2004 and Kodandaram *et al.*, 2010).

Cyantraniliprole (Cyazypyr) is the second generation ryanodine receptor insecticide with cross spectrum activity against lepidopteran and homopteran pests (Selby *et al.*, 2008 and Kodandaram *et al.*, 2010). The target crops of Cyantraniliprole (Cyazypyr) are fruiting vegetables and cucurbits. It controls whiteflies, dipteran leafminers, fruitflies, foliage feeding beetles and lepidopteran larvae. Also, controls aphids, leaf hoppers, thrips, psyllids and weevils. The translaminar activity makes it suitable for soil application (Kodandaram *et al.*, 2010).

Fipronil has contact action on both chewing and sucking insects. Its mode of action is the neuroinhibition of GABA -gated chloride channels mechanism of this compound is starvation based on the inhibition of stylet penetration to plant tissues (Morita *et al.*, 2000). Fipronil exhibits broad activity against various insect pests such as soil insects, foliar feeding pests such as diamondback moth, *Plutella*, *Xylostella*, *Spodoptera* sp. the sucking pests such as thrips and *Lygus* sp. (but not aphids or whiteflies), and on various non crop and household pests. It can be used as foliar spray and seed treatment. Though fipronil is more toxic to various natural enemies than other new insecticides, it has little or no risk to beneficials when applied as a granule or seed treatment (Kodandaram *et al.*, 2010).

Buprofezin is a thiadizine-like compound with long residual activity that acts as a chitin synthesis inhibitor. It has contact and stomach action with some vapour activity (Kodandaram *et al.*, 2010).

Al-Kherb (2011) investigated the effect of three successive treatments with the recommended concentrations of the neonicotinoid insecticides, acetamiprid, imidacloprid and thiamethoxam on immature stages and adults of the whitefly, *Bemisia tabaci* (Gennadius). He conducted insecticide applications against whitefly infesting summer and autumn plantations of cucumber *Cucumis sativus* L. and tomato *Lycopersicon esculentum* Mille. under field conditions. Thiamethoxam showed the highest rates of efficiency against whitefly. The tested insecticides variably affected the non target predatory insects where thiamethoxam was the most toxic compound and followed by imidacloprid and acetamiprid. Their side effect was significantly higher on *Orius* sp. and declined the populations of *Paederus alfieri* Koch, *Coccinella undecimpunctata* (Reiche) and *Chrysoperla carnea* (Steph.). Therefore, the tested neonicotinoids could be considered promising candidates in controlling whitefly with a value of harmful effect on beneficial insect species.

The chloronicotinyls or neonicotinoids (imidacloprid, acetamiprid, nitenpyram, and thiamethoxam) and chitin synthesis inhibitors (buprofezin) have shown good efficacy in controlling whiteflies and other insects (Bacci *et al.*, 2007 and Taylor, 2011).

El-sayed (2013) evaluated four insecticides and two commercial plant extracts for their efficiency against *Bemisia tabaci* on tomato plants. Thiamethoxam (1.82 nymph/ leaf) Imidacloprid gave a good reduction in the mean number of *B. tabaci*.

Govindappa *et al.* (2013) recorded that among the different concentrations of new molecule, cyantraniliprole 10 OD at 60 and 75 g a.i ha⁻¹ have knockdown effect and caused 100 percent mortality at 48 hrs after treatments and also recorded least virus transmission (10 and 5 % respectively). Correspondingly the yields were high in plot received cyantraniliprole 10 OD 75 g a.i ha⁻¹ (32.5 tons ha⁻¹) and significantly superior over the standard check triazophos (23.5 tons ha⁻¹) followed

by cyantraniliprole 10 OD at 60 g.a.i/ha (29.2 tons ha⁻¹) and cyantraniliprole 10 OD at 45 g.a.i/ha (27.4 tons ha⁻¹).

The most effective and widely used class of insecticides to reduce whitefly populations is the neonicotinoids of which at least three (thiomethoxam, imidacloprid and dinotefuron) have been used to reduce incidence of *Tomato yellow leaf curl virus* (TYLCV)-infected tomato plants in many tropical countries (Jane and Lapidot, 2007 and Govindappa *et al.*, 2013).

Barrania and Abou-Taleb (2014) determined the efficiency of two chitin synthesis inhibitors (pyriproxyfen and novaluron), compared with three neonicotinoid insecticides (thiamethoxam, imidacloprid and acetamiprid) and chlorantraniliprole against *Bemisia tabaci*, *Aphis gossypii* and their associated predators in cotton fields. Results showed that, statistically, all tested insecticides were comparable against *B. tabaci* adults except chlorantraniliprole which recorded the least reduction percentages at 2012 and 2013 cotton seasons. Under the same conditions, all treatments have moderate toxic effects on the natural enemy *Chrysopa vulgaris* except chlorantraniliprole which recorded low toxic effects in both seasons.

Das and Islam (2014) selected four newer insecticides (fipronil, imidacloprid, buprofezin and thiamethoxam + emamectin benzoate) from different groups with different mode of action to evaluate their comparative potency against two important sucking insects, *Amrasca devastans* (jassid or leafhopper) and *Bemisia tabaci* (whitefly). Among four, fipronil, imidacloprid and buprofezin were found to be most effective while thiamethoxam + emamectin benzoate was least effective.

The whitefly population was the lowest in case of imidacloprid 70 WS @ 10 g a.i. ha⁻¹ (0.72 to 3.51 flies leaf⁻¹), followed by acetamiprid 20 SP 40 g a.i. ha⁻¹ (0.98 to 3.67 whiteflies leaf⁻¹), diafenthiuron 50WP @ 20 g a.i. ha⁻¹ (1.62 to 4.53 /leaf) and thiamethoxam 25 WP @ 25 g a.i.ha⁻¹ (1.93 to 4.86 leaf⁻¹). All the insecticide treatments were significantly superior to control (7.94 to 8.34 flies leaf⁻¹) (Idris and Mandal, 2014).

Meena and Raju (2014) reported that fipronil 5% SC was most effective insecticide among selected six insecticides along with control followed by profenofos 50% EC for control of whitefly.

Caballero et al. (2015) conducted greenhouse (2006), growth chamber (2007) and field studies (2009–2010) to determine the efficacy of cyantraniliprole for managing *Bemisia tabaci* (Gennadius) biotype B and in interfering with transmission of *Tomato yellow leaf curl virus* (TYLCV) by this whitefly. Cyantraniliprole applied as soil treatments (200 SC) or foliar sprays (100 OD) provided excellent adult whitefly control, TYLCV suppression, and reduced oviposition and nymph survival, comparable to current standards.

Dhar and Bhattacharya (2015) made an attempt to evaluate seven insecticidal treatments with different spray schedules against whitefly and fruit borer infesting okra and tomato. Among the seven insecticidal treatments single application of imidacloprid 17.8% SL followed by twice applications of Spinosad 45% SC gave maximum reduction in infestation of fruit borer and whitefly both in okra and tomato. This treatment was also effective against reduction of disease incidence of *Yellow Vein Mosaic and Leaf Curl virus* in okra and tomato respectively due to effective management of whitefly acting as vector.

Mourya et al. (2015) conducted experiments to understand the efficacy of different novel insecticides (imidacloprid, fipronil, profenofos, indoxacarb, novaluron and spinosad) against major insect pests of tomato crop during *Rabi* season, 2013-14. Imidacloprid and Fipronil found most effective than other insecticidal treatments in controlling whitefly and leaf hopper.

CHAPTER – III

MATERIAL AND METHODS

The present study on “**Studies on leaf curl disease of tomato caused by *Tomato leaf curl virus***” was carried out during 2014-2018. The details of the materials used and the methods or techniques adopted during the course of investigation are presented in the following sections:

3.1 Experimental site

All the field experiments were conducted at the Horticulture Instruction cum Research Farm, College of Agriculture, Raipur during *rabi* 2014-15 to 2017-2018. Polyhouse study was carried out at Centre of Excellence, IGKV, Raipur (C.G) in 2015-16 and 2016-17. Laboratory work was performed in Department of Plant Molecular Biology and Biotechnology, Dr. R.H. Richharia Research Laboratory, IGKV, Raipur (C.G).

3.2 Geographical situation

Raipur is situated in the mid-eastern part of Chhattisgarh state and lies at latitude 21°16 N, longitude 81° 36 E and altitude of 298.56 m.

3.3 Climate

Raipur, the capital of Chhattisgarh comes under dry, sub-humid agro climatic region. The source of rainfall is south-west monsoon. It receives an average rainfall of 1200-1400 mm, out of which about 85 per cent is received during rainy season (June-September) and very little during winter season (October-February). The rainfall pattern has a great variation during rainy season from year to year. May is the hottest and December is the coolest month of the year. The maximum temperature goes as high as 48.1°C during summer and minimum temperature as low as 6 °C during winter months (December-January).

3.4 Weather conditions during crop period

Weekly meteorological parameters i.e. temperature, rainfall, relative humidity, wind velocity, sunshine hours prevailing during the crop period are given in Appendix A –F and illustrated in Fig. 3.1 to 3.6.

3.5 Soil of the experimental field

Soil of the experimental field was clay loam in nature (*Alfisols*) locally known as Dorsa. The soil was slightly acidic and had low nitrogen and medium phosphorus and potassium contents.

3.6 To record the seasonal occurrence of prevalent diseases of tomato under field and polyhouse conditions

3.6.1 Field condition

A study was undertaken during *rabi* 2014-15 to *kharif* 2017 at Horticulture Instruction cum Research Farm, College of Agriculture, Raipur (Chhattisgarh) to know prevalent diseases occurring in tomato. The observations on percent disease incidence and/ or percent disease index (PDI) of each disease were recorded at fortnightly interval.

3.6.2 Polyhouse condition

Occurrence of prevalent diseases of tomato was recorded on tomato being cultivated in the polyhouse at Centre of excellence, IGKV, Raipur in 2015-16 and 2016-17. Five different varieties of tomato (1204, Youvraj, Ruhi, Laila and Sheeja) were grown in polyhouse no. 2 during 2015-16 and six varieties (Nowara, Youvraj, TL16060, Roza, Laila and Sheeja) were grown in poly house no. 3 during 2016-17. Seedlings of each variety were raised in coco peat filled plastic seedling trays and one seed was sown in each cavity of tray. Forty-eight rows of plastic channels were prepared with maintaining 1.5 m row to row distance in each poly house and these channels were filled with coco peat. Twenty-five day old seedlings were transplanted in these plastic channels with 50 cm plant to plant distance on 9th November 2015 and 13 August 2016 in 2015-16 and 2016-17, respectively. In 2015-16 among the five varieties seedlings of four (1204, Ruhi, Laila and Sheeja) were transplanted in four rows (one

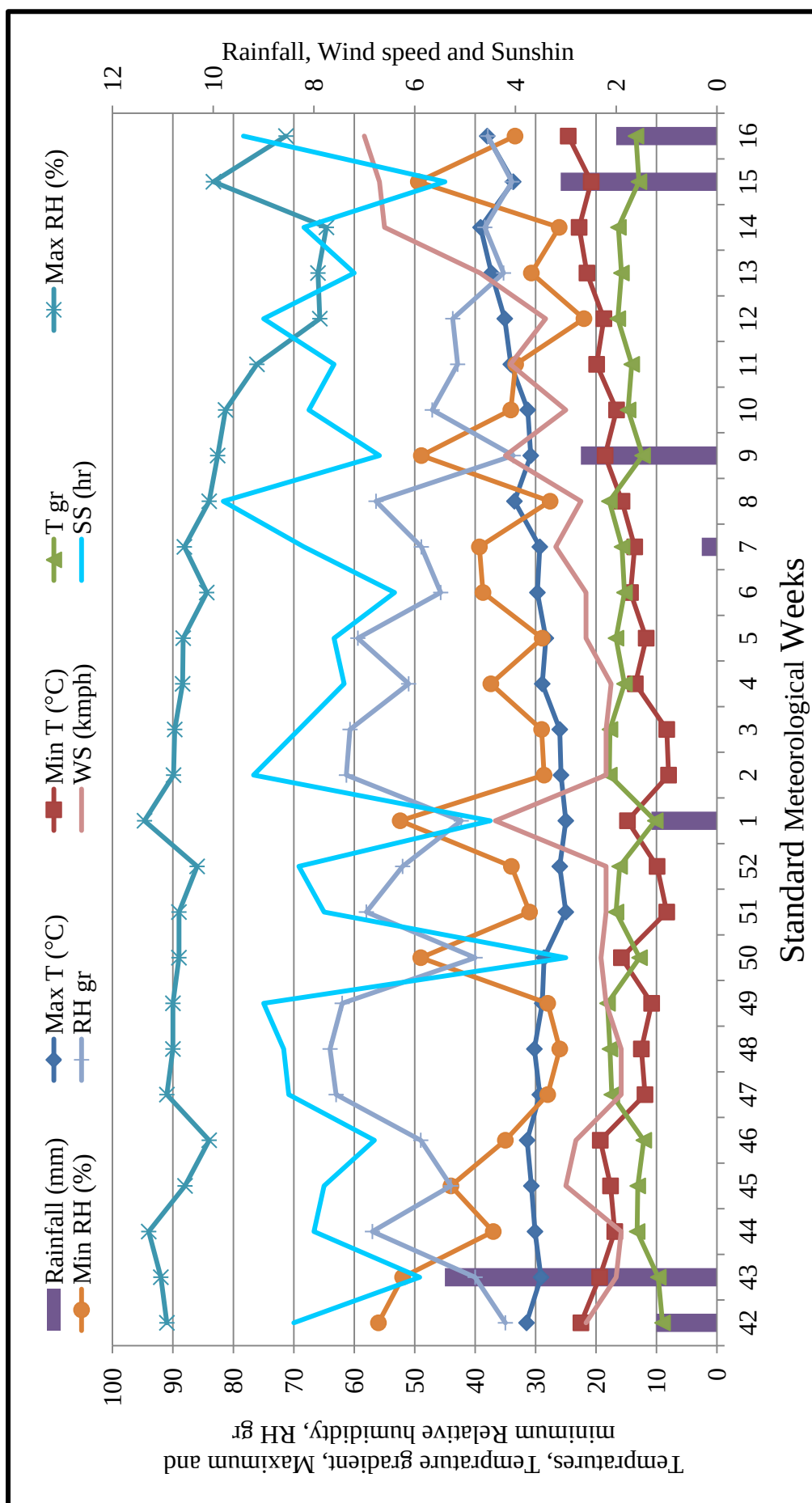


Fig. 3.1: Weekly meteorological observation at experimental site during Rabi 2014-15

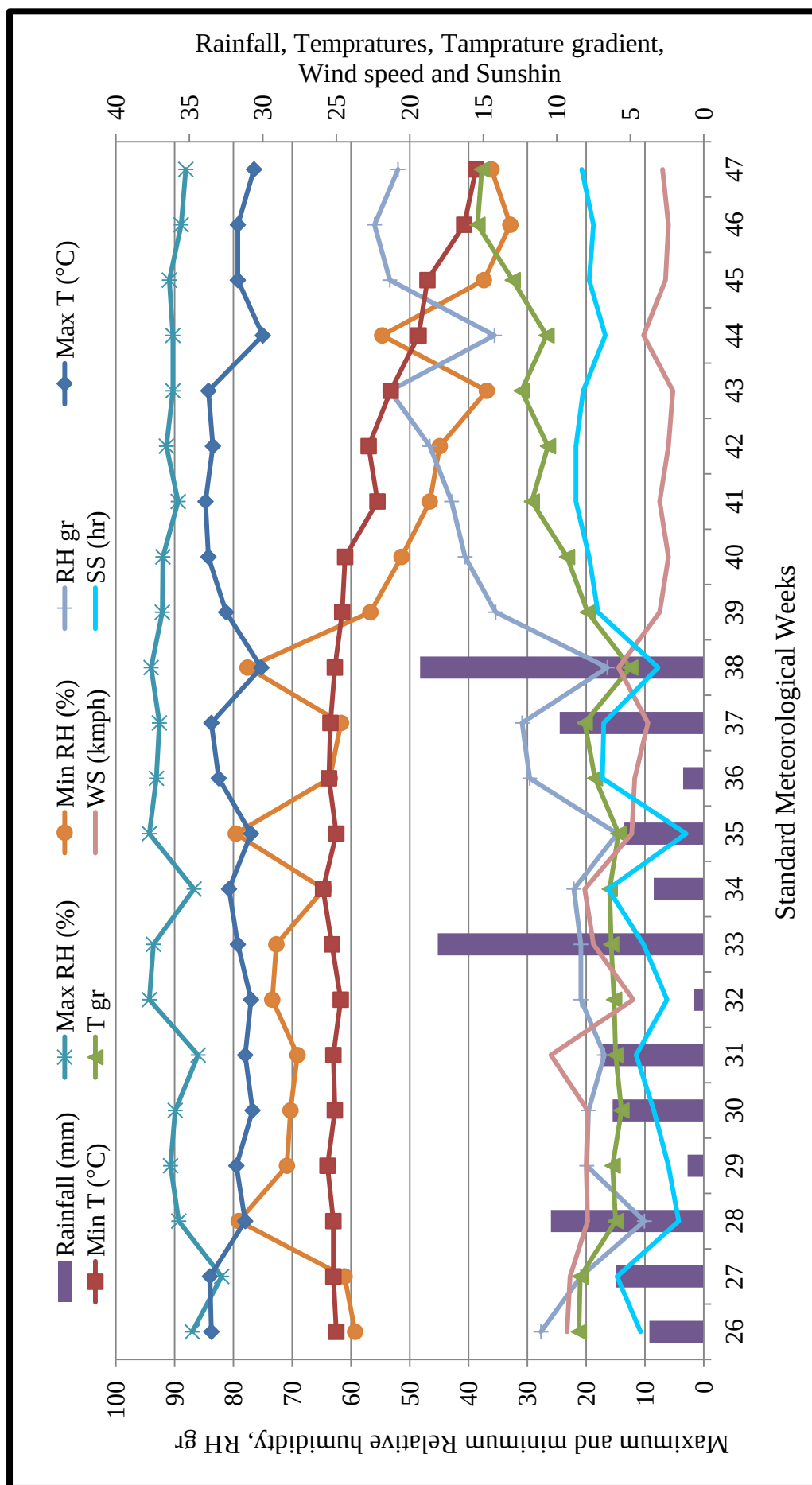


Fig. 3.2: Weekly meteorological observation at experimental site during Kharif 2015

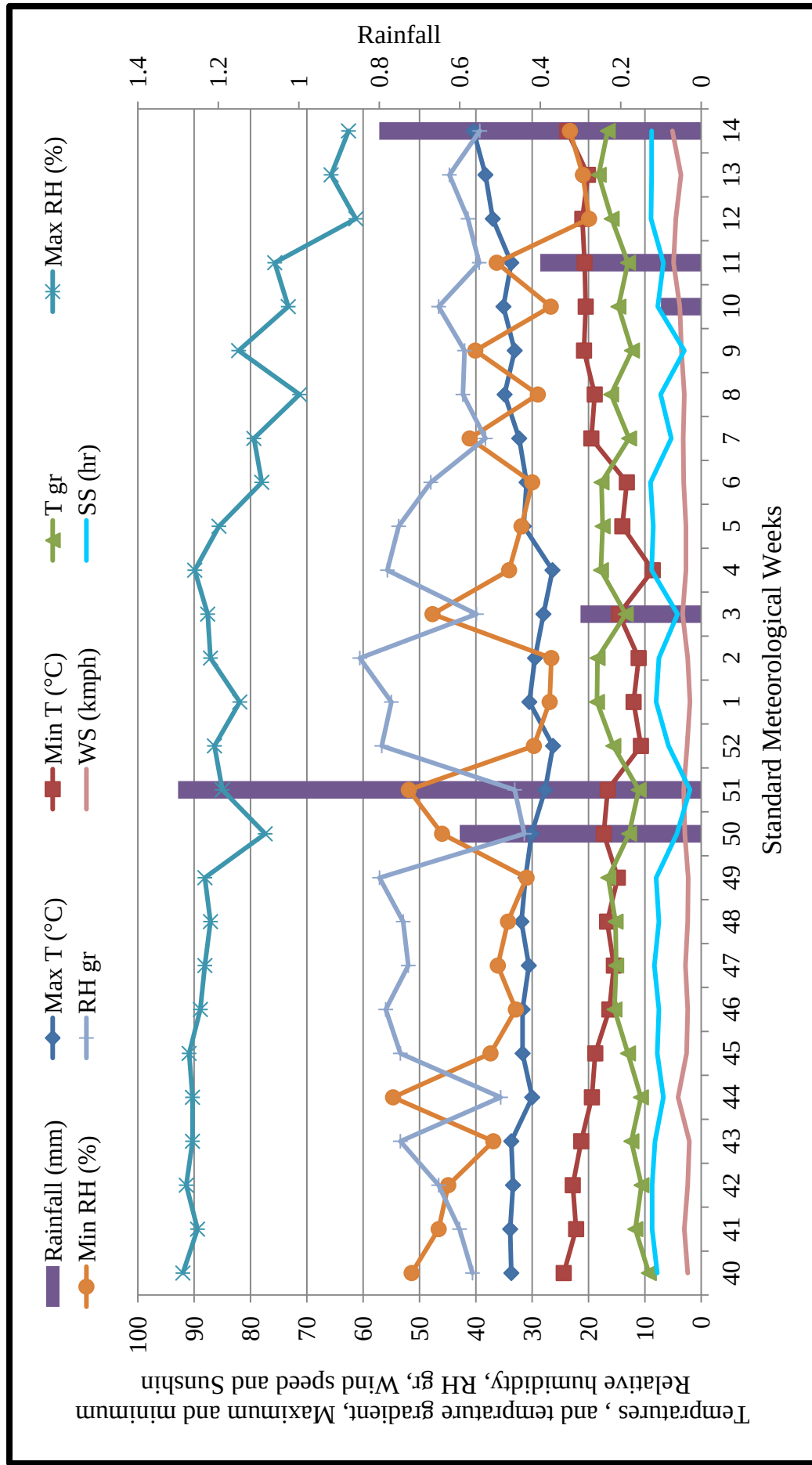


Fig. 3.3: Weekly meteorological observation at experimental site during Rabi 2015-16

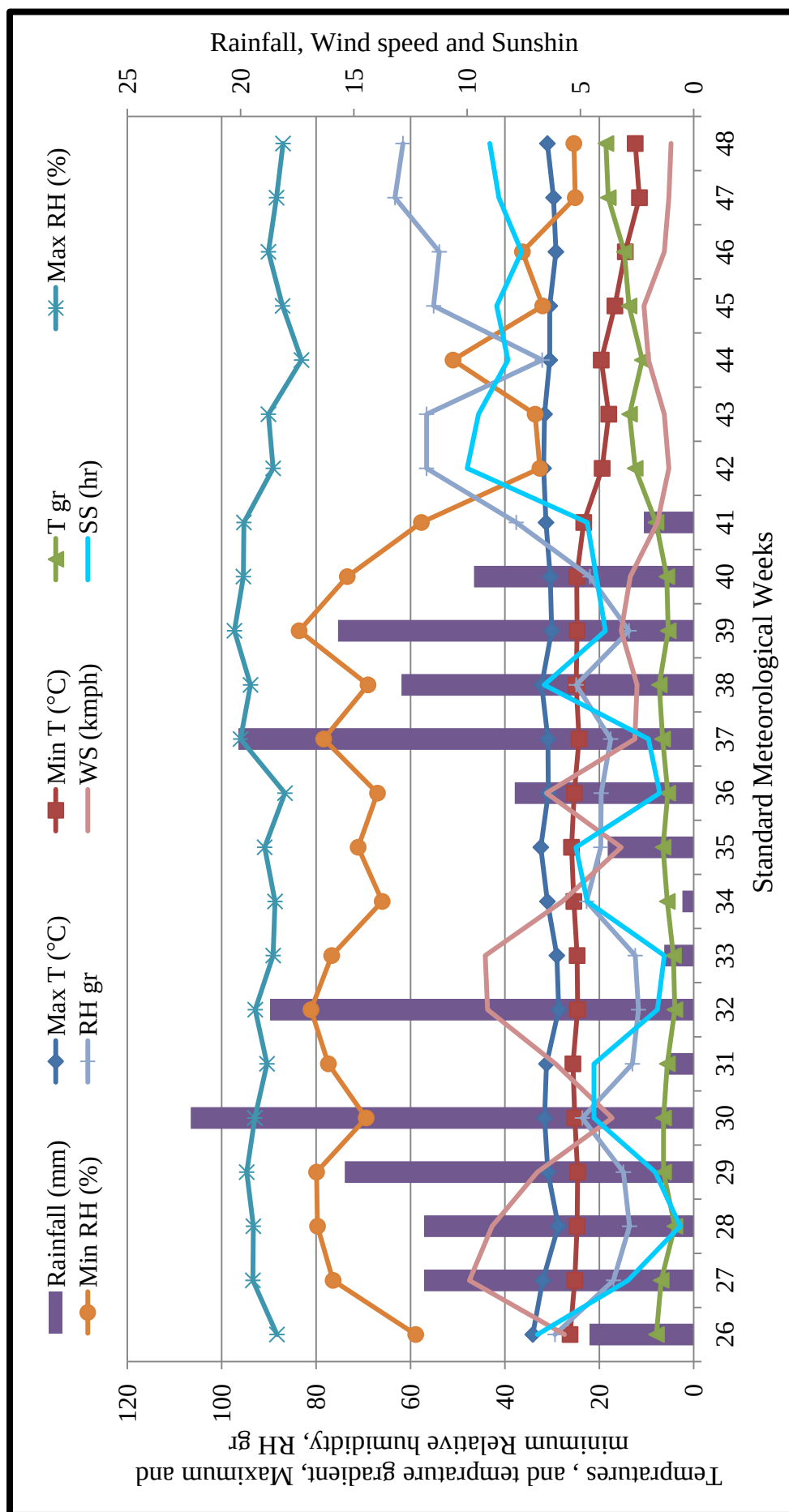


Fig. 3.4: Weekly meteorological observation at experimental site during Kharif 2016

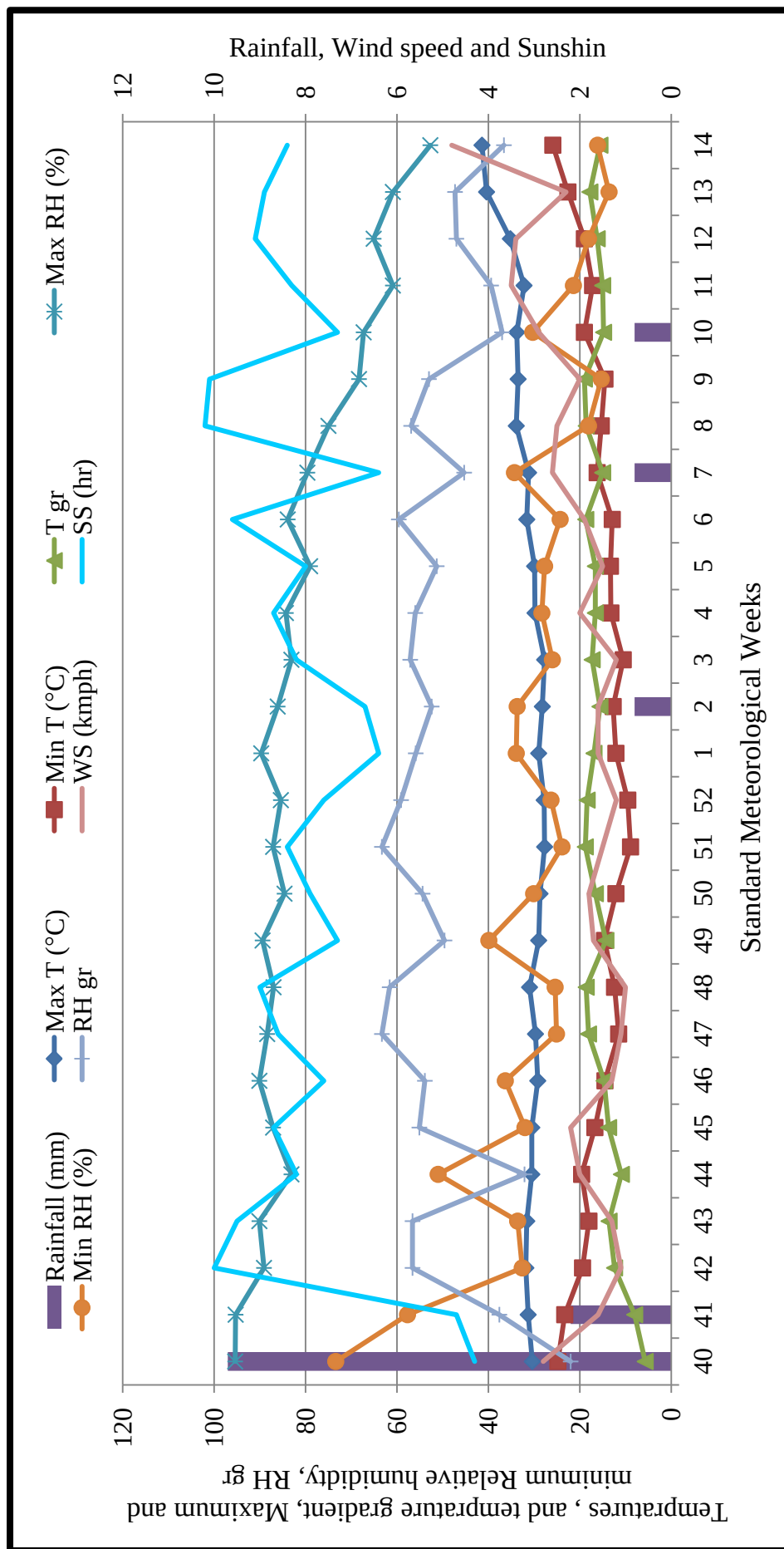


Fig. 3.5: Weekly meteorological observation at experimental site during Rabi 2016-17

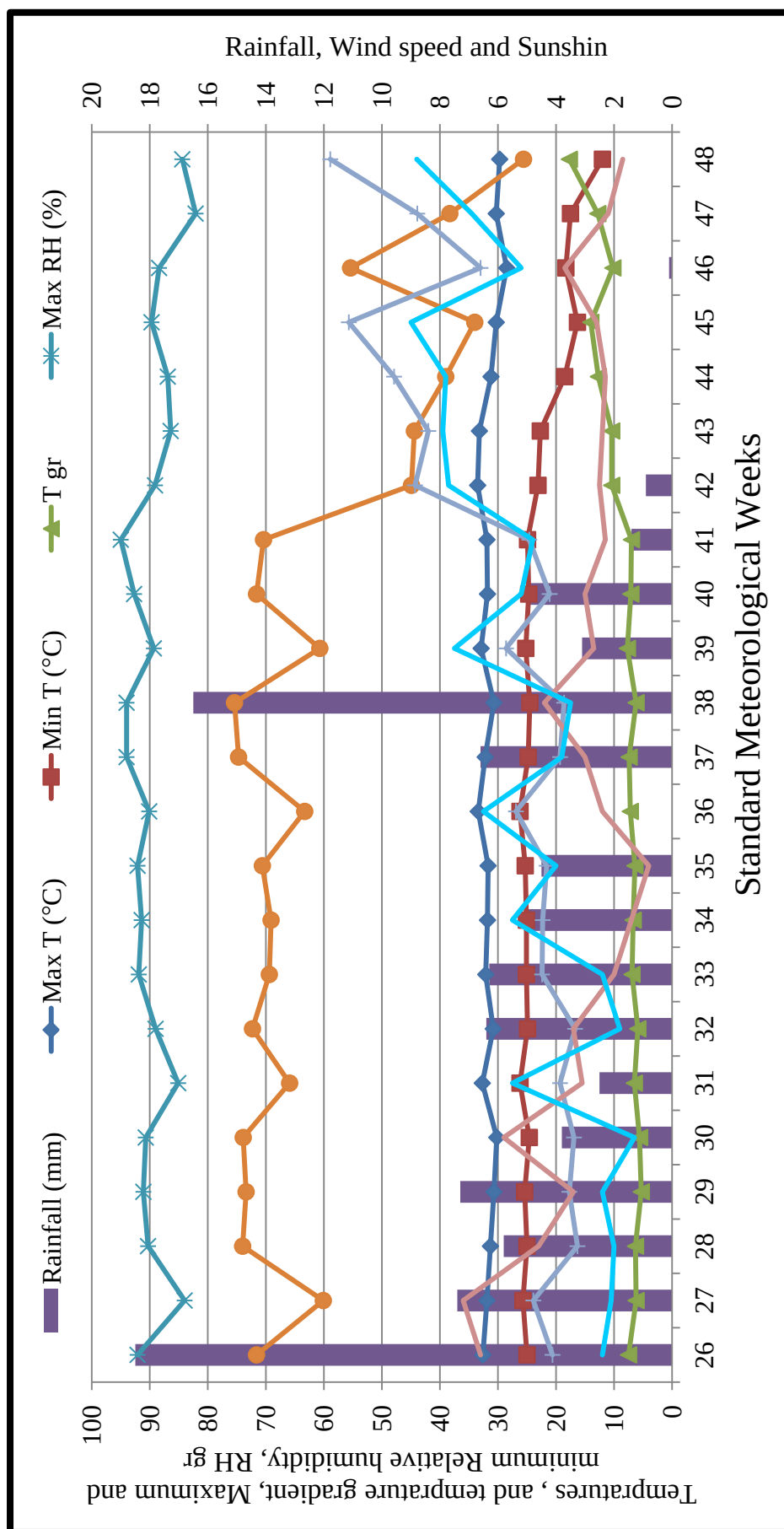


Fig. 3.6: Weekly meteorological observation at experimental site during Kharif 2017

row for each) and one variety viz. Youvraj (1003) was transplanted in remaining 44 rows. In 2016-17 seedlings of four varieties viz. Nowara, Youvraj, TL16060, and Sheeja were transplanted in 12, 27, one and four rows, respectively and Roza and Laila were transplanted in four rows (two for each).

Regular observations on percent incidence and percent disease index (PDI) of prevalent diseases were taken after transplanting to end of the crop at fortnight interval. The rating of diseases were recorded for each plant of every variety thereafter percent disease index (PDI) was calculated for each variety and overall crop by implying formulae suggested by Wheeler (1969). The rating of the disease/s was recorded by following rating scales as described below.

Leaf curl

Disease rating of individual plants was recorded using a slightly modified visual scale of 0–7 (Alegbejo, 1995 and Alegbejo and Banwo, 2006), where: 0 = No visible disease symptom; 1 = Top leaves curled only; 3 = Top leaves curled and slight stunting of plant or All leaves curled without stunting; 5 = All leaves curled and slight stunting of plant and 7 = Severe curling of leaves, stunting of plant and proliferation of auxiliary branches.

Mosaic

Disease symptoms of mosaic were rated on a scale of 0 to 5, where 0 = no symptoms; 1 = Light or dark green mottling or mosaic; 2 = Light or dark green mottling or mosaic with distortion or reduction of younger leaves; 3 = Dark green areas of the mottle often appear thicker and somewhat elevated giving the leaves a blister like appearance with no stunting; 4 = Dark green areas of the mottle often appear thicker and somewhat elevated giving the leaves a blister like appearance with stunting and sometimes yellow mottling of leaves and 5 = Severe stunting of plant with leaves look fern like and sharply pointed and sometimes dark necrotic streaks in stems, petioles, leaves or fruit (Cerkauskas, 2004 and Anonymous. 2012).

Tomato spotted wilt

A visual disease rating was used; 1 = no visible symptoms; 2 = mild purpling, chlorosis, and limited leaf distortion; 3 = moderate purpling, chlorosis, and leaf distortion with some plant stunting; 4 = severe purpling, chlorosis, leaf distortion and

plant stunting; 5 = severe purpling, chlorosis, leaf distortion and extreme stunting (Canady *et al.*, 2001 and Sivparsad and Gubba, 2011).

Early blight

The PDI of the early blight was recorded according to following scale of 0-9 given by Mayee and Datar, 1986. Where 0 = No symptoms; 1 = Small circular, scattered, brown spots, covering 1 per cent or less of the leaf area; 3 = Spots enlarging, dark brown in colour covering 1 to 10 per cent of leaf area and infection on the lower most leaves of the plant; 5 = Spots enlarging, dark brown in colour covering 11 to 25 per cent of leaf area and infection on the lower most leaves of the plant; 7 = Spots dark brown in colour covering 26 to 50 per cent of leaf area and covering one third of the plant and 9 = Spots uniformly dark brown, coalescing, covering 50 per cent or more leaf area and severe infection on all leaves (Abdussamee *et al.*, 2014).

3.7 To detect and identify the tomato leaf curl causing agent

3.7.1 Collection of samples

For the detection and identification of *Tomato leaf curl virus* (ToLCV) four samples including one healthy and three infected samples of tomato crop were collected. The young leaves and twigs of tomato plants showing typical symptoms of leaf curling were collected from three locations viz., severely infected experimental plot in Horticultural Instruction cum Research Farm, College of Agriculture, Raipur and from farmer's fields of Rasni and Nisda villages of Arang Block. These samples were stored in deep freezer at -20 °C. The total genomic DNA was then extracted from the samples and quantification was done by nano drop method, and subjected to PCR with eight sets of primer reported for detection of ToLCV by different scientists.

3.7.2 Extraction of genomic DNA

Total DNA was extracted from the freshly collected leave samples using a CTAB (Cetyl trimethylammonium bromide) method (Doyle and Doyle, 1987) with some modifications and the procedures followed for genomic DNA isolation is given as below:

1. The leaves were cut into small pieces and put into 2 ml centrifuge tube up to 0.5 ml mark

2. Glass beads and 700 μ l extraction (CTAB) buffer were added into each tube
3. The samples were crushed with tissue lyzer (Mol Bio Laboratories Inc., Power lyser TM24) and centrifuged at 14000 rpm for 1 min with centrifuge (Sigma® 1-14)
4. 700 μ l of chloroform: isoamyl alcohol (24:1) was added in each tube and vortexed for few seconds then centrifuged at 14000 rpm for 5 min
5. Supernatant (upper clear layer) was transferred into new 1.5 ml eppendorf tube.
6. Step 4 and 5 were repeated
7. 70 μ l ($1/10^{\text{th}}$ of supernatant) of 3M sodium acetate and 400 μ l of prechilled isopropanol was added in each tube and kept these at 4 °C for 2 hours
8. Tubes were shaken well then centrifuged at 14000 rpm for 20 min and supernatant was discarded
9. Then pellet was washed with 70 percent ethanol (50 μ l)
10. Centrifuged at 14000 rpm for 3 min
11. Air dried the pellet
12. 100 μ l of TE buffer was added in each tube and pellet was dissolved and stored at - 20 °C for further use.

3.7.3 Quantification of the DNA

The DNA samples were quantified using Nanodrop Spectrophotometer (ND2000C, Thermo Scientific). Nucleic acid has maximum absorbance of the ultraviolet light *i.e.*, about 260 nm. The ratio between the reading at 260 nm and 280 nm (OD 260/ OD 280) provides purity for the nucleic acid. Pure preparation of DNA and RNA has a ratio of approximately 1.8 and 2.0 respectively. If there is contamination with protein or phenol the ratio will be significantly less than this value (<1.8) a ratio greater than 2.0 indicates a high proportion of RNA in the DNA sample.

Procedure for quantification of the DNA

One μ l of TE buffer was loaded on the lower measurement pedestal and the sampling arm was lowered into the down position and the blank was set. The blank should be between 0.0 to 0.5 ng μ l⁻¹. The buffer was wiped from both pedestals using blotting paper or tissue paper. Then 1 μ l of DNA sample was loaded on to the lower pedestal and reading showing the quantity of DNA was recorded. Both the

measurement pedestals are wiped with the help of tissue paper and washed with 70 percent ethanol and wiped again. Similar procedure was repeated for all the samples.

3.7.4 Dilution of DNA

The crude DNA after quantification was diluted to $50 \text{ ng } \mu\text{l}^{-1}$ with TE buffer. The volume of crude DNA required to make the desired volume of working (stock) sample with concentration of $50 \text{ ng DNA } \mu\text{l}^{-1}$ was calculated using the following formula then the volume was make up with TE. The diluted DNA was subsequently used for DNA amplification.

C

Where,

C_1 : Concentration of DNA in the crude/ original sample ($\text{ng } \mu\text{l}^{-1}$)

V_1 : Volume of crude sample required for the preparation of stock solution (μl)

C_2 : Desired concentration of DNA in the stock/ working (diluted) sample ($\text{ng } \mu\text{l}^{-1}$)

V_2 : Desired volume of stock (working) sample (μl)

3.7.5 PCR amplification

The extracted DNA samples were amplified with polymerase chain reaction for that first PCR protocol was optimized using various concentrations of primers, template DNA, *Taq* polymerase and annealing temperature. The optimized PCR protocol was used for ToLCV polymorphism detection by using 8 primer sets (Table 3.1).

1.5 μl of diluted DNA of each sample was dispensed at the bottom of the PCR plate. Cocktail was prepared separately in an eppendorff tube as described in the Table 3.2 and 8.5 μl of cocktail was dispensed in each tube then centrifuged for few seconds. Amplification was carried out in thermal cycler for 30 cycles. The details of PCR temperature profile for amplification are summarized in the table 3.3.

After the completion of PCR reaction, 4 μl of 6X loading dye was added to 10 μl PCR products and 5 μl of it was loaded on 5 percent PAGE in a mini-vertical electrophoresis system (CBS scientific, model MGV-202-33) along with 8 μl of 100 bp ladder.

Table 3.1: List of primers used for the detection and identification of ToLCV

Primer name	Primer sequence (5'- 3') [#]	Function or specification	Expected Size of the fragment	Reference
AV 494	GCCCTATAGTATCAGAAAGC	Degenerated primers correspondend to highly conserved regions of the capsid protein gene	~500 bp	Wyatt and Brown, 1996 and Khan, 2000
	CACAG			
AC 1048	GGGATTAGTGAGAGCATGT ACGTACATG			
PAL1v 1978	GCATCTGCAGGCCACATYG TCTTYCCNGT	Replication associated protein and coat protein	~1100 bp	Rojas <i>et al.</i> , 1993 and Khan, 2000
PAR1c 496	AATACTGCAGGGCTTYCTRA TACATRGG			
BGCP F	TGTGARGGYCCWTGYAARG TYCA	Begomovirus specific coat protein	~500 bp	Pandey <i>et al.</i> , 2010 and Kamal <i>et al.</i> , 2015
BGCP R	TASARGCATGWGTACANGC CATATAC			
AV1 F	ATGGCGAAGCGACCAG	Coat protein of <i>Begomovirus</i> genus specific	~800 bp	Tiwari <i>et al.</i> , 2010
AV1 R	TTAATTTGTGACCGAATCAT			
ToLCBVCP F	TCTCGAAGTATCGCCGACTT	Coat protein of <i>Tomato leaf curl Bangalore virus</i>	~771 bp	Hong and Harrison, 1995*
ToLCBVCP R	GGACCTTACATGGACCCTCA			
ToLCGVMP F	GGATGGTTCACGGTTAATGG	Movement protein of ToLC Gujrat Varanasi] segment B	~250 bp	Chakraborty <i>et al.</i> , 2003*
ToLCGVMP R	TCTGCAATCTCTTCCCTCGT			
GAv50	TAACTGACAAAGACATGCG GA	DNA-A- specific oligonucleotide primers	~2757 nt	Chakraborty <i>et al.</i> , 2003
GAc1122	AACATTTGTAGACAGTTCAA ATAT			
GBv74	CTCATCCGATTTGCAACACG T	DNA-B-specific primer combinations	~2688 nt	Chakraborty <i>et al.</i> , 2003
GBc1280	AATTGCATTTTCAAATTCCA TGTTTCGTACA			

* Primer designed with Primer3 from sequenced genome [#] in the primer sequence, B= GCT, D= AGT, H= ACT, K= GT, M= AC, N= AGCT, R= AG, S= GC, V= AGC, W= AT, Y= CT

Table 3.2: PCR mixture for one reaction (volume 10 μ l)

S.N.	Components	Stock concentration	Volume per reaction
1.	DNA	50 ng μ l ⁻¹	1.5 μ l
2.	PCR water (ANW)	-	5.25 μ l
3.	Taq buffer	10X	1.0 μ l
4.	dNTPs	1 mM	1.0 μ l
5.	Forward primer	10 μ M	0.5 μ l
6.	Reverse primer	10 μ M	0.5 μ l
7.	<i>Taq</i> polymerase	1 U μ l ⁻¹	0.25 μ l

Table 3.3: Temperature profile used for PCR amplification using primers

Step	Activity	Temperature ($^{\circ}$ C)	Time	Cycle
1.	Initial denaturation	95	5 min	1
2.	Denaturation	95	30 sec	30
3.	Annealing	55	30 sec	
4.	Extension	72	1 min	
5.	Final extension	72	7 min	1
6.	Storage	4	∞	-

3.7.6 Gel electrophoresis

Five percent polyacrylamide gels (vertical) were used for better separation and visualization of PCR amplified products, since polyacrylamide gels have better resolution for amplified products. Gels were casted in CBS-Scientific electrophoresis unit as per manufacturer's instruction. Glass plates were prepared before making the gel solution.

1. Both glass plates (outer and inner notched glass plates) were cleaned thoroughly with mild detergent and wipe it with alcohol. After complete drying of glass plates gasket was aligned around the sides of rectangular back plate starting from one end. The flat side of gasket was kept on bottom side of the plate.
2. The notches of the gasket were aligned around the rounded corners of the glass plate. Once the gasket is pushed over the bottom edge and corners, work it down the remaining side.
3. The gasketed plate was placed on flat surface with the tubing side up and spacers of 1.5 mm were placed on two sides of plate (rounded corners of spacers were faced outside bottom of the plate).
4. The notched plate was placed on top of the bottom assembly in such a way that spacers were between both plates. Clamps were put on the three sides of plates leaving notch side of unit.
5. The assembly was lifted and stand it on the base of the clamps. It was checked with water to found any leakage.
6. For casting, gel was prepared just prior to pouring then gel solution was poured using notched beaker or syringe from notch side and avoided air bubbles. Comb of 1.5 mm thickness (63 wells) was inserted with tooth side in gel.
7. Later assembly was left for polymerization for 20-30 min.
8. After polymerization process, gasket and clamps were removed and assembly was placed in the electrophoresis unit with clamps where notched plate facing the upper buffer reservoir and notch side was faced inner side of the unit. When single gel was run in one side of dual plate assembly the unnotched back plate was used to seal the open side of upper reservoir.

9. Freshly prepared TBE buffer (1X) was poured in upper and lower chambers of unit. Comb was removed with care so that it did not disturb the wells formed.
10. 8 μ l of ladder was loaded in the first well thereafter 5 μ l of each sample were loaded in separate well.
11. The power leads were aligned, safety cover was attached and connected to power supply. Electrophoresis was done at 185 volts till the dye reached bottom of the gel.
12. After the run completed, the power supply switched off and disassembled the glass plates.
13. The side clamps were removed and notched plate was pulled outside taking into care that the gel sticks to the plane glass plate.
14. The gel was kept for staining in 1X TBE buffer containing 4 μ l 100 ml^{-1} ethidium bromide (10 mg ml^{-1} stock). Staining was done for 60 to 70 seconds then the gel was rinsed with distilled water and visualized the bands on UV transilluminator or gel documentation system.

3.7.7 Sequencing of DNA

3.7.7.1 DNA extraction and purification of viral DNA

The amplified products obtained after PCR amplification were again amplified by polymerase chain reaction with their corresponding primers at same temperature profile and checked on 2 percent agarose gel run at 150 Volts. Thereafter the amplicons were excised from the gel and eluted using the GeneJet Gel Extraction Kit (Thermo Scientific). The protocol followed for the purification of viral DNA is given as below:

1. Gel containing the DNA fragment was excised using a clean razor blade as close to the DNA as possible to minimize the gel volume. The gel slice was placed into a pre-weighed 1.5 ml tube and weighed. The weight of the gel slice was recorded.
2. Binding buffer was added in 1:1 volume of the gel slice (volume: weight).
3. The gel mixture was incubated at 50-60 $^{\circ}\text{C}$ for 10 minutes or until the slice was completely dissolved. The tube was mixed by inversion every few minutes to

facilitate the melting process. When the gel was completely dissolved the gel mixture was vortexed briefly before loading on the column.

4. The length of one of the sample was <500 bp in that case 100 percent of isopropanol was added to the solubilised gel solution in equal volume of gel and mixed thoroughly.
5. 800 µl of the solubilised gel solution (from step 3 and 4) was transferred to the GeneJET purification column and centrifuged at 13000 rpm for 1 minute. The flow-through was discarded and placed the column back into the same collection tube.
6. 100 µl of binding buffer was added to the GeneJET purification column and centrifuged at 13000 rpm for 1 minute. The flow-through was discarded and placed the column back into the same collection tube.
7. 700 µl of wash buffer (diluted with ethanol i.e. 9 ml concentrated wash buffer and 45 ml 96-100% ethanol) was added to the GeneJET purification column and centrifuged at 13000 rpm for 1 minute. The flow-through was discarded and placed the column back into the same collection tube.
8. The empty GeneJET purification column was centrifuged for an additional 1 min at 13000 rpm to completely remove residual wash buffer.
9. The GeneJET purification column was transferred into a clean 1.5 ml microcentrifuge tube. 50 µl of elution buffer was added to the centre of the purification column membrane incubated at room temp for 1 minute then centrifuged at 13000 rpm.
10. The GeneJET purification column was discarded and tubes containing DNA (~30 µl) were kept. The tubes were labelled and the purified DNA was stored at -20 °C.

3.7.7.2 Sequencing of PCR amplicons

The purified DNA fragments were sent to Eurofins Genomics India Pvt Ltd, Bengaluru for sequencing. The sequenced data were analysed with suitable tool and interpretation was made.

3.7.8 Buffers, solutions and reagents

3.7.8.1 Solutions for genomic DNA extraction

1) 1M Tris-HCl solution (pH 8.0)

121.14 g Tris-HCl (molecular weight 121.14 g mol⁻¹) was dissolved in 800 ml distilled water. Volume was made up to 1000 ml with distilled water and was sterilized by autoclaving after adjusting the pH to 8.0 with concentrated HCl.

2) 0.5M EDTA (Ethylenediaminetetraacetic acid) solution (pH 8.0)

186.12 g EDTA.Na₂.2H₂O (molecular weight 372.24 g mol⁻¹) was dissolved in 800 ml distilled water. The solution was stirred vigorously on a magnetic stirrer and the pH was adjusted to 8.0 by adding NaOH pellets (≈20 g). The final volume was made up to 1000 ml with distilled water followed by sterilizing in autoclave at 15 lb sq.in.⁻¹ for 20 min.

3) DNA extraction buffer

Components	Stock concentration	Concentration required	Quantity/ volume (for 100 ml)
Tris-HCl solution	1M	100 mM	10 ml
NaCl (molecular weight, 58.44 g mol ⁻¹)	-	1.4 M	8.18 g
EDTA	0.5 M	20 mM	4 ml
CTAB	-	3%	3 g

All the components were mixed and volume was adjusted to 100 ml with distilled water and the pH was adjusted to 8.0 then autoclaved at 15 lb sq.in.⁻¹ for 20 min.

4) 3M Sodium acetate (CH₃COONa)

24.61 g sodium acetate (molecular weight, 82.0343 g mol⁻¹) was dissolved in 80 ml distilled water. The pH was adjusted to 5.2 by adding glacial acetic acid and final volume was adjusted to 100 ml.

5) Chloroform

6) Ethanol (100% and 70%)

7) Isoamyl alcohol

8) Isopropanol

9) TE buffer (pH 8.0)

10 ml 1M Tris HCl and 2 ml 0.5 M EDTA were mixed and final volume was make up to 1000 ml with autoclaved distilled water.

3.7.8.2 Stock and working solutions for PAGE

1) 10X TBE (Tris-borate-EDTA)

Components	Molecular formula and weight	Concentration required	Quantity
Tris base	$C_4H_{11}NO_3$ (121.14 g mol ⁻¹)	89 mM	10.78 g
Boric acid	H_3BO_3 (61.83 g mol ⁻¹)	89 mM	5.50 g
0.5M EDTA (pH 8.0)	$EDTA.Na_2.2H_2O$ (372.24 g mol ⁻¹)	2 mM	4 ml

Mixed all the components and adjusted the volume to 1000 ml with distilled water. This served as stock solution.

2) 1X TBE

1X TBE was prepared by dissolving 100 ml of 10X TBE to 900 ml distilled water. This served as working solution.

3) Polyacrylamide stock solution (40%)

Dissolved 380 g of acrylamide and 20 g Bis- acrylamide (*N,N'*-methylbisacrylamide) in 600 ml of autoclaved distilled water. Slight heating was done to dissolve acrylamide. The final volume was adjusted to 1000 ml and strained through Watman filter paper no. 1. The pH was checked about 7.0 then stored in brown/dark bottle at room temperature.

4) Polyacrylamide working solution (5%)

Dissolved 125 ml of 40 percent polyacrylamide stock solution to 600 ml 1X TBE and final volume was adjusted to 1000 ml with 1X TBE.

5) 10% APS solution

Dissolved 1 g Ammonium per sulfate (APS) to 10 ml distilled water.

6) 5% Polyacrylamide gel

For preparation of 5 percent polyacrylamide gel, 70 ml polyacrylamide working solution was taken then 900 μ l of 10 percent ammonium per sulfate (APS) and 90 μ l of TEMED (*N,N,N',N'*-Tetramethylethylene diamine) was added to initiate the

polymerization process. The contents were mixed gently by swirling, but bubbles were avoided.

7) Formamide dye was prepared by mixing following components

S.N.	Component	Final concentration	For 10 ml
1.	Formamide	98%	9.8 ml
2.	0.5 M EDTA	10 mM	200 μ l
3.	Xylene cyanol	0.1%	0.01 g
4.	Bromophenol blue	0.1%	0.01 g

8) Staining solution

The most commonly used stain for detecting DNA/RNA is Ethidium bromide. For the preparation of staining solution 40 μ l of Ethidium bromide was dissolved in 500 ml TBE.

3.8 To study the epidemiology of tomato leaf curl disease

An experiment was conducted to determine the effect of weather conditions and vector population on progress of tomato leaf curl disease (ToLCD) at Horticulture Instruction cum Research Farm, College of Agriculture, Raipur (Chhattisgarh) for three consecutive years (*rabi* 2014-15 to *kharif* 2017). Ten plots of 9 sq m were maintained for the purpose and cultivar *Pusa Ruby* was used as test variety. No control measures were applied in these plots. Twenty five days old seedlings were transplanted in main plots with 60 cm row to row and 50 cm plant to plant spacing.

3.8.1 Experimental details

Particulars	2014-15 (Rabi)	2015 (Kharif)	2015-16 (Rabi)	2016 (Kharif)	2016-17 (Rabi)	2017 (Kharif)
Test variety	Pusa Ruby	Pusa Ruby	Pusa Ruby	Pusa Ruby	Pusa Ruby	Pusa Ruby
Plot size (L $\times$ W m)	3.0 $\times$ 3.0	3.0 $\times$ 3.0	3.0 $\times$ 3.0	3.0 $\times$ 3.0	3.0 $\times$ 3.0	3.0 $\times$ 3.0
Row to row spacing (cm)	60	60	60	60	60	60
Plant to plant spacing (cm)	50	50	50	50	50	50
Date of	16/10/	28/06/	15/10/	28/06/	16/10/	29/06/

sowing	2014	2015	2015	2016	2016	2017
Date of	10/11/	22/07/	09/11/	22/07/	10/11/	23/07/
transplanting	2014	2015	2015	2016	2016	2017

3.8.2 Incidence and PDI of ToLCD

Percent disease incidence and disease rating of leaf curl were recorded from each plot at weekly interval. Percent disease incidence was calculated by following formula suggested by Nene (1972):

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

The disease rating was recorded for each plant of every plot by following rating scales as described in section 3.6.2 thereafter percent disease index (PDI) was calculated for each plot by implying formulae suggested by Wheeler (1969).

$$\text{PDI} = \frac{\text{Sum of numerical disease rating}}{\text{Number of plants observed} \times \text{maximum disease rating}} \times 100$$

3.8.3 Monitoring vector population

Adult whiteflies are dull and reluctant to fly away during the early hours of the day when the atmospheric temperature is low with low intensity of light. Even if the tomato leaf is lifted slightly between 6.30 to 8.30 AM, they are not active. This habit of the whitefly was taken into account to estimate the population within the cropped area and counts were taken between these periods. Adult whiteflies were counted on five randomly selected plants of each plot. In each plant three upper, four middle and three lower leaves were examined for adults. Mean of the ten plots were calculated.

3.8.4 Weekly weather or meteorological data

Weekly weather or meteorological data viz. maximum temperature (MAXT), minimum temperature (MINT), temperature gradient, rainfall (RF), maximum relative humidity (RH I), minimum relative humidity (RH II), relative humidity gradient (RH grad), wind speed / velocity (WS) and sun shine (SS) of six seasons viz. *rabi* 2014-15, 2015-16 and 2016-17 and *kharif* 2015, 2016 and 2017 were obtained from Department of Agrometeorology, IGKV, Raipur.

3.9 To evaluate the performance of popular commercial varieties/ hybrids and others (entries) against tomato leaf curl disease

Total 74 entries / varieties of tomato (nineteen tomato leaf curl virus resistance entries, 23 popular commercial varieties and 32 tomato entries) were evaluated against tomato leaf curl disease under natural condition at Horticulture Instruction cum Research Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur to find out resistant entries / varieties.

3.9.1 Experimental materials

3.9.1.1 Tomato leaf curl virus resistance entries (ToLCVRES)

Nineteen tomato leaf curl virus resistant entries obtained from IIVR, Varanasi were evaluated against tomato leaf curl disease. Among the 19 entries 12 viz. 2014/ToLCVRES-1, 2014/ToLCVRES-2, 2014/ToLCVRES-3, 2014/ToLCVRES-4, 2014/ToLCVRES-5, 2015/ToLCVRES-1, 2015/ToLCVRES-2, 2015/ToLCVRES-3, 2015/ToLCVRES-4, 2015/ToLCVRES-5, Punjab Chhuhara and H-24 were evaluated during *rabi* 2015-16 and 2016-17 and seven entries viz. 2016/ToLCVRES-1, 2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES-4, 2016/ToLCVRES-5, 2016/ToLCVRES-6 and 2016/ToLCVRES-7 were evaluated during *rabi* 2016-17 and 2017-18. Punjab Chhuhara was used as susceptible check variety under study.

3.9.1.2 Commercial varieties/ hybrids

Twenty-three commercial varieties/ hybrids with one susceptible check variety viz. Punjab Chhuhara was evaluated against tomato leaf curl disease during *rabi* 2015-16 and 2016-17. Seeds of varieties were procured from local markets their nature and source are described in table 3.4.

3.9.1.3 Tomato entries

Thirty-two tomato entries obtained from Dr. Dhananjay Sharma (AICRP on vegetable) were evaluated against tomato leaf curl disease. Among the 32 tomato entries 18 were determinate and 7 were indeterminate type and remaining 7 were cherry tomato. Out of 18 determinate entries 7 (2014/TODVAR-1, 2014/TODVAR-2, 2014/TODVAR-3, 2014/TODVAR-4, 2014/TODVAR-5, 2014/TODVAR-6, H-86) were evaluated during *rabi* 2015-16 and 2016-17 and 11 (2016/TODVAR-1, 2016/TODVAR-2, 2016/TODVAR-3, 2016/TODVAR-4, 2016/TODVAR-5,

Table 3.4 List of commercial/ hybrids evaluated against tomato leaf curl disease

S. N.	Variety	Nature	Packet size (g)	Manufacturer/ Firm/ Source
1.	MHTM-256	F ₁	10	Maharashtra hybrid seeds company limited (Mahyco)
2.	S-22	Local / desi	10	Hindustan seeds pvt. Ltd.
3.	Bharani	F ₁	10	Shiv shakti bheej bhandar
4.	Arundhati-809	F ₁	10	East west seeds india pvt. Ltd.
5.	Bhagyanwan	F ₁	10	Sakata seeds India pvt. Ltd.
6.	Abhilash	F ₁	10	Seminis (Monsanto holding pvt. Ltd.)
7.	Anvitha (NTH-1032)	F ₁	10	Nath seeds ltd.
8.	Red Ruby	F ₁	10	Garden care
9.	Kohinoor	F ₁	10	Chia tai Co. ltd.
10.	Karan	F ₁	10	Chia tai Co. ltd.
11.	Kareena	F ₁	10	Chia tai Co. ltd.
12.	Priya-6636	F ₁	10	Super seeds pvt. Ltd.
13.	Karishma	F ₁	10	Seminis (Monsanto holding pvt. Ltd.)
14.	VNR-3348	F ₁	10	VNR Seeds Pvt. Ltd.
15.	Nun-7610	F ₁	10	Nunhemp
16.	VNR- 3357	F ₁	10	VNR Seeds Pvt. Ltd.
17.	Kundan	F ₁	10	Atlantic seeds hybrid
18.	Lakshmi (NP-5005)	F ₁	10	Nunhemp
19.	Saksham	F ₁	10	Seminis
20.	NS-962	F ₁	10	Namdhari seeds
21.	Arka Rakshak	F ₁	10	Arka seeds
22.	Pusa Ruby	F ₁	10	Green India hybrid seeds pvt. Ltd.
23.	Punjab Chhuhara	Local / desi	10	Dr. C. P. Khare sir

Table 3.5 Details of tomato entries

Growth habit / Type	No. of entries	Experimental Year	Entry/ variety
Determinate	7	2015-16 and 2016-17	2014/TODVAR-1
			2014/TODVAR-2
			2014/TODVAR-3
			2014/TODVAR-4
			2014/TODVAR-5
			2014/TODVAR-6
	11	2016-17 and 2017-18	H-86 (Kashi Vishesh)
			2016/TODVAR-1
			2016/TODVAR-2
			2016/TODVAR-3
			2016/TODVAR-4
			2016/TODVAR-5
			2016/TODVAR-6
			2016/TODVAR-7
			2016/TODVAR-8
			2016/TODVAR-10
			2016/TODVAR-11
			2016/TODVAR-12
Cherry	7	2015-16 and 2016-17	2015/TOCVAR-1
			2015/TOCVAR-2
			2015/TOCVAR-3
			2015/TOCVAR-4
			2015/TOCVAR-5
			2015/TOCVAR-6
			Swarna Ratan
Indeterminate	7	2015-16 and 2016-17	2015/TOINDVAR-1
			2015/TOINDVAR-2
			2015/TOINDVAR-3
			2015/TOINDVAR-4
			2015/TOINDVAR-5
			2015/TOINDVAR-6
			Arka Vikash

2016/TODVAR-6, 2016/TODVAR-7, 2016/TODVAR-8, 2016/TODVAR-10, 2016/TODVAR-11 and 2016/TODVAR-12) were evaluated during *rabi* 2016-17 and 2017-18. The details of entries were described in table 3.5.

3.9.2 Experimental Details

Experimental details of Tomato leaf curl virus resistance entries and Commercial varieties/ hybrids

Particulars	2014 & 2015/ ToLCVRES-		2016/ToLCVRES		Commercial varieties/ hybrids	
	2015-16	2016-17	2016-17	2017-18	2015-16	2016-17
Number of entries/ varieties	7	7	9	9	23	23
Plot size (L × W m)	4.2 × 3.0	4.2 × 3.0	4.2 × 3.0	4.2 × 3.0	3 × 3	4.5 × 2
Row to row spacing (cm)	60	60	60	60	60	60
Plant to plant spacing (cm)	50	50	50	50	50	50
Design	RBD	RBD	RBD	RBD	RBD	RBD
Replication	3	3	3	3	3	3
Date of sowing	04/10/ 2015	05/10/ 2016	04/10/ 2016	05/10/ 2017	07/10/ 2015	07/10/ 2015
Date of transplanting	29/10/ 2015	30/10/ 2016	29/10/ 2016	30/10/ 2018	29/10/ 2015	29/10/ 2015

Seedlings of each entry / variety of tomato were raised in nursery beds. Seeds of each entry / variety of tomato were sown in separate rows. Twenty-five days old seedlings were transplanted into main field in randomized block design (RBD) and three replications were maintained for each entry / variety except 2015/TOCVAR for which four replications were maintained. No chemicals / pesticides were applied during the course of experiment.

Experimental details of tomato entries

Particulars	2014/TODVAR		2015/TOCVAR		2015/TOINDVAR		2016/TODVAR	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2016-17	2017-18
Number of entries/ varieties	7	7	6	6	7	7	11	11
Plot size	3.5 × 3.0	3.5 × 3.0	4.8 × 4.0	4.8 × 4.0	4.5 × 4.2	4.5 × 4.2	4.0 × 3.6	4.0 × 3.6
(L × W m)								
Row to row spacing (cm)	60	60	60	60	75	75	60	60
Plant to plant spacing (cm)	50	50	50	50	40	40	50	50
Design	RBD	RBD	RBD	RBD	RBD	RBD	RBD	RBD
Replication	3	3	4	4	3	3	3	3
Date of sowing	12/10/ 2015	12/10/ 2016	12/10/ 2015	12/10/ 2016	12/10/ 2015	12/10/ 2016	25/10/2016	25/10/2017
Date of transplanting	06/11/ 2015	06/11/ 2016	06/11/ 2015	06/11/ 2016	06/11/ 2015	06/11/ 2016	19/11/2016	19/11/2017

3.9.3 Observation recorded

3.9.3.1 Percent disease incidence and PDI

Percent incidence and ratings were recorded for each entry / variety from 15 to 90 days after transplanting at 15-day intervals. The rating of leaf curl disease was recorded for each plant of every entry/ variety by using rating scale of 0-7 as suggested by Alegbejo, 1995. Percent disease index (PDI) was calculated for each entry / variety by implying formulae suggested by Wheeler (1969) thereafter on the basis of reactions different entries / varieties were classified into different categories viz. Highly resistant (HR), Resistant (R), Moderately resistant (MR), Moderately susceptible (MS) and Susceptible (S).

ToLCV disease rating scale

Grade / Rating	Symptoms	PDI	Reaction category
0	No visible disease symptom	0	HR
1	Top leaves curled only	1.0-15.9	R
3	Top leaves curled and slight stunting of plant or All leaves curled without stunting	16.0-25.9	MR
5	All leaves curled and slight stunting of plant	26.0-36.9	MS
7	Severe curling of leaves, stunting of plant and proliferation of auxiliary branches	37.0 and above	S

3.9.3.2 Growth, yield and quality parameters

Growth, yield and quality parameters of tomato plants were recorded from each replication (plot) of every entry / variety and statistical analysis of average data were done with RBD.

- 1. Plant height (cm):** The height of five randomly selected tomato plants was measured from the ground level to the tip of the plant canopy by measuring stainless steel scale (1.5 m) and average was calculated.
- 2. Number of primary branches per plant:** The number of primary branches of five randomly selected tomato plants was counted on each plant emerging from the trunk and average was calculated.

- 3. Number of secondary branches per plant:** The number of secondary branches of five randomly selected tomato plants was counted on each plant emerging from the primary branches and average was calculated.
- 4. Days to first flowering:** Days to first flowering was calculated by counting the days taken for first flowering after transplanting.
- 5. Days to 50% flowering:** Days to 50% flowering was calculated by counting the days taken for 50% flowering after transplanting.
- 6. Days to first fruiting:** Days to first fruiting was calculated by counting the days taken for first fruiting after transplanting.
- 7. Number of fruits per plant:** The total number of fruits per plant was counted from five randomly selected plants and average was calculated.
- 8. Fruit yield / weight per plant (kg):** Total fruit yield or weight per plant was calculated by weighing the fruits of five randomly selected plants and mean was calculated.
- 9. Average fruit weight (g):** The weight of each fruit was calculated by weighing the fruits of five randomly selected plants and mean was calculated.
- 10. Marketable yield per hectare (q):** Marketable yield in per unit area (1 sq m) was worked out from per plot yield after that per hectare marketable yield was calculated by multiplying yield in per unit area and 1 ha area (10000 sq m). Finally marketable yield was calculated in quintal per ha.
- 11. Unmarketable yield per hectare (q):** Unmarketable yield in per unit area (1 sq m) was worked out from per plot yield after that per hectare unmarketable yield was calculated by multiplying yield in per unit area and 1 ha area (10000 sq m). Finally unmarketable yield was calculated in quintal per ha.
- 12. Total yield per hectare (q):** Total yield per plot was calculated by adding per ha marketable and unmarketable yield.
- 13. Fruit girth (mm):** Fruit girth / equatorial diameter of five randomly selected fruits from each replication were measured with the help of Vernier scale (Fisher Scientific) and average was calculated.
- 14. Polar diameter (mm):** Fruit height / polar diameter of five randomly selected fruits were measured from top to bottom pole of each fruit with the help of Vernier scale (Fisher Scientific) and average was calculated for each replication.

15. Number of locules per fruit: Number of locules of five randomly selected fruits was counted visually by cutting each fruit horizontally and average was calculated for each replication.

16. Pericarp thickness (mm): The pericarp thickness of five randomly selected fruits from each replication was measured with the help of Vernier scale (Fisher Scientific) and average was calculated.

17. Total soluble solid / TSS (Brix %): The TSS of five randomly selected fruits from each replication was measured with the help of hand refractometer (0-32% Brix) and average was calculated.

18. Fruit shape and colour: Fruit shape and colour of each entry / variety was noted by visual observation.

3.9.3.3 Overall performance of entries / varieties / hybrids

The overall performances of all the entries/ varieties/ hybrids were analyzed on the basis of their reaction, yield, quality and other parameters.

3.10 To study the management of tomato leaf curl disease through vector control

An experiment was conducted during *rabi* 2015-16 and 2016-17. Five insecticides were tested in combination with silver polythene mulch and maize as border crop to find out best and cost effective strategy for management of tomato leaf curl disease through vector control. The thickness of polythene mulch was 30 gauges (7.6 micron or 0.0076 mm). The specification and other details of insecticides used in the experiment are given in table 3.6.

3.10.1 Experimental details

Particulars	2015-16	2016-17
Number of treatments	7	7
Number of replication	4	4
Plot Size	3 × 3 m	3 × 3 m
Design	RBD	RBD
Test cultivar	Pusa Ruby	Pusa Ruby
Row to row spacing (cm)	60	60

Plant to plant spacing (cm)	50	50
Date of sowing	15/10/ 2015	16/10/ 2016
Date of transplanting	09/11/ 2015	10/11/ 2016

3.10.2 Treatment details

T₀ : Growing of maize as a guard crop 15 days before sowing + silver mulching

T₁ : Imidacloprid (17.80% SL)

T₂ : Fipronil (5% SC)

T₃ : Cyantraniliprole / Cyazypyr (10.26 % OD)

T₄ : Buprofezin (25 % SC)

T₅ : Thiamethoxam (25 % WG)

T₆ : Silver polythene mulch only (No insecticide spray)

T₇ : Control (No silver mulch and insecticide spray)

Total seven treatments including one control treatment were plotted in randomized block design and four replications were maintained for each treatment. Total six sprays were done at 10-day intervals. The cultivar *Pusa Ruby* was used as a test variety (Gupta *et al.*, 2007 and Meena and Raju, 2014). Tomato seeds were sown in nursery bed on 15th October 2015 and 16th October 2016 and 25 days old seedlings were transplanted in main plots on 9th November 2015 and 10th November 2016 in *rabi* 2015 and 2016 respectively. The seedlings were planted in plots of 3 × 3 m (9 sq m) size with 60 cm row to row and 50 cm plant to plant spacing. No any other control measures except treatments were applied.

Observations on percent disease incidence, PDI and vector population (adult whitefly) were recorded one day before and 1, 3 and 5 days after each spray. These data were transformed with square root and/or Arc sine (angular) transformation methods. Square root transformation is applied for adult whitefly population. It also used for percent disease incidence and PDI within the range of 0 to 30 per cent. Arc sine (angular) transformation was used for percent disease incidence and PDI within the range of both 0 to 30 and 70 to 100 percent. Later on the transformed data were analysed statistically.

Table 3.6: List of insecticides used for the management of tomato leaf curl disease through vector control

Insecticide	Nature	Trade product	Package size (g l ⁻¹)	Formulation	Dose (a.i. ha ⁻¹)	Dose of market product ha ⁻¹	Treatment dose g or ml l ⁻¹	Spray volume of water (l ha ⁻¹)	Manufacturer/ Firm/ Source
Imidacloprid	Systemic	Confidor	250 ml	17.80 % SL	30.26 ml	170 ml	0.34 ml	500	Bayer Crop Science Ltd.
Fipronil	Systemic	Regent	250 ml	5 % SC	40 ml	800 ml	1.60 ml	500	Bayer Crop Science Ltd.
Cyazapir (Cyazapir)	Systemic	Benevia	180 ml	10.26 % OD	20.52 ml	200 ml	0.40 ml	500	DuPont India Pvt. Ltd.
Buprofezin	Insect growth regulator	Kaal	250 ml	25 % SC	100 ml	400 ml	0.80 ml	500	GSP Crop Science Pvt. Ltd.
Thiamethoxam	Systemic	Evident	100 g	25 % WG	25 g	100 g	0.20 g	500	Biostadt India Ltd.

3.10.3 Yield and economics

Benefit-cost (B:C) ratio was calculated for each treatment in comparison to control (Check) to find out most effective as well as cheap management strategy. To work out cost benefit ratio first treatment wise per hectare treatment cost and marketable yield was calculated then gross return (total return) was calculated for each treatment by multiplying marketable yield and rate of produce. Thereafter net return of each treatment was calculated by deducting gross return of treatment to gross return of control. Net profit per rupee invested was calculated for each treatment by dividing net return per ha to treatment cost per ha.

3.11 Field preparation

Initially field was ploughed with M.B. plough, then its preparation was done by tractor drawn cultivator followed by two cross harrowing to pulverise the soil and by considering the available area plots were prepared for experiments. Ridge of 15 cm height and furrows were prepared in each plot. The path and distance to mark or separate different replications as well as plots were shown in layout plan (Fig 3.7).

3.12 Mulching

Mulch materials were applied at the time of transplanting of tomato seedlings as per the treatments silver polythene sheet of 30 gauges (7.6 micron or 0.0076 mm) was used as mulch, which were spread over the ridges in plots. Holes were made at the specified distance so that tomato plants can grow properly without any obstruction. The edges of the polythene sheet were covered with soil, making small bund to protect the polythene sheet from wind damage.

3.13 Transplanting

Twenty-five day old healthy seedlings were transplanted in experimental plots with treatment specific spacing. One seedling was transplanted in one hill/ hole. Transplanting was done after 3 P.M. to protect the seedlings from hot sunny period.

3.14 Gap filling

The mortality of seedlings was visualized on the field at 3 days after transplanting accordingly gap filling was done to maintain required plant population per unit area.

3.15 Nutrient management

3.15.1 Source and dosage of nutrient

Nutrients	Dose (kg/ha)	Source of nutrients	Quantity of fertilizer (kg)
Nitrogen	100	Urea	217.39
Phosphorus	80	Single Super Phosphate	500
Potash	60	Muriate of potash	100

3.15.2 Application

Prior to harrowing, well-decomposed FYM @ 20 q ha⁻¹ was incorporated uniformly in the soil. Fertilizers were applied to the plots and mixed well with soil. Full dose of phosphorus (P₂O₅) and potash (K₂O) and 25 percent of nitrogenous (N) fertilizers were applied as a basal dose. Remaining dose of nitrogenous (N) fertilizer was applied in two splits doses, *i.e.*, 50 percent at 25 days after planting and 25 percent at 50 days after planting during hoeing and weeding.

3.16 Irrigation and Intercultural operation

At the time of planting sufficient moisture was kept in the soil through irrigation for proper establishment of the plant. Irrigations were given when it required. Two hoeing and hand weeding was done at 25 and 50 days after transplanting to raise a good crop.

3.17 Harvesting and yield

Manual picking of fruits were done when fruits become light colour. Marketable yield, unmarketable yield and total yield of each experimental plot was also taken during harvesting.

3.18 Statistical analysis of data

3.18.1 Epidemiology of tomato leaf curl disease

The data used in the study are the mean values of replicated observations. Correlation coefficients were computed among the leaf curl incidence, PDI, adult whitefly population and weather or meteorological parameters to know the direction of relationships among variables. An online computer programme OPSTAT (developed by O. P. Sheoran, Professor (Statistics), Computer Section, CCS HAU, Hisar) was used for the analysis of correlation coefficients. Regression analysis was carried out to know the degree or extent of contribution of independent variables on dependent variables (percent disease incidence, PDI and vector population). Regression analysis was worked out with a computer programme EXCEL.

3.18.2 Varietal evaluation and management

The experiments were laid out in randomized block design (RBD). The data obtained on various characters under study were analyzed season wise by using the method of analysis of variance for randomized block design and significance was tested by F test (Gomez and Gomez, 1984).

The skeleton of randomized block design (RBD)

Treatment	Replication (R)			Total	Mean
	R ₁	R ₂	R ₃		
T ₁					
T ₂					
T ₃					
.					
.					
.					
T _n					
Total				Grand Total	Grand mean

The skeleton of the analysis of variance (ANOVA)

Source of variation	D.F.	SS	MSS	F cal	F tab value (5%)	T tab value (5%)
Replication	(r-1)	RSS	$\frac{RSS}{RDF}$			
Treatment	(t-1)	TrSS	$\frac{TrSS}{TrDF}$	$\frac{TrMSS}{EMSS}$		
Error	(r-1) (t-1)	ESS	$\frac{ESS}{EDF}$			
Total	(rt-1)	TSS				

- Correction factor (C.F.) :
- Standard error of deviation (SED) :
- Standard error of mean (SEm±) :
- Critical difference (CD) : 5% Level of significance
- Coefficient of variance (CV) :

The following formulae were used for computation of correction factor, standard error of deviation, standard error of mean critical difference and coefficient of variance.

Correction factor (CF)

$$CF = \frac{\text{Grand Total}}{r}$$

Total sum of square (TSS)

Replication sum of square (RSS)

$$RSS = \frac{\sum_{j=1}^r R_j^2}{t} - C.F.$$

Treatment sum of square (TrSS)

$$TrSS = \frac{\sum_{i=1}^t T_i^2}{r} - C.F.$$

Error sum of square (ESS)

$$ESS = TSS - RSS - TrSS$$

Standard error of deviation (SED)

$$SED = \sqrt{\frac{2 \times EMSS}{\text{Number of replication}}}$$

Standard error of mean (SEm±)

$$SEM = \sqrt{\frac{EMSS}{\text{Number of replication}}}$$

Critical difference (CD)

$$CD = t \text{ tab value} \times SED \text{ or } SEM\sqrt{2} \times t \text{ tab value}$$

Coefficient of variance (CV)

$$CV = \frac{\sqrt{EMSS}}{\text{Grand mean}} \times 100$$

Where

R/r = Replication,

T/t = Treatment,

rj = up to jth replication, ti = up to ith treatment,

X = observation or data of treatments

3.18.3 Pooled analysis

The error variances for various parameters of experiments for different years (2 years) were tested for F test and were found non significant (Homogenous) therefore data was pooled.

$$F = \frac{\text{Error variance first year}}{\text{Error variance second year}}$$

F table value was seen at 5% error degree of freedom if F calculated value was less than F table value hence variance was homogenous and data had been pooled

CHAPTER – IV

RESULTS AND DISCUSSION

The data on various aspects of investigation have been presented in this chapter along with appropriate tables, figures and possible interpretations. The results have been given under the following headings:

4.1 Seasonal occurrence of prevalent diseases of tomato under field and polyhouse conditions

Seasonal occurrence of prevalent diseases of tomato was recorded in both fields as well as poly house conditions from 2014 to 2017.

4.1.1 Field condition

In field condition the occurrence of prevalent diseases were recorded for two seasons of three consecutive years i.e. *rabi* (2014-15, 2015-16 and 2016-17) and *kharif* (2015, 2016 and 2017). It was recorded starting from the second fortnight of November to the first fortnight of March in *rabi* and the last week of July to the first fortnight of November in *kharif* (Tables 4.1, 4.2 and 4.3). Five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot appeared in the crop during both the seasons.

4.1.1.1 Leaf curl

In *rabi* 2014-15 and 2015-16 the first appearance of leaf curl was observed in the second fortnight of November with low percent disease incidence (4.83 and 7.30) and PDI (1.46 and 2.87). However, in *rabi* 2016-17 the first symptoms of leaf curl was observed in the first fortnight of November with percent disease incidence of 1.67 and PDI of 0.81. In all three *rabi*, the disease progressed up to the first fortnight of March with maximum percent disease incidence (87.66, 79.07 and 87.91) and PDI (64.68, 59.17 and 68.80) (Tables 4.1, 4.2 and 4.3 and Fig 4.1a).

In *kharif* the first appearance of leaf curl was observed in the first fortnight of August in 2015 and 2017, and in the second fortnight of August in 2016 and progressed up to the first fortnight of November.

Initially the occurrence of the disease started with very low percent disease incidence (1.00, 3.70, and 2.66,) and PDI (0.24, 1.49 and 1.14) which increased with increase in age of the plant and reached maximum in first fortnight of November (68.48, 49.58; 62.36, 45.56; 69.64, 51.30) (Tables 4.1, 4.2 and 4.3 and Fig 4.1a).

The ToLCD was present in almost all fields of Belgaum, Dharwad and Haveri districts surveyed with the disease incidence ranged from 4-100 percent in *rabi* and was in severe form ranging from 60 to 100 percent during summer (Reddy, 2006 and Reddy, *et al.* 2011). Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *kharif* 2013 and *Rabi* 2013-14. The average incidence of leaf curl was recorded from October 2013 to March 2014 in *kharif* and from November 2013 to March 2014 in *rabi* with increasing trend and average maximum disease incidence of 12.24 and 10.94 percent (March 2014) was recorded in both *kharif* and *rabi*, respectively, under field condition (Anon, 2013-14). Ehsanullah, (2014) recorded 10.8 to 91.3 percent disease incidence in major tomato growing districts of Karnataka with highest disease incidence of 70.81 percent in Kolar and least incidence of 21.00 percent in Ramanagara district.

4.1.1.2 Mosaic

In *rabi* (2014-15, 2015-16 and 2016-17) the first appearance of mosaic was observed in the second fortnight of December in 2014-15 whereas in 2015-16 and 2016-17 the disease was observed in first fortnight of January and progressed up to the first fortnight of March. Initially the occurrence of the disease started with very low percent disease incidence (0.69, 0.58 and 1.11) and PDI (0.14; 0.32 and 0.38) which increased with increase in age of the plant and reached maximum in the second fortnight of February (4.18, 2.53; 6.75, 6.68; 5.06, 4.92) (Table 4.1, 4.2 and 4.3 and Fig 4.1b).

In *kharif*, the first occurrence of mosaic was observed in the second fortnight of September in 2015 whereas in 2016 and 2017 the disease was observed in the first fortnight of October and progressed up to the first fortnight of November. Initially percent disease incidence (0.59, 0.96 and 0.67) and PDI of the disease were very low (0.24, 0.48 and 0.15) and gradually increased with increase

in age of the plant and reached maximum in the first fortnight of November (2.75, 1.63; 4.38, 4.10; 2.69, 1.78) (Table 4.4, 4.5 and 4.6 and Fig 4.1b).

Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *kharif* 2013 and *rabi* 2013-14. The average incidence of mosaic was recorded from October 2013 to March 2014 in *kharif* and from December 2013 to March 2014 in *rabi* with increasing trend and average maximum disease incidence of 17.03 percent was recorded in February 2014 (*kharif*) and 12.61 percent in March 2014 (*rabi*) in field condition (Anon, 2013-14). Jalender, *et al.* (2017) conducted a survey in tomato growing areas of Ranga Reddy district during *kharif* 2013 and in Guntur district during *rabi* 2013-14 and recorded natural occurrence of disease incidence which ranged from 6.9 to 15.7 among different Mandals.

4.1.1.3 Tomato spotted wilt

In *rabi* the first symptoms of tomato spotted wilt was observed in the first fortnight of January, the first fortnight of February and the second fortnight of January in 2014-15, 2015-16 and 2016-17, respectively with 0.21, 1.53 and 0.96 percent disease incidence and 0.06, 0.94 and 0.23 PDI. The disease continued up to the first fortnight of March and maximum percent disease incidence (1.52, 2.01 and 3.01) and PDI (0.76, 1.88 and 2.41) were recorded in the second fortnight of February (Table 4.1, 4.2 and 4.3, and Fig 4.1b).

In *kharif* the disease was not observed in 2015. However, it was observed in the first and second fortnight of October in 2016 and 2017, respectively with percent incidence of 0.96 and 0.38 and PDI of 0.53 and 0.35. The disease continued up to the first fortnight of November with maximum percent disease incidence (2.36 and 1.34) and PDI (1.42 and 0.70) (Table 4.1, 4.2 and 4.3, and Fig 4.1b).

Pattaiya, (2006) carried out survey and surveillance of tomato spotted wilt virus disease at fields of three locations viz. Panagar, Jabalpur and Indrana to determine the incidence of virus. A total of five thousand and sixty tomato plant samples from five varieties viz. Pusa early dwarf, JT 99, Pusa ruby, Sourabh and Abhisek were observed for tomato spotted wilt virus. Overall 18 to 34, 15 to 30 and 16 to 24 percent infection was observed in Panagar, Jabalpur and Indrana

respectively in different varieties. Bòzdoğan and Kamberoglu, (2015) conducted a survey in Center (Antalya) district of Turkey and reported 74.28 to 92.30 percent (average 78.57 %) infection of tomato spotted wilt virus in tomato crop during 2007-2009.

4.1.1.4 Early blight

In *rabi* the first occurrence of early blight was recorded in the first fortnight of January and progressed up to the first fortnight of March. Initially percent incidence (0.83, 0.59 and 3.68) and PDI of the disease were very low (0.03, 0.04 and 0.15) which rapidly increased and reached maximum in the first fortnight of March in 2014-15 (71.51 and 38.42) and the second fortnight of February in 2015-16 (70.24, 32.48) and 2016-17 (81.69, 45.15) (Table 4.1, 4.2 and 4.3, and Fig 4.1c).

In *kharif* the disease was observed in the first fortnight of October in 2015 whereas in 2016 and 2017 the disease was observed in the second fortnight of September and continued up to the first fortnight of November. Initially percent incidence (4.03, 2.91 and 0.95) and PDI of the disease were very low (0.32, 0.11 and 0.03) which rapidly increased and reached maximum in the first fortnight of November (52.79, 19.91; 54.57, 26.45 and 56.89 and 29.11) (Table 4.1, 4.2 and 4.3, and Fig 4.1c).

Prasad, (2002) recorded 28.60 to 65.36 percent severity of early blight in northern districts of Karnataka during 2001. Roopa, 2012 undertook a roving survey during 2011 to assess the severity of early blight of tomato in major tomato growing areas of Dharwad, Belgaum, Haveri, Gadag and Bagalkot districts. Disease severity was ranged from 17.30 to 37.25 percent, highest severity was recorded in Haveri (31.03%) and least in Dharwad (20.16%) districts. Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *kharif* 2013 and *rabi* 2013-14. The average severity of early blight was recorded from October 2013 to March 2014 in *kharif* and from November 2013 to March 2014 in *rabi* with increasing trend and average maximum disease severity of 23.33 and 5.96 percent (March 2014) was recorded in both *kharif* and *rabi*, respectively under field condition (Anon, 2013-14).

4.1.1.5 Collar rot

In *rabi* the first appearance of collar rot was observed in the first fortnight of December with percent disease incidence of 1.04, 1.01 and 0.67 and continued up to the first fortnight of March and maximum percent disease incidence (2.25, 4.38 and 3.33) was observed in the first fortnight of January and February and the second fortnight of January in 2014-15, 2015-16 and 2016-17 (Table 4.1, 4.2 and 4.3, and Fig 4.1d).

In *kharif* the disease was observed in the first fortnight of September in 2015 and 2017 whereas in 2016 it was observed in the second fortnight of August. Initially percent incidence of the disease was low (2.05, 3.36 and 1.67) which steadily increased and reached maximum up to the first fortnight of October (2.72, 5.40 and 4.72) (Table 4.4, 4.5 and 4.6, and Fig 4.1d).

In field condition the incidence of collar rot was recorded 5 to 10 percent in Raipur, Chhattisgarh (Anon, 2013-14), 10-45 percent in Himachal Pradesh (Banyal, *et al.* 2008) and 7.61 to 21.79 percent in undulating red and lateritic zone of West Bengal (Mahato, *et al.* (2017).

4.1.2 Polyhouse / protected condition

In polyhouse or protected condition the occurrence of prevalent diseases were recorded for two years from the first fortnight of November to the end of April in 2015-16 and the first fortnight of August to the end of January in 2016-17 within polyhouse. The percent disease incidence and percent disease index were recorded for overall crop as well as for each variety at 15-day intervals (Tables 4.4 and 4.5). Four diseases viz. leaf curl, mosaic, early blight and collar rot were noticed in the crop during both the years.

2015-16

In 2015-16, leaf curl was the first disease which was recorded in the second fortnight of December thereafter mosaic, collar rot and early blight were observed in the first fortnight of January, second fortnight of January and second fortnight of February, respectively, and appeared up to the end of April (Table 4.4). Initially percent incidence of leaf curl (0.03), mosaic (0.03), early blight (0.04) and collar

Table 4.1 Seasonal occurrence of prevalent diseases of tomato under field conditions (Rabi 2014-15 and Kharif 2015)

Disease	Incidence and PDI	At 15-day intervals (Days after transplanting)											
		Rabi 2014-15						Kharif 2015					
		Nov		Dec		Jan		Feb		March		Aug	
		II	I	II	I	II	I	II	I	II	I	II	I
Leaf curl	Incidence	4.83	19.41	22.17	25.33	37.18	63.63	82.53	87.66	1.00	3.71	9.66	16.05
	PDI	1.46	8.82	10.45	13.16	24.01	44.12	60.15	64.68	0.24	1.50	4.66	7.87
Mosaic	Incidence	-	-	0.69	1.17	2.84	4.18	4.18	4.18	-	-	0.59	0.69
	PDI	-	-	0.14	0.33	1.08	1.84	2.53	2.53	-	-	0.24	0.28
Spotted Wilt	Incidence	-	-	-	0.21	0.83	1.18	1.52	1.52	-	-	-	-
	PDI	-	-	-	0.06	0.28	0.49	0.76	0.76	-	-	-	-
Early blight	Incidence	-	-	-	0.83	7.48	22.09	54.24	71.51	-	-	-	4.03
	PDI	-	-	-	0.03	0.73	9.42	22.95	38.42	-	-	-	0.32
Collar rot	Incidence	-	1.04	1.05	2.25	2.25	2.25	2.25	2.25	-	-	2.05	2.39
	PDI	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.2: Seasonal occurrence of prevalent diseases of tomato under field conditions (Rabi 2015-16 and Kharif 2016)

Disease	Incidence and PDI	At 15-day intervals (Days after transplanting)											
		Rabi 2015-16						Kharif 2016					
		Nov		Dec		Jan		Feb		Aug		Sep	
		I	II	I	II	I	II	I	II	I	II	I	II
Leaf curl	Incidence	7.30	15.98	21.17	29.26	42.35	68.52	79.07	3.70	5.74	8.14	20.26	47.92
	PDI	2.87	7.44	11.32	29.26	28.47	49.39	58.62	1.49	2.76	4.11	11.75	26.48
Mosaic	Incidence	-	-	-	0.58	4.08	5.81	6.75	-	-	-	0.96	3.57
	PDI	-	-	-	0.32	3.33	5.48	6.68	-	-	-	0.48	2.37
Spotted Wilt	Incidence	-	-	-	-	-	1.53	2.01	-	-	-	0.96	1.83
	PDI	-	-	-	-	-	0.94	1.88	-	-	-	0.53	0.93
Early blight	Incidence	-	-	-	0.59	10.34	36.45	70.24	-	-	2.91	6.26	23.00
	PDI	-	-	-	0.04	1.35	8.49	32.48	-	-	0.11	0.39	5.78
Collar rot	Incidence	-	1.01	1.01	1.34	3.37	4.38	4.38	3.36	4.05	4.05	5.40	5.40

Table 4.3: Seasonal occurrence of prevalent diseases of tomato under field conditions (Rabi 2016-17 and Kharif 2017)

Disease	Incidence and PDI	At 15-day intervals (Days after transplanting)											
		Rabi 2016-17						Kharif 2017					
		Nov		Dec		Jan		Feb		Aug		Sep	
		I	II	I	II	I	II	I	II	I	II	I	II
Leaf curl	Incidence	1.67	8.51	17.78	27.48	45.48	67.72	83.19	87.91	2.66	7.33	13.28	17.70
												29.67	54.91
	PDI	0.81	4.36	9.90	16.90	32.24	51.47	64.37	68.80	1.14	4.00	7.70	18.74
												40.56	51.30
Mosaic	Incidence	-	-	-	-	1.11	2.51	5.06	5.06	-	-	-	0.67
													1.64
	PDI	-	-	-	-	0.38	1.47	3.85	4.92	-	-	-	0.15
													0.71
Spotted Wilt	Incidence	-	-	-	-	-	0.96	2.33	3.01	-	-	-	-
													0.38
	PDI	-	-	-	-	-	0.23	0.87	2.41	-	-	-	-
													0.35
Early blight	Incidence	-	-	-	-	3.68	16.18	48.97	81.69	-	-	-	0.95
													8.62
	PDI	-	-	-	-	0.15	1.92	14.13	45.15	-	-	-	0.03
													0.75
Collar rot	Incidence	-	-	0.67	2.00	3.00	3.33	3.33	3.33	-	-	1.67	4.14
													4.72
													4.72
													4.72



A: Healthy tomato plant



B: Tomato leaf curl virus infected plants

Fig 4.1a: Occurrence of prevalent diseases of tomato under field conditions



C: Tomato mosaic infected plant



D: Tomato spotted wilt infected plant and fruit

Fig 4.1b: Occurrence of prevalent diseases of tomato under field conditions



E: Symptoms of early blight in tomato (a) plant, (b) leaves, (c) stem and (d) twigs and fruits

Fig 4.1c: Occurrence of prevalent diseases of tomato under field conditions



F: Collar rot of tomato (a) infected plant and (b) sclerotia on collar portion of tomato plant

Fig 4.1d: Occurrence of prevalent diseases of tomato under field conditions

rot (0.07) and PDI of leaf curl (0.01), mosaic (0.01) and early blight (0.02) were very low. The percent incidence of leaf curl (2.42), mosaic (2.08) and collar rot (1.70) and PDI of leaf curl (1.02) and mosaic (1.27) steadily increased. However, the percent incidence and PDI of early blight rapidly increased and reached maximum (52.62 and 37.30) at the end of April (Fig 4.2a to 4.2d).

Leaf curl was first recorded on variety 1204 with percent incidence and PDI of 0.15 and 0.06, respectively in the second fortnight of December thereafter it occurred in Sheeja (0.06 and 0.02) in the first fortnight of January, Youvraj (0.07 and 0.02) in second fortnight of January and Ruhi (0.07 and 0.02) and Laila (0.02 and < 0.01) in first fortnight of February. The maximum percent incidence and PDI was observed in 1204 (4.86 and 2.23) followed by Sheeja (2.49 and 1.20) and Youvraj (2.10 and 0.89) and minimum was recorded in Laila with 1.15 percent incidence and PDI of 0.34 (Appendix G).

Mosaic was first recorded on variety 1204 with percent incidence and PDI of 0.15 and 0.04 in the first fortnight of January thereafter it occurred in Sheeja (0.03 and 0.01) in the first fortnight of February, Youvraj (0.07 and 0.02) first fortnight of March and Laila (0.09 and 0.03) second fortnight of March and Ruhi was free from mosaic. The maximum percent incidence and PDI was observed in 1204 (8.13 and 5.51) followed by Sheeja (1.27 and 0.53) and Youvraj (0.65 and 0.18) and minimum was recorded in Laila with 0.34 percent incidence and PDI of 0.12 (Appendix G).

Early blight was first recorded on variety Youvraj and Ruhi in the second fortnight of February with percent incidence and PDI of 0.04 and 0.01 and 0.17 and 0.08, respectively, thereafter it occurred in 1204 (0.43 and 0.18), Laila (0.15 and 0.06) and Sheeja (0.30 and 0.12) in the first fortnight of March. The incidence and PDI of early blight rapidly increased in all the varieties and reached to maximum at the end of April. The maximum percent incidence and PDI was observed in Ruhi (82.33 and 60.34) followed by 1204 (58.29 and 44.96) and Youvraj (51.75 and 38.54) and minimum was recorded in Laila with percent incidence and PDI of 31.18 and 17.93, respectively (Appendix G).

The first appearance of collar rot was recorded in 1204 and Youvraj in the second fortnight of January with percent incidence of 0.04 and 0.33 respectively.

Thereafter it occurred in Ruhi (0.09) in the first fortnight of February and Laila (0.06) in the first fortnight of March and Sheeja was free from mosaic. The maximum percent incidence was observed in Youvraj (6.70) followed by Ruhi (0.89) and 1204 (0.77) and minimum was recorded in Laila with percent incidence of 0.14 (Appendix G).

2016-17

In 2016-17, collar rot was the first disease which was recorded in the first fortnight of September thereafter leaf curl, early blight and mosaic were observed in the second fortnight of September and first fortnight of October, respectively, and appeared up to the end of January (Table 4.5). Initially percent incidence of leaf curl (0.10), mosaic (0.05), early blight (0.25) and collar rot (0.01) and PDI of leaf curl (0.03), mosaic (0.01) and early blight (0.11) were very low. The percent incidence and PDI of leaf curl (19.40 and 14.37) and early blight (59.91 and 35.61) rapidly increased whereas the percent incidence and PDI of mosaic (7.12 and 4.86) slowly increased and reached maximum at the end of January. However, the percent incidence of collar rot steadily increased and reached maximum (0.20) in the second fortnight of November (Fig 4.2a to 4.2d).

The first appearance of leaf curl was recorded on variety Nowara and Youvraj with 0.55 and 0.02 percent incidence and PDI of 0.16 and less than 0.01 percent, respectively, in the second fortnight of September. Thereafter it occurred in TL16060 (2.25 and 0.64) and Sheeja (1.11 and 0.40) in the first fortnight of October, Roza (0.55 and 0.24) and Laila (1.00 and 0.14) in the second fortnight of October. The maximum percent incidence and PDI was observed in Nowara (46.27 and 35.09) followed by TL16060 (37.08 and 25.84) and Sheeja (14.57 and 11.40) and minimum was recorded in Laila with 3.23 percent incidence and PDI of 2.61 (Appendix H).

Four (Nowara, Youvraj, Laila and Sheeja) were infected with mosaic and two varieties viz. TL16060 and Roza were free from the disease. The mosaic was first recorded on variety Nowara with percent incidence and PDI of 0.30 and 0.06, respectively, in the first fortnight of October. The disease also occurred in Youvraj (0.07 and 0.02) and Sheeja (0.29 and 0.12) in the second fortnight of October and

Table 4.4: Seasonal occurrence of prevalent diseases of tomato under polyhouse conditions (2015-16)

Disease	Incidence and PDI	At 15-day intervals (Days after transplanting)									
		Dec		Jan		Feb		March		April	
		II	I	II	I	II	I	II	I	II	
Leal curl	Incidence	0.03	0.09	0.22	0.41	0.69	0.96	1.37	2.04	2.42	
	PDI	0.01	0.05	0.13	0.23	0.33	0.50	0.69	0.89	1.02	
Mosaic	Incidence	-	0.03	0.13	0.48	0.95	1.27	1.61	1.90	2.08	
	PDI	-	0.01	0.04	0.13	0.26	0.46	0.80	1.13	1.27	
Early blight	Incidence	-	-	-	-	0.04	0.74	4.98	21.42	52.62	
	PDI	-	-	-	-	0.02	0.45	2.73	13.14	37.30	
Collar rot	Incidence	-	-	0.07	0.32	0.57	1.05	1.32	1.64	1.70	

Table 4.5: Seasonal occurrence of prevalent diseases of tomato under poly house conditions (2016-17)

Disease	Incidence and PDI	At 15-day intervals (Days after transplanting)									
		Sep		Oct		Nov		Dec		Jan	
		I	II	I	II	I	II	I	II	I	II
Leal curl	Incidence	-	0.10	1.06	2.49	4.82	10.08	12.21	14.55	16.43	19.40
	PDI		0.03	0.40	1.20	3.09	5.95	7.32	9.58	11.09	14.37
Mosaic	Incidence	-	-	0.05	0.40	2.02	5.63	5.94	6.42	6.72	7.12
	PDI			0.01	0.22	1.23	2.75	3.04	3.50	3.92	4.86
Early blight	Incidence	-	0.25	2.08	3.74	8.59	28.37	39.18	46.04	51.58	59.91
	PDI		0.11	1.07	2.12	6.12	14.74	19.15	24.82	29.15	35.61
Collar rot	Incidence	0.01	0.11	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20



A: Healthy tomato plant in polyhouse



B: Tomato leaf curl

Fig 4.2a: Occurrence of prevalent diseases of tomato under polyhouse conditions



C: Tomato mosaic

Fig 4.2b: Occurrence of prevalent diseases of tomato under poly house conditions



D: Early blight of tomato

Fig 4.2c: Occurrence of prevalent diseases of tomato under polyhouse conditions



E: Collar rot of tomato

Fig 4.2d: Occurrence of prevalent diseases of tomato under polyhouse conditions

Laila (0.51 and 0.10) in the first fortnight of November. The maximum infection of mosaic was recorded in Nowara with percent incidence of 34.13 and PDI of 23.52 followed by Sheeja (6.11 and 4.04) and Laila (1.69 and 1.12) and minimum was recorded in Youvraj with 0.78 percent incidence and PDI of 0.48 (Appendix H).

Early blight was first traced on variety Nowara and Youvraj with 0.38 and 1.13 percent incidence and PDI of 0.18 and 0.47, respectively, in the second fortnight of September. Thereafter it occurred in Roza (3.50 and 1.06), Laila (2.00 and 1.01) and Sheeja (2.00 and 0.85) in the first fortnight of October and TL16060 (2.00 and 0.92) in the second fortnight of October. The maximum percent incidence and PDI of early blight was observed in Roza (69.79 and 43.25) followed by Youvraj (64.53 and 37.44) and Nowara (66.05 and 34.71) and minimum was recorded in Laila with 49.03 percent incidence and PDI of 30.75 (Appendix H).

Among the six varieties of tomato two (Nowara and Youvraj) were infected with collar rot and remaining varieties viz. TL16060, Roza, Laila and Sheeja were free from the disease. The disease was first recorded on variety Youvraj in the first fortnight of September thereafter it occurred in Nowara in the second fortnight of September with percent incidence of 0.07 and 0.09 respectively. The maximum infection of collar rot was observed in Youvraj with percent incidence of 1.08 and minimum was recorded in Nowara with 0.11 percent incidence (Appendix H).

Barboza, *et al.* (2014) reported 14 percent leaf curl incidence under greenhouse. *Tomato yellow leaf curl virus* (TYLCV) with incidence of 28.9 percent was the most important restriction factor in greenhouse tomato (Valizadeh, *et al.* 2011). De Sá, *et al.* 2008 noticed that leaf curl incidence was greater than 90 percent in tomato crops grown in greenhouse from July to December.

Kaya, *et al.* (2009) performed a study to find out the virus diseases in tomato plants growing at the protected production areas in Mugla province between 2002 and 2004. The incidence of TMV and CMV in the leaf samples were 30.00 and 2.56 percent respectively. Massumi, *et al.* (2009) recorded the incidence of *Tobacco mosaic virus*, *Potato virus Y*, *Tomato mosaic virus* and *Cucumber mosaic virus* were 5.6, 5.0, 4.8 and 23.4 percent respectively, in greenhouses in Kerman, Hormozgan, Sistan-Baluchestan, Yazd and Boushehr provinces of Iran.

Soni, *et al.* (2017) carried out surveys to know the distribution and prevalence of early blight of tomato disease at polyhouse units of Udaipur, Rajsamand, and Chittorgarh districts of southern Rajasthan during the *kharif*. The overall mean disease incidence recorded from 33.94 to 69.28 percent in protected condition (Polyhouse) on different cultivars, respectively. The highest disease incidence in protected condition (polyhouse) was recorded (69.28%) on cultivar Mithili in district Rajsamand (Location-Nandoli) and lowest incidence (33.94%) recorded in district Udaipur (Location- RCA) on cultivar NUN-7711, respectively. Amar and Banyal, (2011) conducted polyhouse surveys during the year 2008–09 and 2009–10 to record occurrence of different diseases of tomato at various locations of Himachal Pradesh. On tomato, early blight was the major disease with high in the polyhouses having light soils. The incidence of collar rot was recorded 10 to 20 percent. Lievens, *et al.* (2004) observed a severe collar/foot rot on two month old wilted tomato (*Lycopersicum esculentum*) plants in a large scale (2.5 ha) commercial greenhouse setting in Belgium.

4.2 Detection and identification of leaf curling causing agent in tomato

4.2.1 Detection of tomato leaf curl virus in field samples

Out of eight sets of primers in four set of DNA (three infected and one check) only two primers viz., AV1 and ToLCV MP were amplified in samples collected from experimental plot in Horticultural Instruction cum Research Farm, College of Agriculture, Raipur and from farmer's fields of Rasni village of Arang Block. With comparison from standard ladder expected annealing position of these primers viz. AV1 and ToLCGVMP amplified DNA fragments of approximately 800 bp and 200 bp, respectively, were obtained from ToLCV infected leaves (Table 4.6, Fig 4.3 and 4.4). The DNA fragment of 800 bp is assumed to contain part of *Begomovirus* genus specific coat protein encoding gene (AV1) as reported by Tiwari *et al.*, (2010). Whereas, 200 bp amplified DNA fragment is assumed to contain part of movement protein encoding gene of *Tomato leaf curl Gujarat virus* (Chakraborty *et al.*, 2003). No PCR amplification was observed for DNA isolated from healthy tomato leaves with all primer sets. Tiwari *et al.* (2010) applied the same set (AV1) of primer for molecular detection and identification of *Tomato leaf*

curl virus (ToLCV) in bitter gourd. An analogous approach was used by Reddy *et al.* (2011) for the detection of ToLCV in tomato. It can be seen that this method is sensitive enough to detect Tomato leaf curl virus in infected tomato leaves and twigs. The present findings confirm the results reported by previous workers (Tiwari *et al.*, 2010 and Chakraborty *et al.*, 2003), therefore it confirms that the PCR amplified product of 800 and 200 bp represent the *Tomato leaf curl virus* genome (Table 4.6, Fig 4.3 and 4.4).

The flexibility of this rapid, PCR based approach allows the detection of *Tomato leaf curl virus* (ToLCV) present in the leaf and twigs. It offers several advantages and has great implications in disease forecasting programmes as well as identification and differentiation of geminivirus species. An early detection of ToLCV either in tomato plants or in vector will facilitate the farmers to design strategies for preventing the disease (Khan, 2000).

4.2.2 Sequencing of selected gene/ ORFs

Amplification of genes was performed on genomic DNA using specifically designed primers against tomato leaf curl virus. PCR fragments thus obtained in this study were gel purified and sent for sequencing. Sequencing of fragment was done on Sanger sequencing platform through Eurofins Genomics India Pvt Ltd. This generates a) 774 b) 735 c) 174 d) 176 bp sequence (Appendix I and J). Then this sequence was analyzed by various *In silico* tool to establish their candidature as tomato leaf curl virus genes.

Homology search of predicted sequences was done by performing BLAST search at NCBI database. The BLAST search revealed highest identity which was presented in table. Obtained results from the BLAST database showed that all the samples have more than 90 percent nucleotide (nt) identities with tomato leaf curl virus (ToLCV) coat protein (CP) and movement protein (MP) gene reported from various geographic locations (Appendix K and L).

The coat protein gene of isolated virus showed 93 to 99 percent nucleotide similarity with *Tomato leaf curl New Delhi virus* isolate ToLCNDV-AVT1 segment DNA A, complete sequence [AY428769.1], *Tomato leaf curl New Delhi*

Table 4.6: PCR detection of ToLCV in the tomato samples collected from different locations

Primer set	Amplification confirmation (+/-) with product size (approx.)			
	1 (Check)	2 (Raipur)	3 (Rasni)	4 (Nisda)
AV 494/ AC 1048	-	-	-	-
PAL1v 1978/ PAR1c 496	-	-	-	-
BGCP F/R	-	-	-	-
AV1 F/R	-	+	+	-
		(~800 bp)	(~800 bp)	
ToLCBVCP F/R	-	-	-	-
ToLCGVMP F/R	-	+	+	-
		(~200 bp)	(~200 bp)	
GAv50/ GAc1122	-	-	-	-
GBv74/ GBc1280	-	-	-	-

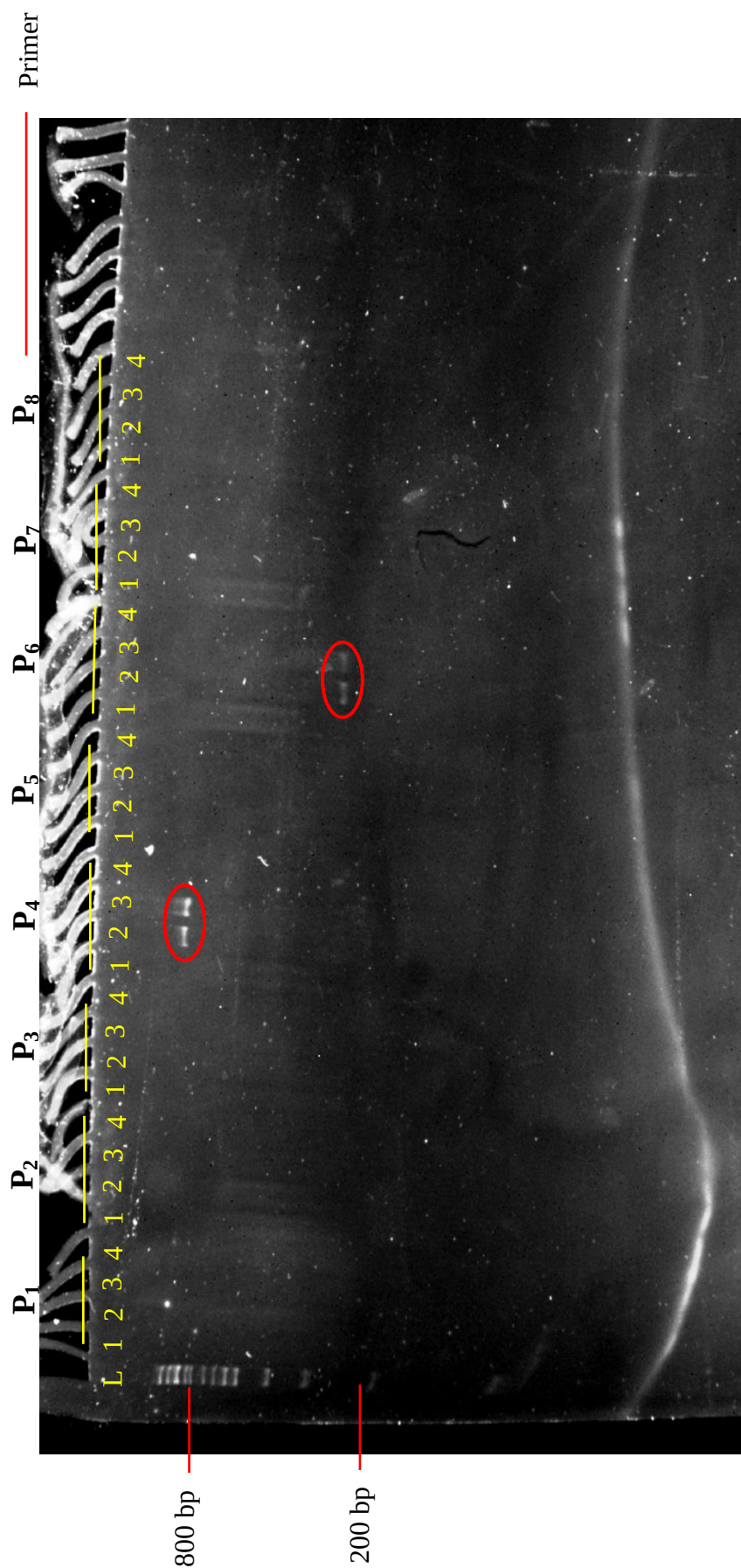


Fig. 4.3: Results of PCR amplification of DNA obtained from healthy and infected samples of tomato leaves against ToLCV. A 5 μ l aliquot of the 10 μ l PCR product was analysed in 5% polyacrylamide gel. L= standard ladder of 100 bp, P₄ = AV1 primer, P₆ = ToLCGVMP primer. Samples of tomato, 1= Check (healthy), 2, 3 and 4= infected samples (2= Raipur, 3= Rasni and 4= Nisda).

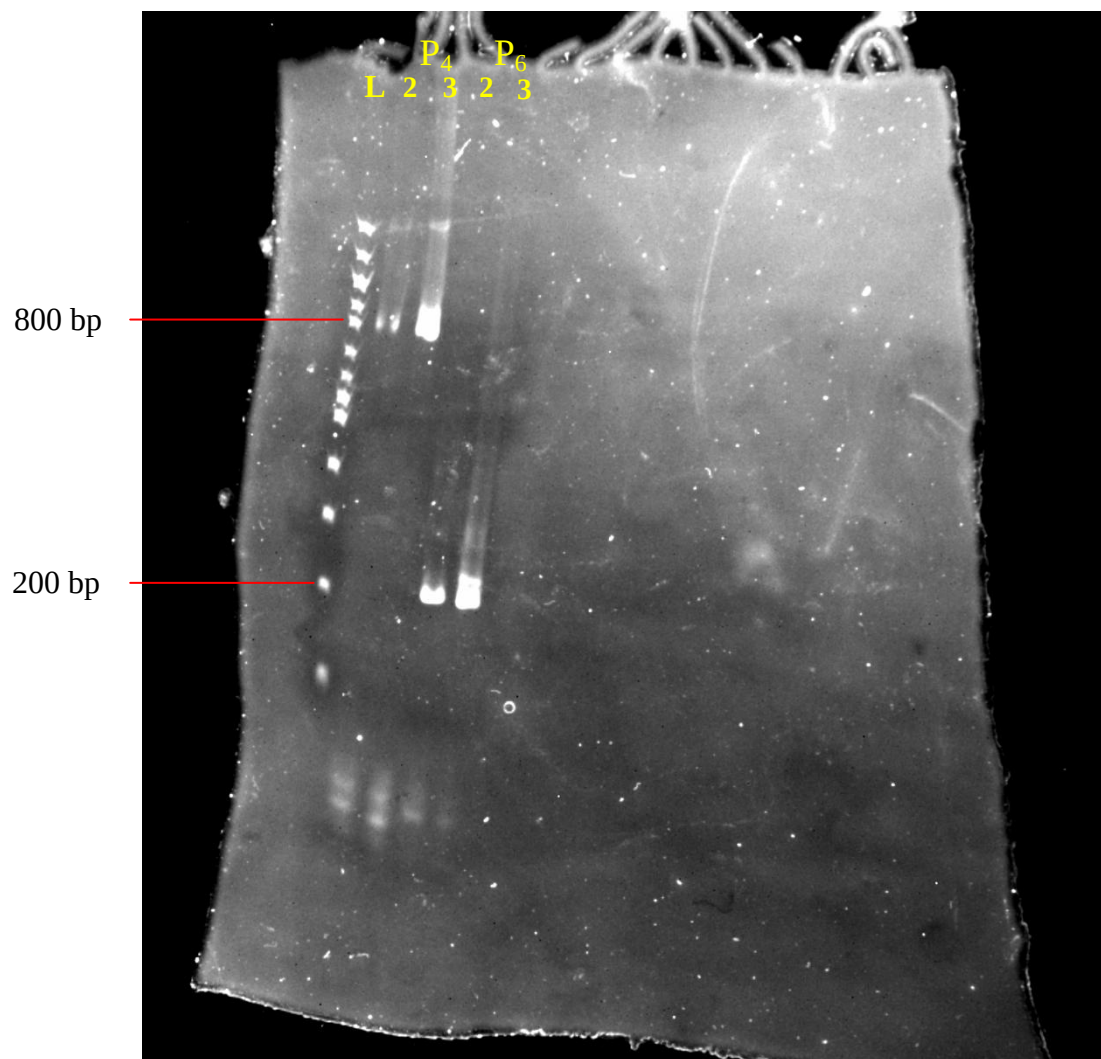


Fig. 4.4: Reconfirmation of amplification of infected samples with primers (P₄ = AV1 and P₆ = ToLCGVMP)

virus isolate India:ToLCNDV-CKTD:2017 segment DNA-A, complete sequence [MF807949.1], *Tomato leaf curl New Delhi virus* isolate begomovirus genome assembly, segment: I [LT556071.1], *Tomato leaf curl New Delhi virus* segment DNA-A, complete sequence [EF068246.1], *Tomato leaf curl New Delhi virus* coat protein (AV1) gene, complete cds [HQ840736.1], *Tomato leaf curl New Delhi virus* segment DNA A, complete sequence [EF620534.1], *Tomato leaf curl virus* AV1 gene for coat protein, isolate 1 [AJ810340.1], *Tomato leaf curl New Delhi virus*-India isolate Lucknow segment DNA-A, complete sequence [KC513822.1], *Tomato leaf curl New Delhi virus* segment A, complete sequence [AY939926.1] and *Tomato leaf curl New Delhi virus* [LN878118.1]. Whereas, movement protein gene of isolated virus shared 97 to 98 percent nucleotide similarity with *Tomato leaf curl New Delhi virus*, segment DNA-B, clone 211B1-10RS232 [LT168887.1], *Tomato leaf curl New Delhi virus*, segment DNA-B, clone 188B1-43RS221 [LT168883.1], *Tomato leaf curl New Delhi virus*, segment DNA-B, clone 295B1-5RS149 [LT168868.1], *Tomato leaf curl New Delhi virus* complete sequence, clone SAZ31 [LN713270.1], *Tomato leaf curl New Delhi virus* [India:Guntur:OY136B:2006] segment DNA-B, complete sequence [GU112087.1], *Tomato leaf curl New Delhi virus*, segment DNA-B, clone 182B3-5RS116 [LT168853.1], *Tomato leaf curl New Delhi virus*-[Lucknow] BR1 gene and BL1 gene [X89653.1], *Tomato leaf curl Gujarat virus* - [Varanasi] segment B, complete sequence [AY190291.1], *Tomato leaf curl Gujarat virus* isolate VIRO 841 segment DNA-B, complete sequence [KU196751.1] and *Tomato leaf curl Gujarat virus* clone VIRO 213 segment DNA-B, complete sequence [KP235538.1].

4.2.3 Phylogenetic analysis

The phylogenetic analysis of ToLCV based on nucleotide sequence of CP from tomato showed a closest relationship with isolates of *Tomato leaf curl New Delhi virus* [AY428769.1, MF807949.1, EF620534.1, AJ810340.1, LN878118.1, LT556071.1, EF068246.1, HQ840736.1, KC513822.1 and AY939926.1]. The nucleotide sequence of MP also showed a closest relationship with isolates of *Tomato leaf curl New Delhi virus* [LT168887.1, LT168883.1, LT168868.1,

LN713270.1, GU112087.1, LT168853.1 and X89653.1] followed by *Tomato leaf curl Gujarat virus* [AY190291.1 and KU196751.1, KP235538.1] (Appendix M).

Since the CP genes are highly conserved region in begomoviruses, it can be used to identify the presence of this genus. According to International Committee on Taxonomy of Viruses (ICTV) begomoviruses can be predicted through CP gene sequences when complete genomic sequences are not available (Kamal *et al.*, 2015). The NCBI-BLAST database search and multiple sequence alignment showed more than 90% sequence similarities with several previously reported ToLCV coat protein (CP) and movement protein genes (Chakraborty *et al.*, 2003 and Tiwari *et al.*, 2010). More than 90% nucleotide sequence identity has been suggested as a guideline for predicting viral strain and less than 90% for distinct begomovirus strain (Kamal *et al.*, 2015 and Rybicki, 1998). The Phylogenetic study and NCBI-BLAST search results for the CP and MP sequences clearly indicates that the isolated virus strain from the infected tomato leaves is ToLCV strain. The constructed phylogenetic tree suggests the closeness and evolutionary relationship among the ToLCVs.

4.3 Epidemiology of tomato leaf curl disease

4.3.1 Epidemiology of tomato leaf curl disease during *Rabi* 2014-15

4.3.1.1 Population of adult whitefly (*B. tabaci*) and incidence of ToLCD

During *Rabi* 2014-15 the first trace of adult whitefly (0.54) was noted at 14 days after transplanting that is 48th Standard meteorological week (SMW). The population of adult whitefly increased up to the 50th SMW (28 DAT) from 0.54 to 1.60. Then its population gradually increased up to 52nd SMW (42 DAT) from 1.60 to 1.80. However, the population slightly declined (1.78) on the 1st SMW (49 DAT) because during this period weather parameters like maximum temperature was lowest (25 °C) with rainfall of 1.3 mm, maximum and minimum relative humidity of 94.7 and 52.4 percent and wind velocity of 4.4 kmph were recorded. The latter phase observation, indicated that the population of whitefly rapidly increased from 3rd SMW (63 DAT) with 2.44 whitefly per ten leaves and reached maximum (6.00) on 8th SMW (91 DAT). Since this period (8th SMW) maximum and minimum temperatures were 33.5 and 15.7 °C, respectively, whereas maximum and minimum relative humidity was 84 and 27.6 percent respectively,

temperature and relative humidity gradient were 17.8 and 56.4 respectively. Further, wind velocity (speed) and sun shine were 2.7 kmph and 9.8 hours, respectively. However, no rainfall was recorded during this period. The population then subsumed slowly up to 10th SMW (105 DAT) (Table 4.7 and Fig 4.7-4.9).

The first incidence of tomato leaf curl disease (ToLCD) was recorded at 46th SMW (7 DAT) with 1.00 and 0.14 percent disease incidence and percent disease index (PDI) respectively. From 48 to 50th SMW (14 to 28 DAT) the leaf curl infection was rapidly increased from 3.72 and 0.91 to 19.16 and 8.70 percent disease incidence and percent disease index respectively. This was then gradually increased from 50th to 2nd SMW (28 to 56 DAT) from 19.16 and 8.70 to 24.82 and 12.48 percent disease incidence and percent disease index respectively. At 3rd SMW (63 DAT) the percent incidence and percent disease index of leaf curl was 28.38 and 17.21 percent which then rapidly increased attaining 77.87 and 56.61 percent incidence and percent disease index at 8th SMW (91 DAT). The maximum incidence (87.66%) and percent disease index (64.68%) was recorded at 10th SMW i.e. 105 DAT (Table 4.7 and Fig 4.7-4.9).

4.3.1.2 Correlation of ToLCD with its vector and weather parameters

A significant negative correlation ($r = -0.567$, $p = 0.001$) was recorded between the adult whitefly population and maximum relative humidity. Whereas other parameters viz. maximum temperature, minimum temperature, temperature gradient, rainfall, minimum relative humidity, wind speed and sun shine showed non significant positive correlation with adult whitefly population. There was non significant negative correlation ($r = -0.365$) between whitefly population and relative humidity gradient (Table 4.8 and Fig 4.7-4.9).

A highly significant positive correlation ($r = 0.976$, $p = 0.001$) was recorded between percent leaf curl incidence and adult whitefly population. Maximum temperature and wind speed showed significant positive correlation ($r = 0.488$ and 0.489 , $p = 0.005$) with percent leaf curl incidence. There was highly significant negative correlation ($r = -0.630$, $p = 0.001$) between percent leaf curl incidence and maximum relative humidity. Other parameters viz. minimum temperature, rainfall, minimum relative humidity and sun shine hours showed non

significant positive correlation with percent leaf curl incidence while temperature and relative humidity gradient exhibited non significant negative effect on percent leaf curl incidence (Table 4.8 and Fig 4.7-4.9).

A highly significant positive correlation was recorded between percent disease index (PDI) and incidence of leaf curl ($r = 0.997$, $p = 0.001$), and PDI and adult whitefly population ($r = 0.968$, $p = 0.001$). PDI of leaf curl illustrated significant positive correlation with maximum temperature ($r = 0.548$, $p = 0.005$) and wind speed ($r = 0.484$, $p = 0.005$). A highly significant negative correlation ($r = -0.665$, $p = 0.001$) was noted between PDI and maximum relative humidity. Whereas rest other parameters exhibited non significant correlation with PDI of leaf curl (Table 4.8 and Fig 4.7-4.9).

4.3.1.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been presented in Table 4.9. The weather parameters were found to contribute around 94.10 percent ($R^2 = 0.941$) impact on population of whitefly (*B. tabaci*) when acted together. Regression also expressed that with every unit increase in rainfall and wind speed there was significant decrease ($b = -1.102$) in whitefly and positive increase ($b = 3.906$) in population of whitefly.

Population of whitefly and weather parameters conjointly caused 96.40 percent ($R^2 = 0.964$) of total change in percent leaf curl incidence. Regression also expressed that with every unit increase in population of whitefly and maximum relative humidity there was significant positive increase of ($b = 16.530$ and 130.247) percent leaf curl incidence but with every unit increase in minimum relative humidity and relative humidity gradient significantly reduce of ($b = -128.076$ and -128.841) percent leaf curl incidence (Table 4.9).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 97.0 percent ($R^2 = 0.970$) effect on percent disease index of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 0.918$) PDI of leaf curl (Table 4.9).

Table 4.7: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (Rabi 2014-15)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
12-18 Nov 2014	46	7	0.14	1.00	0.00	31.4	19.3	12.1	0.0	84.0	35.0	49.0	2.8	6.8
26 Nov - 02 Dec	48	14	0.91	3.72	0.54	30.2	12.5	17.7	0.0	90.0	26.0	64.0	1.9	8.6
03-09 Dec	49	21	4.76	11.55	1.20	28.9	10.8	18.1	0.0	90.0	28.0	62.0	2.2	9.0
10-16 Dec	50	28	8.70	19.16	1.60	28.6	15.8	12.8	0.0	89.0	49.0	40.0	2.3	3.0
17-23 Dec	51	35	9.55	20.92	1.72	25.0	8.3	16.7	0.0	89.0	31.0	58.0	2.2	7.8
24-31 Dec	52	42	10.29	21.95	1.80	26.0	9.9	16.1	0.0	86.0	34.0	52.0	2.2	8.3
01-07 Jan 2015	1	49	11.47	23.5	1.78	25.0	14.8	10.2	1.3	94.7	52.4	42.3	4.4	4.5
08-14 Jan	2	56	12.48	24.82	1.92	25.8	8.0	17.8	0.0	89.9	28.6	61.3	2.2	9.2
15-21 Jan	3	63	17.21	28.38	2.44	26.0	8.3	17.7	0.0	89.7	29.0	60.7	2.2	8.3
29 Jan - 04 Feb	5	70	22.84	35.63	3.36	28.3	11.7	16.7	0.0	88.3	28.9	59.4	2.6	7.6
05-11 Feb	6	77	31.01	46.48	4.08	29.7	14.3	15.3	0.0	84.4	38.7	45.7	2.6	6.4
12-18 Feb	7	84	42.04	61.26	4.98	29.3	13.6	15.7	0.3	88.1	39.3	48.9	3.2	8.2
19-25	8	91	56.61	77.87	6.00	33.5	15.7	17.8	0.0	84.0	27.6	56.4	2.7	9.8
26 Feb - 04 Mar	9	98	61.56	84.40	5.74	30.8	18.5	12.3	2.7	82.6	48.9	33.7	4.2	6.7
05-11 Mar	10	105	64.68	87.66	5.26	31.3	16.6	14.7	0.0	81.3	34.1	47.1	3.0	8.1

SMW= Standard meteorological SMW

Table 4.8: Correlation of tomato leaf curl disease with its vector and weather parameters (*Rabi* 2014-15)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.935 ^{**}	1		
Incidence (%)	0.950 ^{**}	0.997 ^{**}	1	
Whitefly	0.958 ^{**}	0.968 ^{**}	0.976 ^{**}	1
T max (°C)	0.296 ^{NS}	0.548 [*]	0.488 [*]	0.467 ^{NS}
T min (°C)	0.209 ^{NS}	0.439 ^{NS}	0.395 ^{NS}	0.320 ^{NS}
T gr	0.003 ^{NS}	-0.072 ^{NS}	-0.070 ^{NS}	0.017 ^{NS}
Rainfall (mm)	0.344 ^{NS}	0.395 ^{NS}	0.400 ^{NS}	0.352 ^{NS}
RH max (%)	-0.496 [*]	-0.665 ^{**}	-0.630 ^{**}	-0.567 [*]
RH min (%)	0.148 ^{NS}	0.169 ^{NS}	0.193 ^{NS}	0.152 ^{NS}
RH gr	-0.334 ^{NS}	-0.420 ^{NS}	-0.428 ^{NS}	-0.365 ^{NS}
WS (kmph)	0.459 ^{NS}	0.484 [*]	0.489 [*]	0.440 ^{NS}
SS (hr)	0.183 ^{NS}	0.183 ^{NS}	0.166 ^{NS}	0.190 ^{NS}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.9: Regression equation of tomato leaf curl disease with its vector and weather parameters (Rabi 2014-15)

Variables / factors	Whitefly × weather (Wh×w)		Incidence × whitefly and weather (I×Wh ×w)		PDI × incidence, whitefly and weather (P×I×Wh×w)	
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependent variable (Y)	Whitefly			Incidence		
						PDI
Intercept (a)	1.617	0.151	0.886	-74.379	-0.950	0.396
Incidence (X ₁)	-	-	-	-	-	-
Whitefly (X ₂)	-	-	-	16.530**	5.063	0.007**
T max (X ₃)	-4.762	-1.016	0.356	-18.295	-0.487	0.652
T min (X ₄)	4.773	1.016	0.356	18.660	0.496	0.646
T gr (X ₅)	6.290	1.339	0.238	11.882	0.297	0.781
Rainfall (X ₆)	-1.102*	-2.826	0.037*	3.068	0.669	0.540
RH max (X ₇)	1.223	0.244	0.817	130.247*	3.538	0.024*
RH min (X ₈)	-1.457	-0.295	0.780	-128.076*	-3.523	0.024*
RH gr (X ₉)	-1.621	-0.326	0.758	-128.841*	-3.509	0.025*
WS (X ₁₀)	3.906**	5.950	0.002**	-18.666	-1.370	0.242
SS (X ₁₁)	-0.521	-1.557	0.180	7.778	2.612	0.059
Relationship	Regression equation					
(Wh×w)	Y = 1.617 - 4.762X ₃ + 4.773X ₄ + 6.290X ₅ - 1.102X ₆ + 1.223X ₇ - 1.457X ₈ - 1.621X ₉ + 3.906X ₁₀ - 0.521X ₁₁					
(I×Wh ×w)	Y = -74.379 + 16.530X ₂ -18.295X ₃ + 18.660X ₄ + 11.882X ₅ + 3.068X ₆ + 130.247X ₇ -128.076X ₈ -128.841X ₉ -18.666X ₁₀ + 7.778X ₁₁					
(P×I×Wh×w)	Y = 11.745 + 0.918X ₁ -2.606X ₂ + 8.621X ₃ -8.130X ₄ -7.707X ₅ + 0.561X ₆ -21.890X ₇ + 21.274X ₈ + 21.696X ₉ + 2.834X ₁₀ -1.455X ₁₁					
						R²
						0.941
						0.964
						0.970

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

4.3.2 Epidemiology of Tomato leaf curl disease during *Rabi* 2015-16

4.3.2.1 Population of adult whitefly (*B. tabaci*) and incidence of ToLCD

In *Rabi* 2015-16, the first trace of adult whitefly (0.40) was noted at 47th Standard meteorological week (SMW) i.e. 14 days after transplanting (DAT). From 49th to 51st SMW the number of adult whitefly was slightly declined but slightly increased at 52nd SMW (0.92) then again reduced at 1st SMW (0.84). The number then increased rapidly up to 7th SMW (84 DAT) from 0.90 to 5.40 and reached maximum (6.78) up to 8th SMW (91 DAT). Since this period (8th SMW) the maximum and minimum temperature was 34.9 and 18.9 °C respectively, whereas maximum and minimum relative humidity was 71.3 and 29.0 percent respectively, temperature and relative humidity gradient was 16.0 and 42.3 respectively. Further, wind velocity (speed) and sun shine were 3.0 kmph and 7.2 hours respectively. However, no rainfall was recorded during this period. The population then subsided slowly up to 10th SMW (105 DAT) (Table 4.10 and Fig 4.10-4.12).

The first trace of tomato leaf curl disease (ToLCD) was noted at 47th SMW (14 days after transplanting) with percent leaf curl incidence and index of 1.33 and 0.38. From 47th to 50th SMW (14 – 28 DAT) the extent of leaf curl infection was rapidly increased from 1.33 and 0.38 to 14.21 and 6.29 percent disease incidence and percent disease index respectively. This was then subsided and gradually increased from 50th to 3rd SMW (28 – 63 DAT) from 14.21 and 6.29 to 31.20 and 19.18 percent disease incidence and PDI respectively. At 5th SMW (70 DAT) the percent incidence and PDI of leaf curl was 36.96 and 24.39 percent which then increased rapidly attaining 75.34 and 54.59 percent incidence and PDI at 8th SMW (91 DAT). The maximum incidence (80.41%) and PDI (61.71%) was recorded at 10th SMW, 105 days after transplanting (Table 4.10 and Fig 4.10-4.12).

4.3.2.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly for *Rabi* 2015-16 has been summarised in Table 4.11. It was revealed from the data that maximum temperature ($r = 0.726$, $p = 0.001$), minimum temperature ($r = 0.641$, $p = 0.001$) and wind speed ($r = 0.689$, $p = 0.001$) expressed

highly significant positive correlation with whitefly population but maximum relative humidity ($r = -0.750$, $p = 0.001$) showed highly significant negative correlation. Other parameters viz. temperature gradient, rainfall, minimum relative humidity, relative humidity gradient and sun shine showed non significant negative correlation with adult whitefly population (Table 4.11 and Fig 4.10-4.12).

There was highly significant positive correlation with percent leaf curl incidence and whitefly population ($r = 0.972$, $p = 0.001$), maximum temperature ($r = 0.668$, $p = 0.001$) and wind speed ($r = 0.701$, $p = 0.001$) but negative with maximum relative humidity ($r = -0.740$, $p = 0.001$). Rest other parameters viz. temperature gradient, rainfall, minimum relative humidity, relative humidity gradient and sun shine exhibited non significant negative correlation with percent leaf curl incidence (Table 11 and Fig 4.10-4.12).

A highly significant positive correlation was recorded between percent disease index and incidence ($r = 0.997$, $p = 0.001$), adult whitefly population ($r = 0.975$, $p = 0.001$), maximum temperature ($r = 0.711$, $p = 0.001$), minimum temperature ($r = 0.642$, $p = 0.001$) and wind speed ($r = 0.716$, $p = 0.001$) but found negative with maximum relative humidity ($r = -0.737$, $p = 0.001$). Whereas rest other parameters viz. temperature gradient, rainfall, minimum relative humidity, relative humidity gradient and sun shine exhibited non significant correlation with percent disease index of leaf curl (Table 4.11 and Fig 4.10-4.12).

4.3.2.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters for *Rabi* 2015-16 have been depicted in Table 4.12. None of the weather parameters independently put significant influence on population of whitefly but found to contribute around 91.70 percent ($R^2 = 0.917$) impact on population of whitefly (*B. tabaci*) when acted together.

Population of whitefly and weather parameters studied, taken together were responsible for 94.80 percent ($R^2 = 0.948$) of total change in percent leaf curl incidence. Regression also expressed that with every unit increase in population of

Table 4.10: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Rabi* 2015-16)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
12-18 Nov 2015	46	7	0.00	0.00	0.00	31.7	16.3	15.4	0.0	88.9	32.9	56.0	2.4	7.5
19-25 Nov	47	14	0.38	1.33	0.40	30.6	15.5	15.1	0.0	88.1	36.1	52.0	2.8	8.3
03-09 Dec	49	21	3.87	9.69	0.82	31.2	14.8	16.5	0.0	88.1	31.0	57.1	2.3	8.0
10-16 Dec	50	28	6.29	14.21	0.72	30.1	17.3	12.8	0.6	77.4	46.0	31.4	2.9	4.3
17 -23 Dec	51	35	8.30	17.30	0.68	27.7	16.6	11.1	1.3	85.0	51.9	33.1	3.1	2.0
24-30 Dec	52	42	9.08	18.67	0.92	26.3	10.7	15.6	0.0	86.4	29.7	56.7	2.5	5.8
31 Dec – 6 Jan 2016	1	49	13.00	23.05	0.84	30.5	12.0	18.5	0.0	81.9	26.9	55.0	2.0	8.0
07-13 Jan	2	56	16.00	27.81	0.90	29.5	11.1	18.4	0.0	87.1	26.6	60.6	2.4	7.5
14-20 Jan	3	63	19.18	31.20	1.86	28.0	14.6	13.4	0.3	87.6	47.7	39.9	3.3	4.2
28 Jan – 3 Feb	5	70	24.39	36.96	2.90	31.5	14.0	17.5	0.0	85.6	31.9	53.7	2.7	8.5
04-10 Feb	6	77	33.92	49.53	4.50	31.0	13.2	17.7	0.0	78.0	30.0	48.0	3.1	9.0
11-17 Feb	7	84	47.31	65.82	5.40	32.3	19.5	12.8	0.0	79.4	41.1	38.3	3.2	5.3
18-24 Feb	8	91	54.59	75.34	6.78	34.9	18.9	16.0	0.0	71.3	29.0	42.3	3.0	7.2
25 Feb – 2 Mar	9	98	58.62	79.07	6.14	33.1	20.8	12.3	0.0	82.1	40.1	42.0	3.5	3.0
03-09 Mar	10	105	61.71	80.41	5.70	35.1	20.5	14.7	0.1	73.3	26.7	46.6	3.8	7.7

SMW = Standard meteorological SMW

Table 4.11: Correlation of tomato leaf curl disease with its vector and weather parameters (*Rabi* 2015-16)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.956**	1		
Incidence (%)	0.971**	0.997**	1	
Whitefly	0.917**	0.975**	0.972**	1
T max (°C)	0.546*	0.711**	0.668**	0.726**
T min (°C)	0.439 ^{NS}	0.642**	0.603*	0.641**
T gr	-0.039 ^{NS}	-0.149 ^{NS}	-0.140 ^{NS}	-0.134 ^{NS}
Rainfall (mm)	-0.236 ^{NS}	-0.256 ^{NS}	-0.234 ^{NS}	-0.285 ^{NS}
RH max (%)	-0.672**	-0.737**	-0.740**	-0.750**
RH min (%)	-0.173 ^{NS}	-0.161 ^{NS}	-0.148 ^{NS}	-0.146 ^{NS}
RH gr	-0.256 ^{NS}	-0.306 ^{NS}	-0.320 ^{NS}	-0.328 ^{NS}
WS (kmph)	0.664**	0.716**	0.701**	0.689**
SS (hr)	-0.057 ^{NS}	-0.071 ^{NS}	-0.095 ^{NS}	-0.023 ^{NS}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.12: Regression equation of tomato leaf curl disease with its vector and weather parameters (Rabi 2015-16)

Variables / factors	Whitefly × weather (Wh×w)			Incidence × whitefly and weather (I×Wh ×w)			PDI × incidence, whitefly and weather (P×I×Wh×w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	-13.106	-0.712	0.508	-31.477	-0.327	0.760	-24.658	-2.900	0.063
Incidence (X ₁)	-	-	-	-	-	-	0.788**	18.111	0.001**
Whitefly (X ₂)	-	-	-	8.971*	4.019	0.016*	-0.917	-2.102	0.126
T max (X ₃)	6.576	0.719	0.504	-50.056	-1.045	0.355	15.474*	3.287	0.046*
T min (X ₄)	-6.170	-0.681	0.526	50.293	1.065	0.347	-14.657	-3.145	0.051
T gr (X ₅)	-5.575	-0.601	0.574	54.820	1.144	0.316	-15.661*	-3.259	0.047*
Rainfall (X ₆)	-2.087	-1.277	0.258	-3.084	-0.328	0.759	-0.283	-0.342	0.755
RH max (X ₇)	11.212	0.719	0.504	-44.604	-0.546	0.614	13.512	1.831	0.164
RH min (X ₈)	-11.331	-0.727	0.500	44.006	0.538	0.619	-13.577	-1.841	0.163
RH gr (X ₉)	-11.304	-0.726	0.500	44.284	0.542	0.616	-13.348	-1.812	0.168
WS (X ₁₀)	2.805	2.509	0.054	13.330	1.589	0.187	1.947	2.087	0.128
SS (X ₁₁)	-0.773	-1.915	0.114	-5.371	-2.024	0.113	0.319	0.969	0.404
Relationship (Wh×w)	Regression equation								
(I×Wh ×w)	Y = -13.106 + 6.576X ₃ - 6.170X ₄ - 5.575X ₅ - 2.087X ₆ + 11.212X ₇ - 11.331X ₈ - 11.304X ₉ + 2.805X ₁₀ - 0.773X ₁₁								
(P×I×Wh×w)	Y = -31.477 + 8.971X ₂ - 50.056X ₃ + 50.293X ₄ + 54.820X ₅ - 3.084X ₆ - 44.604X ₇ + 44.006X ₈ + 44.284X ₉ + 13.330X ₁₀ - 5.371X ₁₁								
	Y = -24.658 + 0.788X ₁ - 0.917X ₂ + 15.474X ₃ - 14.657X ₄ - 15.661X ₅ - 0.283X ₆ + 13.512X ₇ - 13.577X ₈ - 13.348X ₉ + 1.947X ₁₀ + 0.319X ₁₁								
	R²								
	0.917								
	0.948								
	0.952								

Significance: Highly significant (***) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

whitefly there was significant positive increase of ($b = 8.971$) percent leaf curl incidence (Table 4.12).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 95.20 percent ($R^2 = 0.952$) effect on percent disease index of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence and maximum temperature there was significant positive increase of ($b = 0.788$ and 15.474) percent disease index of leaf curl. However there was significant reduction was observed in percent disease index of leaf curl by ($b = -15.661$) with every unit increase of temperature gradient (Table 4.12).

4.3.3 Epidemiology of Tomato leaf curl disease during *Rabi* 2016-17

4.3.3.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

In *Rabi* 2016-17 the first trace of adult whitefly (0.18) was recorded at about 47th standard meteorological week (SMW) i.e. 7 days after transplanting (DAT) and rapidly increased up to 1st SMW (4.00). At 3th SMW (56 DAT) the number of adult whitefly was 4.24 which then rapidly increased attaining 7.06 at 6th SMW (77 DAT) and reached maximum (7.40) up to 7th SMW (84 DAT). During this period (7th SMW) maximum and minimum temperature was 31.2 and 16.2 °C respectively, whereas maximum and minimum relative humidity was 79.6 and 34.3 percent respectively, temperature and relative humidity gradient was 15.0 and 45.3 respectively. Further, wind velocity (speed) and sun shine were 2.6 kmph and 6.4 hours respectively. However, 0.8 mm rainfall was recorded during this period. The population then subsided slowly up to 11th SMW (105 DAT) (Table 4.13 and Fig 4.13-4.15).

The first trace of tomato leaf curl disease (ToLCD) was noted at 47th SMW, 7 days after transplanting with percent leaf curl incidence and percent disease index of 1.67 and 0.81 percent respectively and slowly increased up to 48th SMW (4.69% and 2.39%). From 48th to 50th SMW (14 to 28 DAT) the extent of leaf curl infection was slightly rapid increased from 4.69 and 2.39 to 16.90 and 9.27 percent disease incidence and PDI respectively. This was then gradually increased from 50th to 52nd SMW (28 to 42 DAT) from 16.90 and 9.27 to 22.99 and 13.24 percent

disease incidence and PDI respectively. Thereafter it was rapidly increased and attained 83.19 and 64.37 percent incidence and PDI at 7th SMW. The maximum incidence (88.59%) and PDI (69.47%) was recorded at 11th SMW, 105 days after transplanting (Table 4.13 and Fig 4.13-4.15).

4.3.3.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly for the year 2016-17 (*Rabi*) has been summarised in Table 4.14. It was revealed from the data that maximum and minimum temperature exhibited significant positive correlation with whitefly population with correlation coefficient (r) of 0.575 and 0.532 respectively but maximum relative humidity showed significant negative correlation ($r = -0.595$, $p = 0.001$). A highly significant positive correlation was recorded between whitefly population and wind speed ($r = 0.635$, $p = 0.001$). Other parameters viz. temperature gradient, minimum relative humidity and relative humidity gradient showed non significant negative correlation with adult whitefly population but rainfall and sun shine expressed non significant positive correlation (Table 4.14 and Fig 4.13-4.15).

There was highly significant positive correlation was noted with percent leaf curl incidence and whitefly population ($r = 0.956$, $p = 0.001$), maximum temperature ($r = 0.726$, $p = 0.001$), minimum temperature ($r = 0.677$, $p = 0.001$) and wind speed ($r = 0.761$, $p = 0.001$) but negative with maximum relative humidity ($r = -0.789$, $p = 0.001$). A significant negative correlation was observed between percent leaf curl incidence and relative humidity gradient ($r = -0.565$, $p = 0.005$). The non significant negative correlation was recorded of percent leaf curl incidence with temperature gradient and minimum relative humidity but rainfall and sun shine expressed non significant positive correlation (Table 4.14 and Fig 4.13-4.15).

The highly significant positive correlation was recorded with percent disease index and incidence of leaf curl ($r = 0.999$, $p = 0.001$), adult whitefly population ($r = 0.946$, $p = 0.001$), maximum temperature ($r = 0.753$, $p = 0.001$), minimum temperature ($r = 0.696$, $p = 0.001$) and wind speed ($r = 0.764$, $p = 0.001$) but found negative with maximum relative humidity ($r = -0.798$, $p = 0.001$). A

Table 4.13: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Rabi* 2016-17)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH	WS (kmph)	SS (hr)
18-24 Nov	47	7	0.81	1.67	0.18	29.7	11.5	18.1	0.0	88.4	25.1	63.3	1.1	8.6
25 Nov - 01 Dec	48	14	2.39	4.69	0.44	31.0	12.4	18.6	0.0	87.0	25.4	61.6	1.0	9.0
02-08 Dec	49	21	5.84	11.38	0.88	29.0	14.6	14.3	0.0	89.4	39.9	49.6	1.7	7.3
09-15 Dec	50	28	9.27	16.90	1.70	28.7	12.1	16.6	0.0	84.6	30.1	54.4	1.8	7.9
16-22 Dec	51	35	10.74	18.95	2.18	27.7	8.9	18.8	0.0	87.1	23.9	63.3	1.5	8.4
23-29 Dec	52	42	13.24	22.99	2.64	27.8	9.5	18.4	0.0	85.4	26.3	59.1	1.2	7.6
30 Dec - 05 Jan 2017	1	49	21.77	33.46	4.00	29.0	12.1	16.9	0.0	89.7	33.9	55.9	1.6	6.4
13-19 Jan	3	56	28.96	41.89	4.24	27.7	10.5	17.3	0.0	83.1	26.0	57.1	1.2	8.2
20-26 Jan	4	63	40.44	54.44	5.16	29.8	13.2	16.6	0.0	84.3	28.3	56.0	2.0	8.7
27 Jan - 02 Feb	5	70	48.12	63.85	5.70	29.9	13.3	16.6	0.0	79.0	27.7	51.3	1.5	8.0
03-09 Feb	6	77	59.85	77.41	7.06	31.6	12.9	18.7	0.0	83.9	24.3	59.6	1.9	9.6
10-16 Feb	7	84	64.37	83.19	7.40	31.2	16.2	15.0	0.8	79.6	34.3	45.3	2.6	6.4
17-23 Feb	8	91	67.06	86.56	6.74	33.9	15.3	18.6	0.0	75.0	18.1	56.9	2.5	10.2
24 Feb - 02 Mar	9	98	68.80	87.91	6.04	33.5	14.5	19.0	0.0	68.3	15.3	53.0	2.0	10.1
10-16 Mar	11	105	69.47	88.59	5.52	32.2	17.2	15.0	0.0	60.9	21.4	39.4	3.5	8.3

Table 4.14: Correlation of tomato leaf curl disease with its vector and weather parameters (Rabi 2016-17)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.979**	1		
Incidence (%)	0.985**	0.999**	1	
Whitefly	0.931**	0.946**	0.956**	1
T max (°C)	0.668**	0.753**	0.726**	0.575*
T min (°C)	0.632**	0.696**	0.677**	0.532*
T gr	-0.087 ^{NS}	-0.080 ^{NS}	-0.084 ^{NS}	-0.055 ^{NS}
Rainfall (mm)	0.247 ^{NS}	0.313 ^{NS}	0.311 ^{NS}	0.379 ^{NS}
RH max (%)	-0.832**	-0.798**	-0.789**	-0.595*
RH min (%)	-0.460 ^{NS}	-0.446 ^{NS}	-0.433 ^{NS}	-0.301 ^{NS}
RH gr	-0.592*	-0.563*	-0.565*	-0.450 ^{NS}
WS (kmph)	0.773**	0.764**	0.761**	0.635**
SS (hr)	0.276 ^{NS}	0.331 ^{NS}	0.309 ^{NS}	0.189 ^{NS}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.15: Regression equation of tomato leaf curl disease with its vector and weather parameters (Rabi 2016-17)

Variables / factors	Whitefly × weather (Wh×w)			Incidence × whitefly and weather (I×Wh ×w)			PDI × incidence, whitefly and weather (P×I×Wh×w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	-23.731	-0.825	0.447	53.463	2.477	0.068	-6.989	-0.312	0.775
Incidence (X ₁)	-	-	-	-	-	-	0.939	2.882	0.063
Whitefly (X ₂)	-	-	-	9.584**	30.441	0.000**	-1.357	-0.434	0.694
T max (X ₃)	-22.686	-1.361	0.232	20.656	1.504	0.207	10.052	0.898	0.436
T min (X ₄)	22.986	1.339	0.238	-20.058	-1.424	0.228	-9.609	-0.853	0.456
T gr (X ₅)	23.606	1.477	0.200	-19.128	-1.419	0.229	-10.710	-0.994	0.393
Rainfall (X ₆)	2.991	0.740	0.492	2.749	0.917	0.411	1.842	0.858	0.454
RH max (X ₇)	-10.347	-0.817	0.451	-18.792	-1.979	0.119	7.362	0.846	0.460
RH min (X ₈)	10.516	0.837	0.441	17.952	1.901	0.130	-7.461	-0.879	0.444
RH gr (X ₉)	10.206	0.803	0.459	17.255	1.814	0.144	-7.038	-0.841	0.462
WS (X ₁₀)	1.809	0.954	0.384	1.230	0.847	0.445	-1.403	-1.365	0.266
SS (X ₁₁)	0.927	0.607	0.571	3.007	2.698	0.054	-0.486	-0.398	0.717
Relationship (Wh×w)	Regression equation								
	Y = -23.731 - 22.686X ₃ + 22.986 X ₄ + 23.606 X ₅ + 2.991 X ₆ - 10.347 X ₇ + 10.516 X ₈ + 10.206 X ₉ + 1.809 X ₁₀ + 0.927 X ₁₁								
(I×Wh ×w)	Y = 53.463 + 9.584X ₂ + 20.656 X ₃ - 20.058 X ₄ - 19.128 X ₅ + 2.749 X ₆ - 18.792 X ₇ + 17.952 X ₈ + 17.255 X ₉ + 1.230 X ₁₀ + 3.007 X ₁₁								
(P×I×Wh×w)	Y = -6.989 + 0.939X ₁ - 1.357X ₂ + 10.052X ₃ - 9.609X ₄ - 10.710X ₅ + 1.842X ₆ + 7.362X ₇ - 7.461X ₈ - 7.038X ₉ - 1.403X ₁₀ - 0.486X ₁₁								
	R²								
	0.744								
	0.889								
	0.902								

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

significant negative correlation was observed between leaf curl PDI and relative humidity gradient ($r = -0.563$, $p = 0.005$). The non significant negative correlation was recorded of leaf curl PDI with temperature gradient and minimum relative humidity but rainfall and sun shine showed non significant positive correlation (Table 4.14 and Fig 4.13-4.15).

4.3.3.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been presented in Table 4.15. None of the weather parameters independently did not put significant influence on population of whitefly but found to contribute around 74.40 percent ($R^2 = 0.744$) impact on population of whitefly (*B. tabaci*) when acted together.

Population of whitefly and weather parameters studied, taken together were responsible for 88.90 percent ($R^2 = 0.889$) of total change in percent leaf curl incidence. Regression also expressed that with every unit increase in population of whitefly there was significant positive increase of ($b = 9.584$) percent leaf curl incidence.

None of the parameters independently did not put significant influence on percent disease index (PDI) of leaf curl but found to contribute 90.20 percent ($R^2 = 0.902$) impact on leaf curl PDI when acted together.

4.3.4 Epidemiology of Tomato leaf curl disease during Rabi 2014-15 to 2016-17

4.3.4.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

The first trace of adult whitefly (0.06) was recorded at about 7 days after transplanting (DAT) and rapidly increased up to 28 DAT (1.34) during Rabi 2014-15 to 2016-17. From 28 to 56 DAT the number of adult whitefly was slowly increased from 1.34 to 2.35 however at 49 DAT (2.21) it was rapidly increased. From 63 to 84 DAT the number of adult whitefly was rapidly increased from 3.15 to 5.93 and reached maximum (6.51) up to 91 DAT. During this period maximum and minimum temperature was 34.1 and 16.6 °C respectively, whereas maximum and minimum relative humidity was 76.8 and 24.9 percent respectively, temperature and relative humidity gradient was 17.5 and 51.9 respectively. Further,

wind velocity (speed) and sun shine were 2.7 kmph and 9.1 hours respectively. However, no rainfall was recorded during this period. The population then subsumed rapidly up to 105 DAT (Table 4.16 and Fig 4.16-4.18).

The first trace of tomato leaf curl disease (ToLCD) was noted at 7 days after transplanting with percent disease incidence and index (PDI) of 0.89 and 0.32. The percent leaf curl incidence was rapidly increased from 14 (3.25%) to 28 DAT (16.76%) then reduced and gradually increased from 28 to 56 DAT (31.51%). Thereafter it was increased rapidly up to 91 DAT (79.92%) then subsumed and reached maximum (85.55%) at 105 days after transplanting (whereas percent disease index of leaf curl was slowly increased from 7 (0.32%) to 42 DAT (10.87%) then rapidly increased from 56 (19.15%) to 91 DAT (59%) and subsumed with attaining maximum (65.29%) at 105 DAT Table 4.16 and Fig 4.16-4.18).

4.3.4.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly has been depicted in Table 4.17. It was revealed from the data that maximum temperature and wind speed exhibited highly significant positive correlation with whitefly population with correlation coefficient (r) of 0.623 and 0.791 but negative with maximum relative humidity ($r = -0.802$, $p = 0.001$). A significant positive and negative correlation was observed for percent leaf curl incidence with minimum temperature ($r = 0.540$, $p = 0.005$) and relative humidity gradient ($r = -0.546$, $p = 0.005$) respectively. While other parameters viz. temperature gradient and minimum relative humidity showed non significant negative correlation with adult whitefly population but rainfall and sun shine expressed non significant positive correlation (Table 4.17 and Fig 4.16-4.18).

There was highly significant positive correlation was noted with percent leaf curl incidence and whitefly population ($r = 0.981$, $p = 0.001$), maximum temperature ($r = 0.649$, $p = 0.001$), and wind speed ($r = 0.853$, $p = 0.001$) but negative with maximum relative humidity ($r = -0.875$, $p = 0.001$). A significant positive and negative correlation was observed of percent leaf curl incidence with minimum temperature ($r = 0.600$, $p = 0.005$) and relative humidity gradient ($r = -0.593$, $p = 0.005$) respectively. While other parameters viz. temperature gradient

and minimum relative humidity showed non significant negative correlation with percent leaf curl incidence but rainfall and sun shine expressed non significant positive correlation (Table 4.17 and Fig 4.16-4.18).

The highly significant positive correlation was recorded with leaf curl PDI and incidence ($r = 0.998$, $p = 0.001$), adult whitefly population ($r = 0.975$, $p = 0.001$), maximum temperature ($r = 0.693$, $p = 0.001$), minimum temperature ($r = 0.640$, $p = 0.001$) and wind speed ($r = 0.858$, $p = 0.001$) but found negative with maximum relative humidity ($r = -0.888$, $p = 0.001$). A significant negative correlation was observed between percent disease index of leaf curl and relative humidity gradient ($r = -0.586$, $p = 0.005$). The non significant negative correlation was recorded for PDI with temperature gradient and minimum relative humidity and positive with rainfall and sun shine (Table 4.17 and Fig 4.16-4.18).

4.3.4.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been presented in Table 4.18. None of the weather parameters independently indicated significant influence on population of whitefly but found to contribute around 88.80 percent ($R^2 = 0.888$) impact on population of whitefly (*B. tabaci*) when acted together.

Population of whitefly and weather parameters studied, taken together were responsible for 92.60 percent ($R^2 = 0.926$) of total change in percent leaf curl incidence. Regression also expressed that with every unit increase in population of whitefly there was significant positive increase of ($b = 9.200$) percent leaf curl incidence.

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 94.0 percent ($R^2 = 0.940$) effect on PDI of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 0.719$) leaf curl PDI.

The present findings are more or less in agreement with the findings of Chakraborty (2012) the first trace of *B. tabaci* population was noted at about 48 SMW (0.15 ± 0.02 individual's leaf⁻¹). The number then increased gradually in the early season up 52 SMW (0.37 ± 0.04 individuals leaf⁻¹), reached a peak at 6 SMW

Table 4.16: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Rabi* 2014-15 to 2016-17)

DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
7	0.32	0.89	0.06	30.9	15.7	15.2	0.0	87.1	31.0	56.1	2.1	7.6
14	1.23	3.25	0.46	30.6	13.5	17.1	0.0	88.4	29.2	59.2	1.9	8.6
21	4.82	10.87	0.97	29.7	13.4	16.3	0.0	89.2	33.0	56.2	2.1	8.1
28	8.09	16.76	1.34	29.1	15.1	14.1	0.2	83.7	41.7	41.9	2.3	5.1
35	9.53	19.06	1.53	26.8	11.3	15.5	0.4	87.0	35.6	51.5	2.3	6.1
42	10.87	21.20	1.79	26.7	10.0	16.7	0.0	85.9	30.0	55.9	2.0	7.2
49	15.41	26.67	2.21	28.2	13.0	15.2	0.4	88.8	37.7	51.1	2.7	6.3
56	19.15	31.51	2.35	27.7	9.9	17.8	0.0	86.7	27.1	59.7	1.9	8.3
63	25.61	38.01	3.15	27.9	12.0	15.9	0.1	87.2	35.0	52.2	2.5	7.1
70	31.78	45.48	3.99	29.9	13.0	16.9	0.0	84.3	29.5	54.8	2.3	8.0
77	41.59	57.81	5.21	30.8	13.5	17.2	0.0	82.1	31.0	51.1	2.5	8.3
84	51.24	70.09	5.93	30.9	16.4	14.5	0.4	82.4	38.2	44.2	3.0	6.6
91	59.42	79.92	6.51	34.1	16.6	17.5	0.0	76.8	24.9	51.9	2.7	9.1
98	62.99	83.79	5.97	32.5	17.9	14.5	0.9	77.7	34.8	42.9	3.2	6.6
105	65.29	85.55	5.49	32.9	18.1	14.8	0.0	71.8	27.4	44.4	3.4	8.0

Table 4.17: Correlation of tomato leaf curl disease with its vector and weather parameters (Rabi 2014-15 to 2016-17)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.971 ^{**}	1		
Incidence (%)	0.982 ^{**}	0.998 ^{**}	1	
Whitefly	0.966 ^{**}	0.975 ^{**}	0.981 ^{**}	1
T max (°C)	0.523 [*]	0.693 ^{**}	0.649 ^{**}	0.623 ^{**}
T min (°C)	0.465 ^{NS}	0.640 ^{**}	0.600 [*]	0.540 [*]
T gr	-0.061 ^{NS}	-0.128 ^{NS}	-0.121 ^{NS}	-0.040 ^{NS}
Rainfall (mm)	0.287 ^{NS}	0.307 ^{NS}	0.319 ^{NS}	0.286 ^{NS}
RH max (%)	-0.817 ^{**}	-0.888 ^{**}	-0.875 ^{**}	-0.802 ^{**}
RH min (%)	-0.216 ^{NS}	-0.229 ^{NS}	-0.208 ^{NS}	-0.187 ^{NS}
RH gr	-0.535 [*]	-0.586 [*]	-0.593 [*]	-0.546 [*]
WS (kmph)	0.816 ^{**}	0.858 ^{**}	0.853 ^{**}	0.791 ^{**}
SS (hr)	0.157 ^{NS}	0.195 ^{NS}	0.166 ^{NS}	0.191 ^{NS}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.18: Regression equation of tomato leaf curl disease with its vector and weather parameters (Rabi 2014-15 to 2016-17)

Variables / factors	Whitefly × weather (Wh×w)			Incidence × whitefly and weather (I×Wh ×w)			PDI × incidence, whitefly and weather (P×I×Wh×w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	-7.924	-0.298	0.778	141.424	1.788	0.148	5.010	0.173	0.873
Incidence (X ₁)	-	-	-	-	-	-	0.719*	5.278	0.013*
Whitefly (X ₂)	-	-	-	9.200**	6.972	0.002**	0.995	0.763	0.501
T max (X ₃)	-3.248	-0.309	0.770	-51.751	-1.651	0.174	10.910	0.985	0.397
T min (X ₄)	3.304	0.311	0.768	50.094	1.585	0.188	-10.753	-0.978	0.400
T gr (X ₅)	4.654	0.433	0.683	48.806	1.512	0.205	-12.950	-1.174	0.325
Rainfall (X ₆)	-0.814	-0.409	0.699	10.990	1.843	0.139	3.388	1.533	0.223
RH max (X ₇)	-23.443	-1.481	0.199	-3.825	-0.068	0.949	33.737	2.208	0.114
RH min (X ₈)	23.361	1.485	0.198	2.517	0.045	0.966	-33.744	-2.222	0.113
RH gr (X ₉)	23.114	1.468	0.202	2.298	0.041	0.969	-33.519	-2.212	0.114
WS (X ₁₀)	3.063	1.702	0.149	7.679	1.151	0.314	-1.888	-0.900	0.435
SS (X ₁₁)	-0.011	-0.008	0.994	5.325	1.319	0.258	1.940	1.471	0.238
Relationship	Regression equation								
(Wh×w)	Y = -7.924 - 3.248X ₃ + 3.304 X ₄ + 4.654 X ₅ - 0.814 X ₆ - 23.443 X ₇ + 23.361 X ₈ + 23.114 X ₉ + 3.063 X ₁₀ - 0.011 X ₁₁								
(I×Wh ×w)	Y = 141.424 + 9.200X ₂ - 51.751X ₃ + 50.094X ₄ + 48.806X ₅ + 10.990X ₆ - 3.825X ₇ + 2.517X ₈ + 2.298X ₉ + 7.679X ₁₀ + 5.325X ₁₁								
(P×I×Wh×w)	Y = 5.010 + 0.719X ₁ + 0.995X ₂ + 10.910X ₃ - 10.753X ₄ - 12.950X ₅ + 3.388X ₆ + 33.737X ₇ - 33.744X ₈ - 33.519X ₉ - 1.888 X ₁₀ + 1.940 X ₁₁								
	R²								
	0.888								
	0.926								
	0.940								

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)



Fig 4.5: Experimental plots for epidemiology study in *Kharif*



Fig 4.6: Experimental plots for epidemiology study in *Rabi*

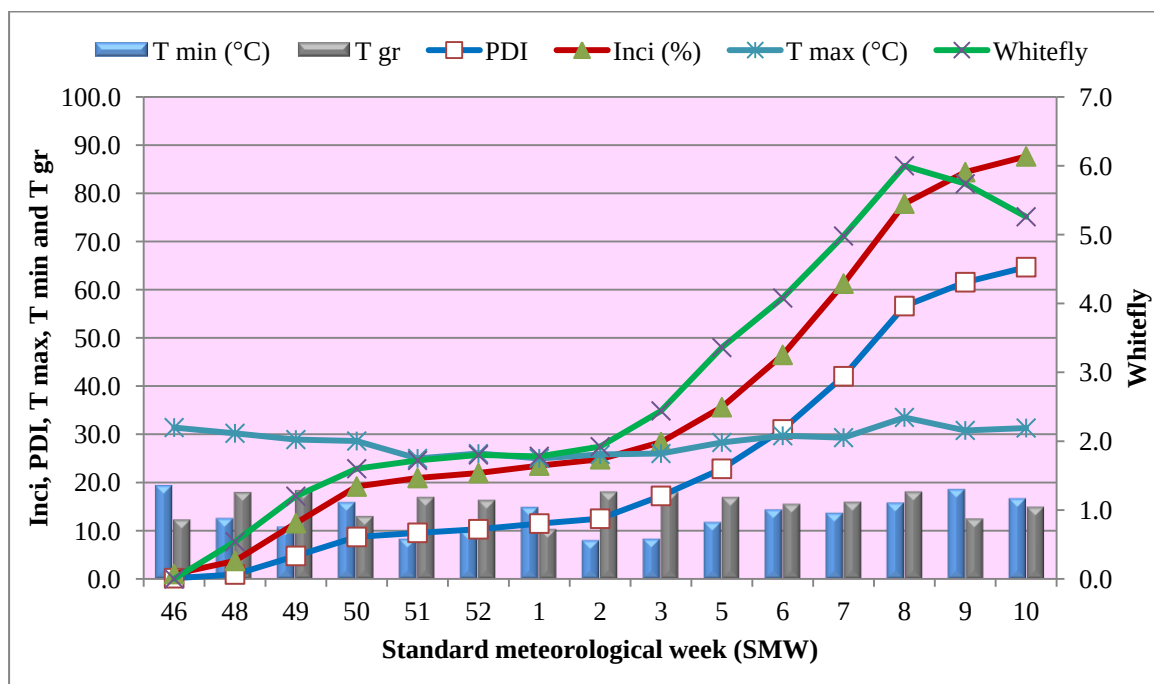


Fig. 4.7: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (Rabi 2014-15)

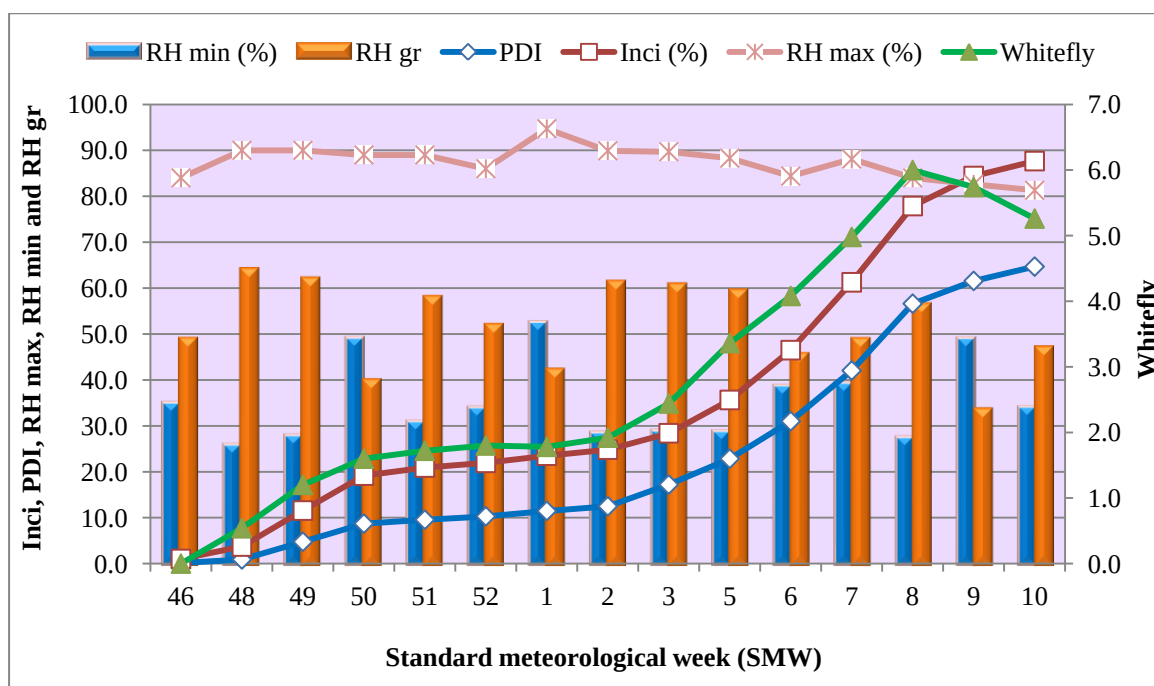


Fig. 4.8: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Rabi 2014-15)

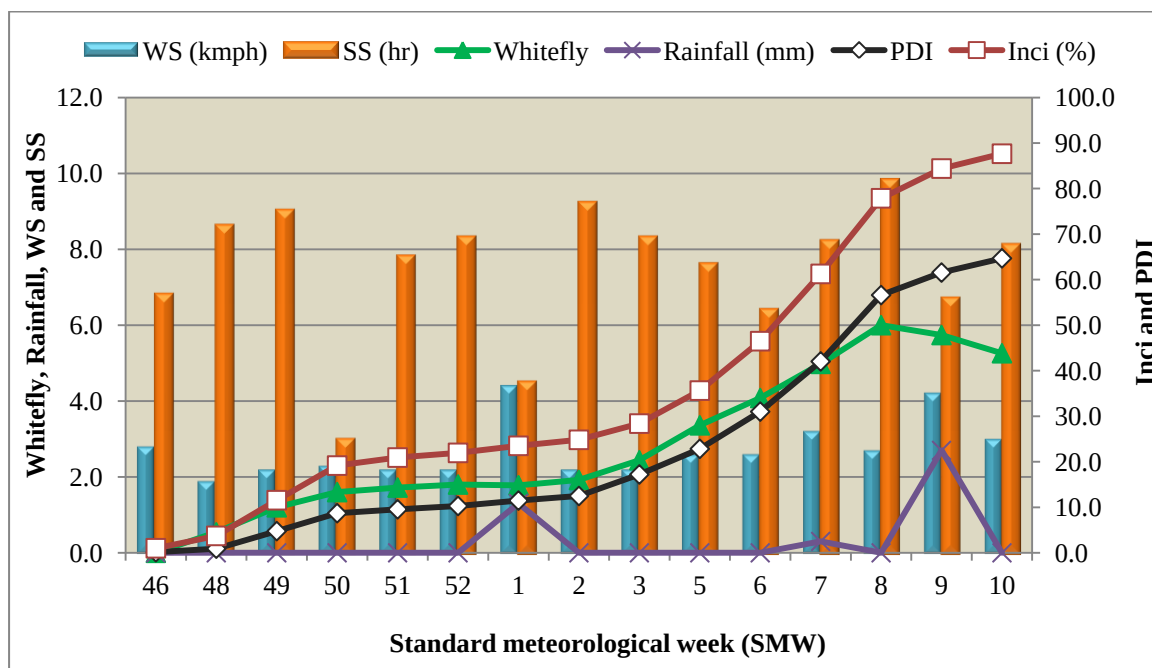


Fig. 4.9: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (*Rabi 2014-15*)

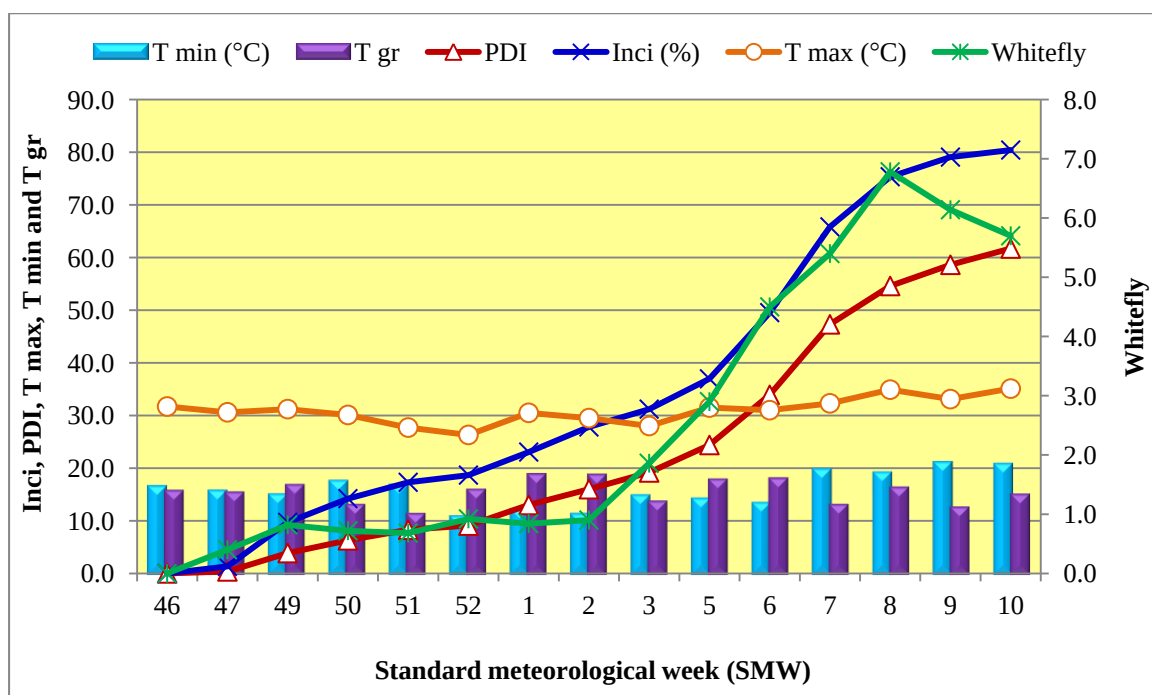


Fig. 4.10: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (*Rabi 2015-16*)

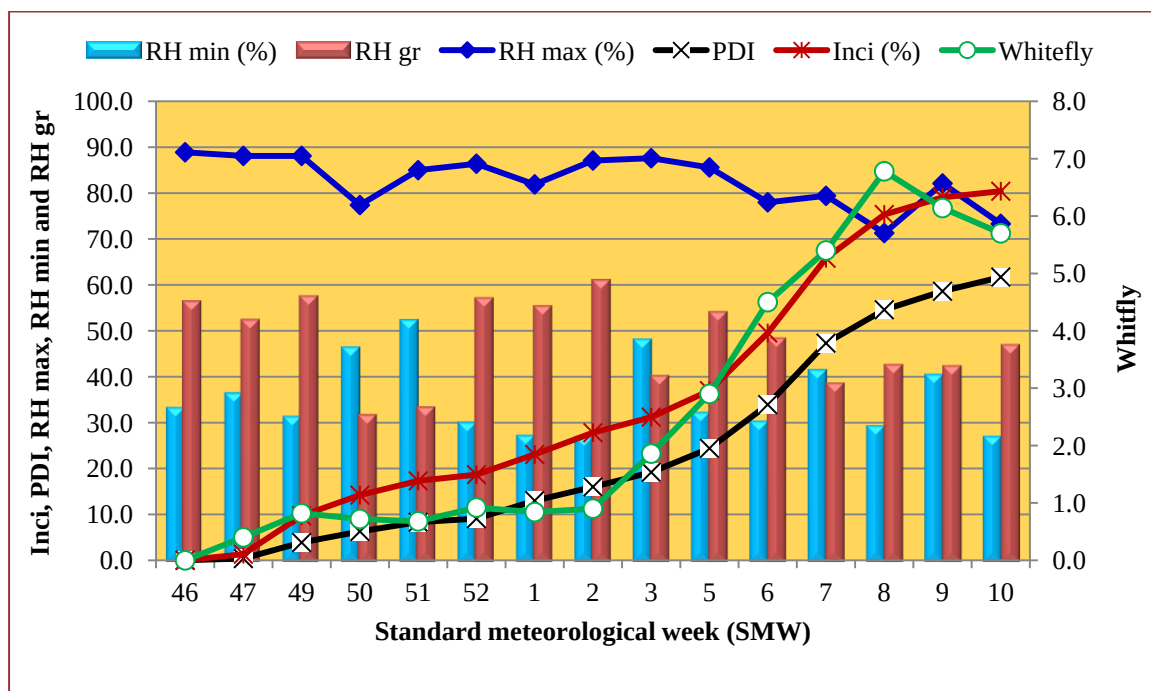


Fig. 4.11: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (*Rabi 2015-16*)

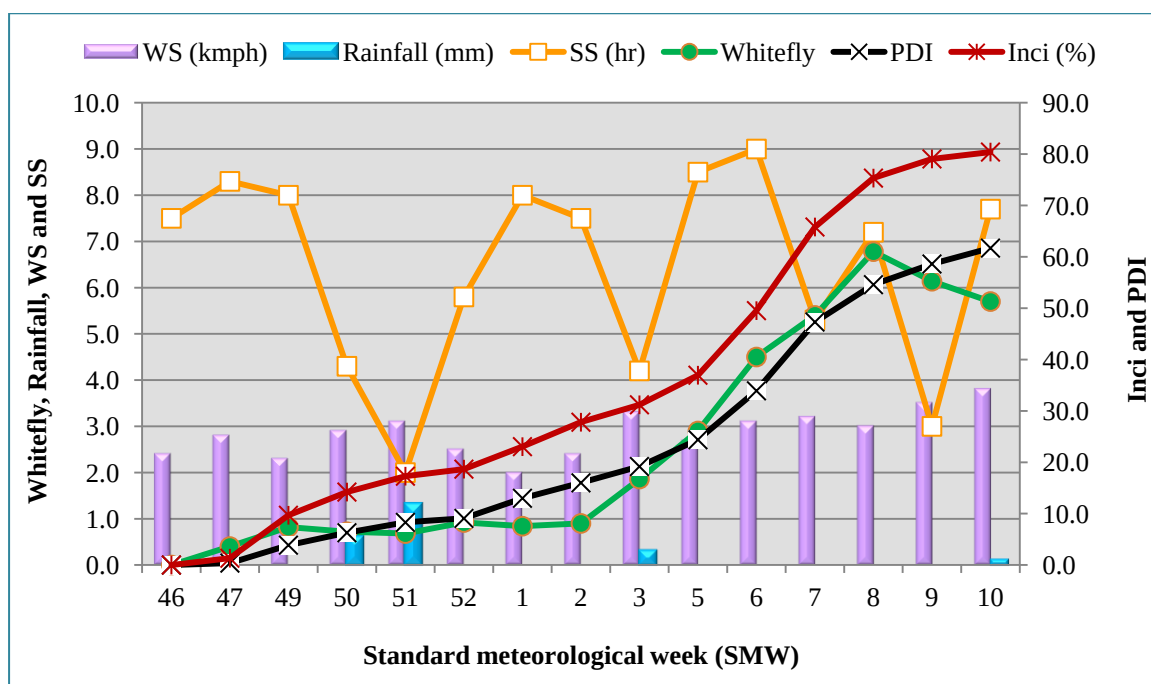


Fig. 4.12: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (*Rabi 2015-16*)

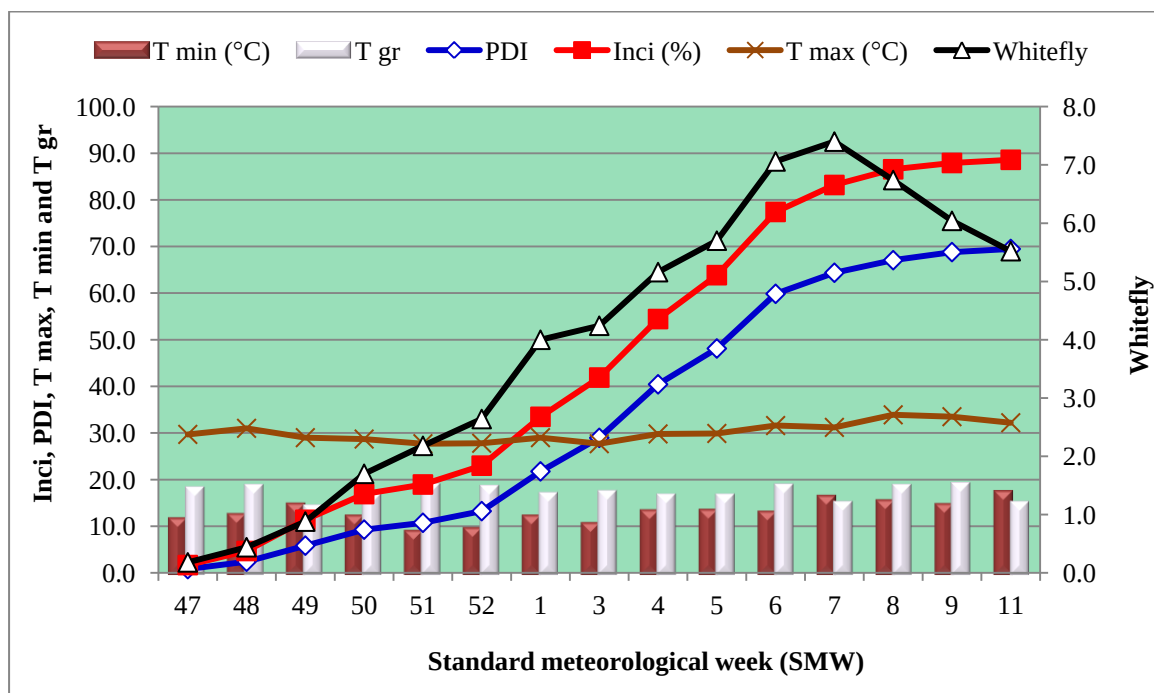


Fig. 4.13: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (Rabi 2016-17)

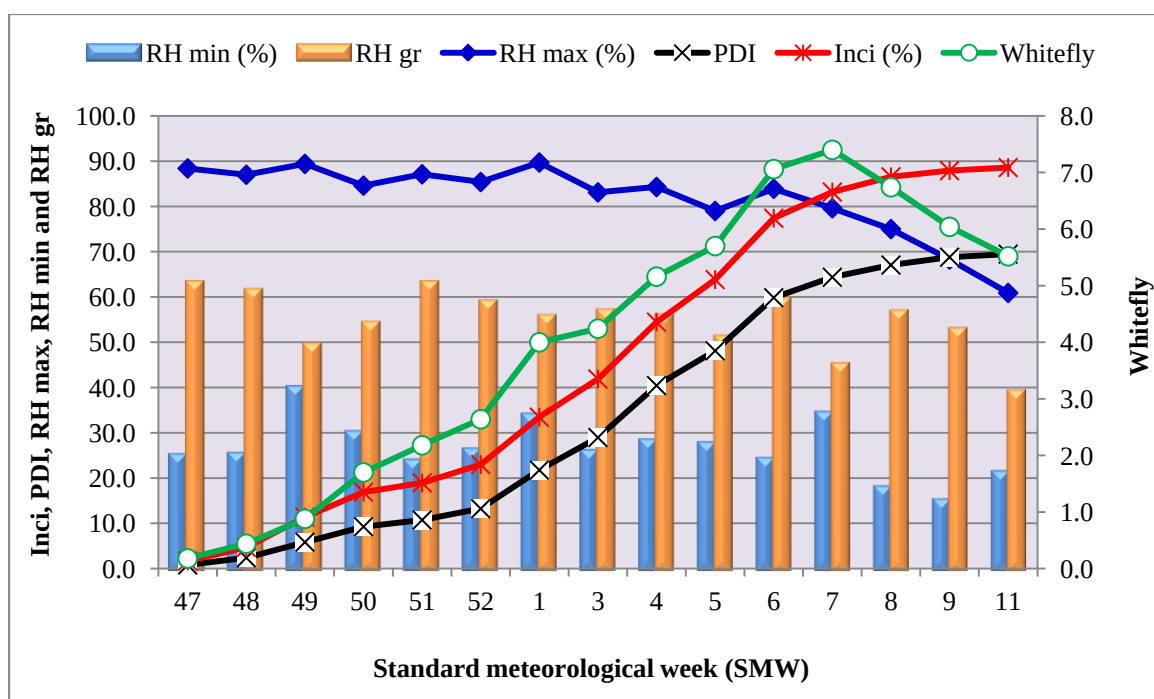


Fig. 4.14: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Rabi 2016-17)

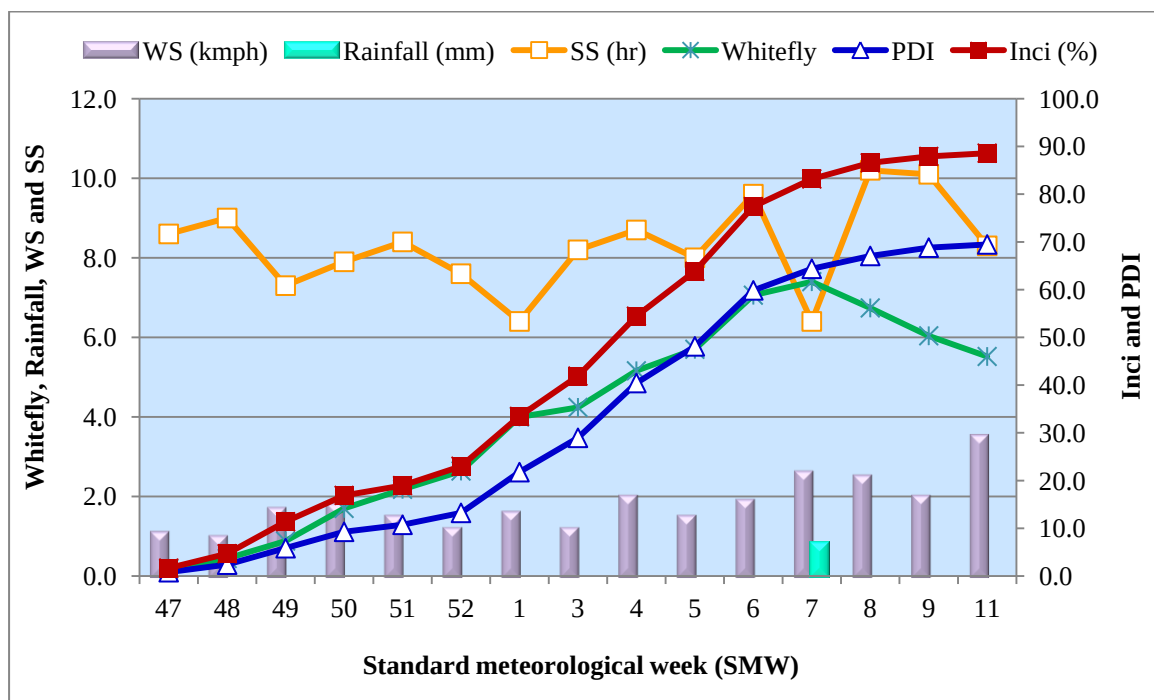


Fig. 4.15: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (*Rabi 2016-17*)

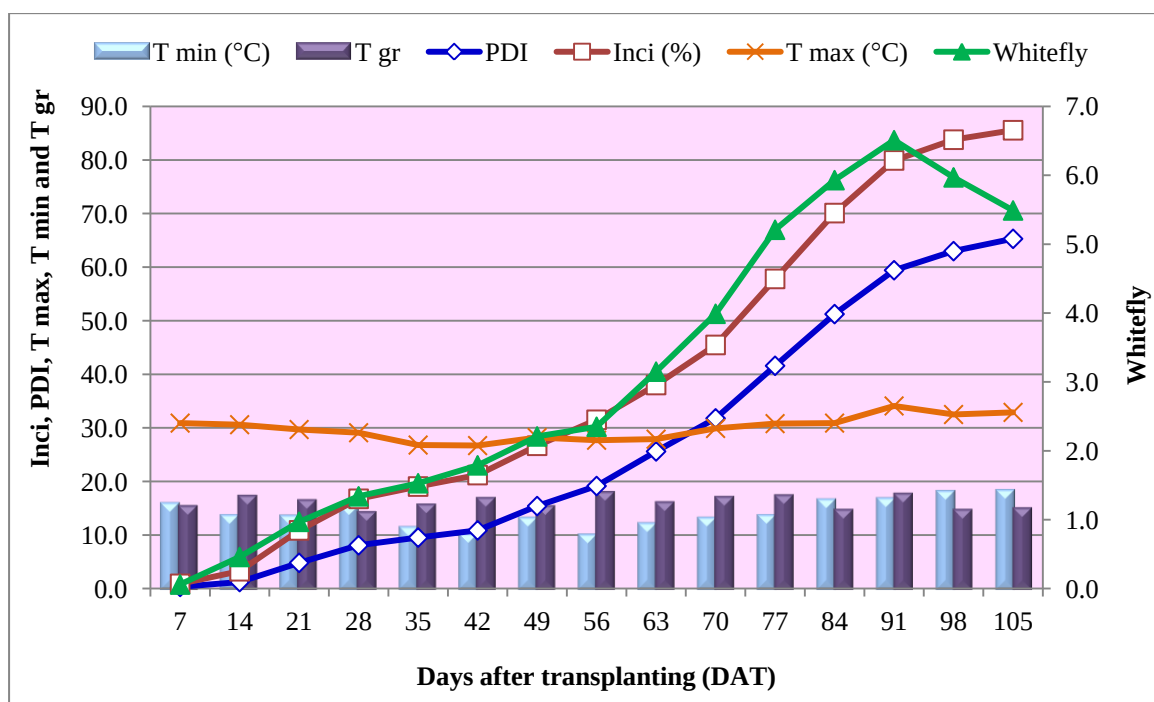


Fig. 4.16: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (*Rabi 2014-15 to 2016-17*)

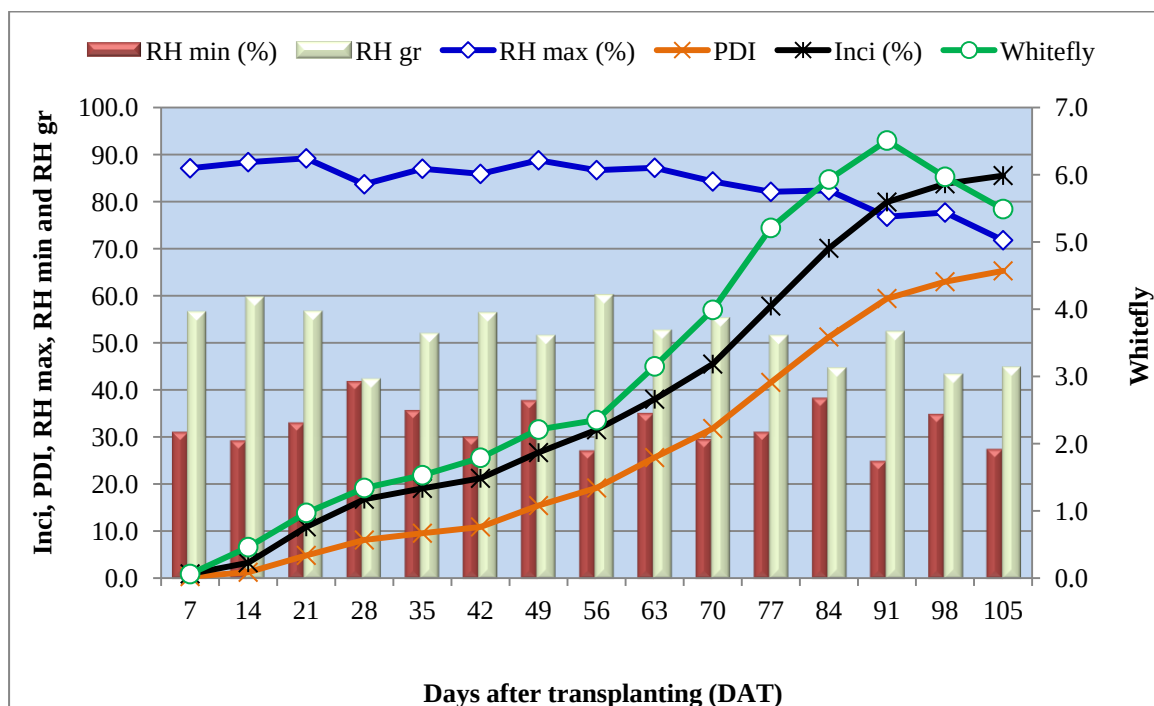


Fig. 4.17: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Rabi 2014-15 to 2016-17)

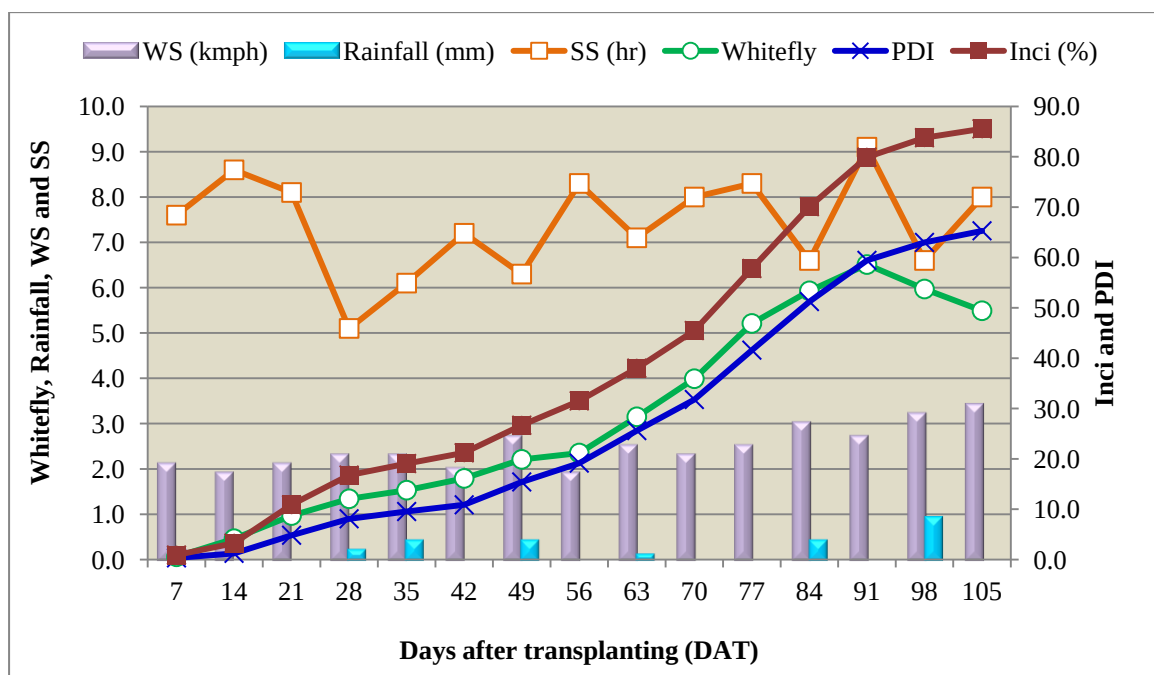


Fig. 4.18: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (Rabi 2014-15 to 2016-17)

(3.57 ± 0.48 individuals leaf⁻¹) which was maintained up to 9 SMW (2.54 ± 0.67 individuals leaf⁻¹). Persistent maximum relative humidity (RHmax) (83 - 91 %) imparted a significantly negative impact on the abundance of white fly population in all the years, especially at the late growth stage. Drizzling rainfall (Rfall) had an insignificant positive effect on the pest structure. A significantly negative relation was also noticed with the Tav_g in 2006, 2007 and 2008, but in 2005 relations were insignificantly positive. In contrary to present findings he also reported a significant negative correlation between number of whiteflies and *Tomato yellow leaf curl virus* (TYLCV) incidence. With the exception of 2007, in all the years *B. tabaci* population showed a significant negative relation with the maximum and minimum temperature. Significant positive relations occurred between the relative humidity gradient (RHgr) and the field flies population in all in except 2005 where the relation was insignificantly positive. Vijaya Lakshmi, *et al.* (2015) reported that from the correlation and regression of the two years data (2013-14 and 2014-15), the results indicated that significant positive correlation was obtained with maximum temperature (2013, $r = 0.77$; 2014, $r = 0.81$) and minimum temperature (2013, $r = 0.62$; 2014, $r = 0.74$). Significant negative correlation was obtained with afternoon relative humidity (2013, $r = -0.66$; 2014, $r = -0.65$) in both the years. The disease initiated during the third week of November and gradually increased and reached maximum up to 100% by March second week where high maximum temperatures prevailed. Coefficient of multiple determination (R^2) was also significant (R^2 for 2013 = 0.731; 2014 = 0.777) and implies that 75.4 (mean of two years) of the variation in the development of the *Tomato leaf curl virus* was explained by the five independent variables minimum and maximum temperature, morning and afternoon relative humidity, rainfall and one dependent variable (whitefly population). Thus the incidence of *Tomato leaf curl virus* and whitefly population was highly influenced by the climate change. Bhutani and Jotwani, (1984) have noted that the activity of adult fly decreased with the onset of rain. Bharadwaj and Kushwaha, (1984) noted that white fly population had negative correlation with RH and positive correlation with temperature in Rajasthan condition. Green and Kalloo, (1994) reported that the epidemiology of whitefly-

transmitted geminiviruses is characterized by a close correlation between disease incidence and whitefly populations which often show strong seasonal fluctuations.

4.3.5 Epidemiology of Tomato leaf curl disease during *Kharif* 2015

4.3.5.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

In *Kharif* 2015 the first trace of adult whitefly (0.20) was noted at about 32nd Standard meteorological week (SMW) i.e. 14 days after transplanting (DAT) which gradually increased with fluctuation up to 37th SMW (49 DAT). The number then increased rapidly up to 42nd SMW (77 DAT) from 0.60 to 4.10 and reached maximum (4.48) up to 43rd SMW (84 DAT). During this period (43rd SMW) maximum and minimum temperature was 33.7 and 21.3 °C respectively, whereas maximum and minimum relative humidity was 90.3 and 36.9 percent respectively, temperature and relative humidity gradient was 12.4 and 53.4 respectively. Further, wind velocity (speed) and sun shine was 2.1 kmph and 8.2 hours respectively. However, no rainfall was recorded during this period. The population then subsided slowly up to 47th SMW (105 DAT) (Table 4.19 and Fig 4.19-4.21).

The first trace of tomato leaf curl disease (ToLCD) was noted at 32nd SMW i.e. 14 days after transplanting with percent leaf curl incidence of 0.93 and 0.19 percent disease index. From 32nd to 37th SMW (14 – 49 DAT) the extent of leaf curl infection was gradually increased from 0.93 to 7.80 percent disease incidence whereas PDI of leaf curl was gradually increased up to 40th SMW (10.60%). After that percent leaf curl incidence and PDI were rapidly increased from 37th and 40th SMW to 45th SMW from 7.80 and 10.60 to 66.72 and 48.27 percent disease incidence and PDI respectively. The maximum incidence (69.80%) and PDI (50.56%) was recorded at 47th SMW, 105 days after transplanting (Table 4.19 and Fig 4.19-4.21).

4.3.5.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly for *Kharif* 2015 has been presented in Table 4.20. There was highly significant negative correlation was noted with population of whitefly and minimum temperature, rainfall, minimum relative humidity and wind speed

with correlation coefficient (r) of -0.791, -0.620, -0.895 and -0.708 respectively. However temperature gradient ($r = 0.905$, $p = 0.001$), relative humidity gradient ($r = 0.897$, $p = 0.001$) and sun shine ($r = 0.723$, $p = 0.001$) illustrated highly significant positive correlation with whitefly population. Rest two parameters viz. maximum temperature and maximum relative humidity exhibited non significant positive and negative correlation (Table 4.20 and Fig 4.19-4.21).

There was highly significant negative correlation was noted with percent leaf curl incidence and minimum temperature, minimum relative humidity and wind speed with correlation coefficient (r) of -0.936, -0.895 and -0.648 respectively. However whitefly population ($r = 0.947$, $p = 0.001$), temperature gradient ($r = 0.958$, $p = 0.001$), relative humidity gradient ($r = 0.888$, $p = 0.001$) and sun shine ($r = 0.658$, $p = 0.001$) illustrated highly significant positive correlation with percent leaf curl incidence. A significant negative correlation ($r = -0.555$, $p = 0.005$) was recorded between percent leaf curl incidence and rainfall. Rest two parameters viz. maximum temperature and maximum relative humidity exhibited non significant negative correlation (Table 4.20 and Fig 4.19-4.21).

There was highly significant positive correlation was noted with percent disease index (PDI) and incidence of leaf curl, population of whitefly, temperature gradient, relative humidity gradient and sun shine with correlation coefficient (r) of 0.995, 0.922, 0.940, 0.855 and 0.610 respectively. However minimum temperature ($r = -0.950$, $p = 0.001$) and minimum relative humidity ($r = -0.867$, $p = 0.001$) illustrated highly significant negative correlation with PDI. The significant negative correlation was recorded between PDI and rainfall ($r = -0.523$, $p = 0.005$) and wind speed ($r = -0.596$, $p = 0.005$). Rest two parameters viz. maximum temperature and maximum relative humidity showed non significant negative correlation (Table 4.20 and Fig 4.19-4.21).

4.3.5.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been depicted in Table 4.21. It was revealed for the experimental data that weather parameters studied, taken together were responsible for 90.5 percent ($R^2 = 0.905$) of total change in

Table 4.19: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Kharif* 2015)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
30 July – 5 Aug	31	7	0.00	0.00	0.00	31.2	25.2	6.0	7.0	86.0	69.1	16.9	10.4	4.6
06-12 Aug	32	14	0.19	0.93	0.20	30.8	24.7	6.1	0.7	94.3	73.4	20.9	4.8	2.5
13-19 Aug	33	21	0.24	1.00	0.00	31.7	25.3	6.3	18.1	93.6	72.7	20.9	7.5	4.1
20-26 Aug	34	28	1.27	2.89	0.44	32.3	25.9	6.4	3.4	86.7	64.6	22.1	8.1	6.5
27 Aug - 02 Sep	35	35	1.50	3.71	0.42	30.8	25.0	5.8	5.4	94.3	79.6	14.7	4.9	1.2
03-09 Sep	36	42	2.86	6.44	0.86	33.0	25.5	7.4	1.4	93.1	63.6	29.6	4.7	6.9
10-16 Sep	37	49	3.36	7.80	0.60	33.5	25.4	8.1	9.8	92.6	61.7	30.9	3.8	6.8
24-30 Sep	39	56	6.74	14.26	1.26	32.5	24.6	7.9	0.0	92.1	56.7	35.4	3.0	7.2
01-07 Oct	40	63	10.60	22.68	2.12	33.7	24.4	9.3	0.0	92.0	51.4	40.6	2.4	7.8
08-14 Oct	41	70	22.39	38.54	3.80	33.9	22.2	11.7	0.0	89.4	46.6	42.9	3.0	8.7
15-21 Oct	42	77	30.19	45.00	4.10	33.4	22.8	10.6	0.0	91.4	44.9	46.6	2.4	8.7
22-28 Oct	43	84	37.35	53.73	4.48	33.7	21.3	12.4	0.0	90.3	36.9	53.4	2.1	8.2
29 Oct - 04 Nov	44	91	42.70	59.20	4.20	30.0	19.4	10.7	0.0	90.3	54.7	35.6	4.1	6.7
05-11 Nov	45	98	48.27	66.72	4.10	31.7	18.8	13.0	0.0	90.9	37.4	53.4	2.6	7.8
19-25 Nov	47	105	50.56	69.80	3.54	30.6	15.5	15.1	0.0	88.1	36.1	52.0	2.8	8.3

SMW= Standard meteorological SMW

Table 4.20: Correlation of tomato leaf curl disease with its vector and weather parameters (Kharif 2015)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.933 ^{**}	1		
Incidence (%)	0.955 ^{**}	0.995 ^{**}	1	
Whitefly	0.920 ^{**}	0.922 ^{**}	0.947 ^{**}	1
T max (°C)	0.099 ^{NS}	-0.121 ^{NS}	-0.047 ^{NS}	0.174 ^{NS}
T min (°C)	-0.859 ^{**}	-0.950 ^{**}	-0.936 ^{**}	-0.791 ^{**}
T gr	0.942 ^{**}	0.940 ^{**}	0.958 ^{**}	0.905 ^{**}
Rainfall (mm)	-0.574 [*]	-0.523 [*]	-0.555 [*]	-0.620 ^{**}
RH max (%)	-0.152 ^{NS}	-0.290 ^{NS}	-0.277 ^{NS}	-0.230 ^{NS}
RH min (%)	-0.898 ^{**}	-0.867 ^{**}	-0.895 ^{**}	-0.895 ^{**}
RH gr	0.915 ^{**}	0.855 ^{**}	0.888 ^{**}	0.897 ^{**}
WS (kmph)	-0.784 ^{**}	-0.596 [*]	-0.648 ^{**}	-0.708 ^{**}
SS (hr)	0.730 ^{**}	0.610 ^{**}	0.658 ^{**}	0.723 ^{**}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.21: Regression equation of tomato leaf curl disease with its vector and weather parameters (Kharif 2015)

Variables / factors	Whitefly $\times$ weather (Wh $\times$ w)			Incidence $\times$ whitefly and weather (I $\times$ Wh $\times$ w)			PDI $\times$ incidence, whitefly and weather (P $\times$ I $\times$ Wh $\times$ w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	-8.896	-0.255	0.809	91.410	0.659	0.546	-24.963	-0.262	0.810
Incidence (X ₁)	-	-	-	-	-	-	1.108	3.401*	0.042*
Whitefly (X ₂)	-	-	-	7.796*	4.418	0.012*	-3.313	-1.188	0.320
T max (X ₃)	-17.503*	-3.062	0.028*	-11.554	-0.302	0.778	-2.909	-0.115	0.915
T min (X ₄)	17.455*	3.020	0.029*	6.691	0.175	0.870	3.685	0.147	0.892
T gr (X ₅)	17.498*	3.012	0.030*	9.816	0.255	0.811	2.189	0.087	0.936
Rainfall (X ₆)	0.034	0.414	0.696	0.169	0.511	0.636	-0.012	-0.053	0.961
RH max (X ₇)	-16.691*	-2.635	0.046*	26.197	0.678	0.535	-18.029	-0.678	0.546
RH min (X ₈)	16.763*	2.685	0.044*	-25.865	-0.672	0.538	18.069	0.683	0.544
RH gr (X ₉)	16.930*	2.685	0.044*	-25.610	-0.659	0.546	18.261	0.685	0.543
WS (X ₁₀)	0.230	0.614	0.566	0.283	0.185	0.863	0.718	0.715	0.526
SS (X ₁₁)	-0.252	-0.977	0.373	1.049	0.944	0.399	-0.805	-1.005	0.389
Relationship	Regression equation								
(Wh $\times$ w)	Y = -8.896 - 17.503X ₃ + 17.455X ₄ + 17.498X ₅ + 0.034X ₆ - 16.691X ₇ + 16.763X ₈ + 16.930X ₉ + 0.230X ₁₀ - 0.252X ₁₁								
(I $\times$ Wh $\times$ w)	Y = 91.410 + 7.796X ₂ - 11.554X ₃ + 6.691X ₄ + 9.816X ₅ + 0.169X ₆ + 26.197X ₇ - 25.865X ₈ - 25.610X ₉ + 0.283X ₁₀ + 1.049X ₁₁								
(P $\times$ I $\times$ Wh $\times$ w)	Y = -24.963 + 1.108X ₁ - 3.313X ₂ - 2.909X ₃ + 3.685X ₄ + 2.189X ₅ - 0.012X ₆ - 18.029X ₇ + 18.069X ₈ + 18.261X ₉ + 0.718X ₁₀ - 0.805X ₁₁								
R²	R²								
	0.905								
	0.937								
	0.940								

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

population of whitefly. Regression also expressed that with every unit increase in maximum temperature and maximum relative humidity there was significant decrease of ($b = -17.503$ and -16.691) whitefly population. However with every unit increase in minimum temperature, temperature gradient, minimum relative humidity and relative humidity gradient there was significant positive increase of ($b = 17.455, 17.498, 16.763$ and 16.930) whitefly population.

Population of whitefly and weather parameters were found to contribute around 93.70 percent ($R^2 = 0.937$) of total change in percent leaf curl incidence when acted jointly. Regression also expressed that with every unit increase in population of whitefly there was significant positive increase of ($b = 7.796$) percent leaf curl incidence (Table 4.21).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 94.0 percent ($R^2 = 0.940$) effect on percent disease index of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 1.108$) percent disease index (Table 4.21).

4.3.6 Epidemiology of Tomato leaf curl disease during *Kharif* 2016

4.3.6.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

In *Kharif* 2016 the first trace of adult whitefly (0.56) was recorded during the 34th Standard meteorological week (SMW) i.e. 28 days after transplanting (DAT) on tomato which gradually increased up to 35th SMW (35 DAT). The number then declined gradually up to 38th SMW (49 DAT) from 0.74 to 0.54. During 39th SMW the adult whitefly population was 0.70. From 40th to 44th SMW the whitefly population rapidly increased. The maximum whitefly population (4.00) was recorded on 44th SMW (91 DAT) during this period maximum and minimum temperature was 30.5 and 19.6 °C respectively, whereas maximum and minimum relative humidity was 83.1 and 51.0 percent respectively, temperature and relative humidity gradient was 10.9 and 32.1 respectively. Further, wind velocity (speed) and sun shine was 2.0 kmph and 8.2 hours respectively. However, no rainfall was recorded during this period. The population then subsided slowly up to 47 SMW (105 DAT) (Table 4.22 and Fig 4.22-4.24).

The first trace of tomato leaf curl disease (ToLCD) was observed during 34th SMW i.e. 28 days after transplanting with percent leaf curl incidence of 2.02 and 0.68 percent PDI. From 34th to 40th SMW (28 to 63 DAT) the extent of leaf curl infection was gradually increased from 2.02 and 0.68 to 8.43 and 4.29 percent disease incidence and PDI respectively. Thereafter percent leaf curl incidence and PDI were rapidly increased from 41st SMW to 46 SMW from 13.50 and 7.13 to 60.81 and 43.91 percent disease incidence and PDI respectively. The maximum incidence (63.48%) and PDI (46.80%) was recorded during 47th SMW, 105 days after transplanting (Table 4.22 and Fig 4.22-4.24).

4.3.6.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly has been depicted in Table 4.23. There was highly significant negative correlation was noted with population of whitefly and minimum temperature, minimum relative humidity and wind speed with correlation coefficient (r) of -0.879, -0.848 and -0.712 respectively. However temperature gradient ($r = 0.890$, $p = 0.001$), relative humidity gradient ($r = 0.812$, $p = 0.001$) and sun shine ($r = 0.787$, $p = 0.001$) illustrated highly significant positive correlation with whitefly population. A significant negative correlation ($r = -0.529$, $p = 0.005$) was recorded between whitefly population and rainfall. Remaining two parameters viz. maximum temperature and maximum relative humidity exhibited non significant negative correlation (Table 4.23 and Fig 4.22-4.24).

There was highly significant negative correlation was noted with percent leaf curl incidence and minimum temperature, minimum relative humidity and wind speed with correlation coefficient (r) of -0.953, -0.857 and -0.661 respectively. However whitefly population ($r = 0.971$), temperature gradient ($r = 0.932$), relative humidity gradient ($r = 0.830$) and sun shine ($r = 0.739$) illustrated highly significant positive correlation with percent leaf curl incidence. A significant negative correlation ($r = -0.504$) was recorded between percent leaf curl incidence and rainfall. Rest two parameter viz. maximum temperature and maximum relative humidity exhibited non significant negative correlation (Table 4.23 and Fig 4.22-4.24).

There was highly significant positive correlation was noted with percent disease index and incidence of leaf curl, whitefly population, temperature gradient, relative humidity gradient and sun shine with correlation coefficient (r) of 0.998, 0.957, 0.922, 0.808 and 0.708 respectively. However minimum temperature ($r = -0.955$, $p = 0.001$), minimum relative humidity ($r = -0.838$, $p = 0.001$) and wind speed ($r = -0.622$, $p = 0.001$) illustrated highly significant negative correlation with leaf curl PDI. A significant negative correlation was recorded between percent disease index of leaf curl and rainfall ($r = -0.497$, $p = 0.005$). However, other parameters viz. maximum temperature and maximum relative humidity showed non significant negative correlation (Table 4.23 and Fig 4.22-4.24).

4.3.6.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been depicted in Table 4.24. It was revealed from the experimental data that weather parameters studied, taken together were responsible for 87.30 percent ($R^2 = 0.873$) of total change in population of whitefly. Regression also expressed that with every unit increase in wind velocity (speed) there was significant decrease of ($b = -0.376$) whitefly population.

Population of whitefly and weather parameters were found to contribute around 94.90 percent ($R^2 = 0.949$) of total change in percent leaf curl incidence when acted jointly. Regression also expressed that with every unit increase in population of whitefly there was significant positive increase of ($b = 9.402$) percent leaf curl incidence (Table 4.24).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 96.20 percent ($R^2 = 0.962$) effect on PDI of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 0.914$) percent disease index.

Table 4.22: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Kharif* 2016)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
29 Jul - 04 Aug	31	7	0.00	0.00	0.00	31.2	25.6	5.6	1.1	90.4	77.4	13.0	6.1	4.4
05-11 Aug	32	14	0.00	0.00	0.00	28.6	24.6	4.0	18.7	92.9	81.1	11.7	9.1	1.6
12-18 Aug	33	21	0.00	0.00	0.00	29.0	24.7	4.3	1.3	89.1	76.7	12.4	9.2	1.3
19-25 Aug	34	28	0.68	2.02	0.56	31.0	25.4	5.6	0.5	88.7	66.0	22.7	5.8	4.7
26 Aug - 01 Sep	35	35	1.49	3.70	0.74	32.4	25.9	6.5	3.8	90.9	71.1	19.7	3.2	5.2
02-08 Sep	36	42	2.21	4.71	0.66	30.8	25.3	5.5	7.9	86.6	67.0	19.6	6.5	1.5
16-22 Sep	38	49	2.76	5.74	0.54	32.2	24.9	7.3	12.9	93.9	69.0	24.9	2.5	6.6
23-29 Sep	39	56	3.04	6.40	0.70	30.1	24.7	5.4	15.7	97.3	83.6	13.7	3.2	3.9
30 Sep - 06 Oct	40	63	4.29	8.43	0.82	30.4	24.8	5.7	9.7	95.4	73.4	22.0	2.8	4.3
07-13 Oct	41	70	7.13	13.50	1.12	31.3	23.3	8.0	2.2	95.3	57.7	37.6	1.6	4.7
14-20 Oct	42	77	13.60	22.97	1.96	31.8	19.4	12.4	0.0	89.1	32.6	56.6	1.1	10.0
21-27 Oct	43	84	24.90	38.51	2.94	31.6	18.0	13.6	0.0	90.1	33.6	56.6	1.3	9.5
28 Oct - 03 Nov	44	91	35.95	51.68	4.00	30.5	19.6	10.9	0.0	83.1	51.0	32.1	2.0	8.2
11-17 Nov	46	98	43.91	60.81	3.76	29.2	14.5	14.7	0.0	90.1	36.3	53.9	1.3	7.6
18-24 Nov	47	105	46.80	63.48	3.30	29.7	11.5	18.1	0.0	88.4	25.1	63.3	1.1	8.6

SMW = Standard meteorological SMW

Table 4.23: Correlation of tomato leaf curl disease with its vector and weather parameters (Kharif 2016)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.867**	1		
Incidence (%)	0.893**	0.998**	1	
Whitefly	0.907**	0.957**	0.971**	1
T max (°C)	0.006 ^{NS}	-0.239 ^{NS}	-0.198 ^{NS}	-0.072 ^{NS}
T min (°C)	-0.843**	-0.955**	-0.953**	-0.879**
T gr	0.874**	0.922**	0.932**	0.890**
Rainfall (mm)	-0.384 ^{NS}	-0.497*	-0.504*	-0.529*
RH max (%)	-0.180 ^{NS}	-0.437 ^{NS}	-0.426 ^{NS}	-0.474 ^{NS}
RH min (%)	-0.834**	-0.838**	-0.857**	-0.848**
RH gr	0.856**	0.808**	0.830**	0.812**
WS (kmph)	-0.855**	-0.622**	-0.661**	-0.712**
SS (hr)	0.770**	0.708**	0.739**	0.787**

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.24: Regression equation of tomato leaf curl disease with its vector and weather parameters (Kharif 2016)

Variables / factors	Whitefly × weather (Wh×w)			Incidence × whitefly and weather (I×Wh ×w)			PDI × incidence, whitefly and weather (P×I×Wh×w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	34.338	3.220	0.023	55.398	0.602	0.580	4.728	0.178	0.870
Incidence (X ₁)	-	-	-	-	-	-	0.914**	6.617	0.007**
Whitefly (X ₂)	-	-	-	9.402*	4.268	0.013*	-2.654	-1.852	0.161
T max (X ₃)	-3.289	-0.571	0.593	-15.321	-0.523	0.628	-0.940	-0.113	0.918
T min (X ₄)	2.771	0.473	0.656	12.951	0.439	0.684	0.948	0.114	0.917
T gr (X ₅)	2.848	0.475	0.655	17.097	0.566	0.602	0.980	0.113	0.917
Rainfall (X ₆)	0.011	0.347	0.743	-0.090	-0.583	0.591	-0.020	-0.441	0.689
RH max (X ₇)	-0.177	-0.052	0.961	5.863	0.348	0.745	2.533	0.536	0.629
RH min (X ₈)	-0.004	-0.001	0.999	-5.790	-0.344	0.748	-2.594	-0.550	0.620
RH gr (X ₉)	-0.013	-0.004	0.997	-6.176	-0.368	0.731	-2.648	-0.562	0.613
WS (X ₁₀)	-0.376*	-2.710	0.042*	-0.469	-0.436	0.685	0.120	0.396	0.719
SS (X ₁₁)	0.060	0.445	0.675	-0.914	-1.344	0.250	0.104	0.459	0.677
Relationship (Wh×w)	Regression equation								
(I×Wh ×w)	Y = 34.338 - 3.289X ₃ + 2.771X ₄ + 2.848X ₅ + 0.011X ₆ - 0.177X ₇ - 0.004X ₈ - 0.013X ₉ - 0.376X ₁₀ + 0.060X ₁₁								
	Y = 55.398 + 9.402X ₂ - 15.321X ₃ + 12.951X ₄ + 17.097X ₅ - 0.090X ₆ + 5.863X ₇ - 5.790X ₈ - 6.176X ₉ - 0.469X ₁₀ - 0.914X ₁₁								
(P×I×Wh×w)	Y = 4.728 + 0.914X ₁ - 2.654X ₂ - 0.940X ₃ + 0.948X ₄ + 0.980X ₅ - 0.020X ₆ + 2.533X ₇ - 2.594X ₈ - 2.648X ₉ + 0.120X ₁₀ + 0.104X ₁₁								
	R ²								
	0.873								
	0.949								

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

4.3.7 Epidemiology of Tomato leaf curl disease during *Kharif* 2017

4.3.7.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

In *Kharif* 2017 the first trace of adult whitefly (0.30) was recorded during the 34th Standard meteorological week (SMW) i.e. 28 days after transplanting (DAT) on tomato. The whitefly population was first gradually then rapidly increased up to 36th SMW (1.20). The number then slightly declined on 38th SMW and recovered from 40th SMW (1.42). From 41st to 44th SMW the whitefly population rapidly increased. The maximum whitefly population (4.80) was recorded on 44th SMW (91 DAT) during this period maximum and minimum temperature was 31.2 and 18.5 °C respectively, whereas maximum and minimum relative humidity was 86.9 and 39.0 percent respectively, temperature and relative humidity gradient was 12.7 and 47.9 respectively. Further, wind velocity (speed) and sun shine was 2.3 kmph and 7.8 hours respectively. However, no rainfall was recorded during this period. The population then subsided slowly up to 47 SMW (105 DAT) (Table 4.25 and Fig 4.25-4.27).

The first trace of tomato leaf curl disease (ToLCD) was observed during 32nd SMW i.e. 14 days after transplanting with 1.0 percent leaf curl incidence and 0.24 percent disease index. From 32nd to 41st SMW (14 – 70 DAT) the extent of leaf curl infection was gradually increased from 1.00 and 0.24 to 23.67 and 13.76 percent disease incidence and PDI respectively. Thereafter percent leaf curl incidence and PDI were rapidly increased from 41st SMW to 44 SMW from 23.67 and 13.76 to 60.58 and 46.40 percent disease incidence and PDI respectively. The maximum incidence (70.99%) and PDI (52.38%) was recorded during 47th SMW, 105 days after transplanting (Table 4.25 and Fig 4.25-4.27).

4.3.7.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly has been depicted in Table 4.26. There was highly significant negative correlation was noted with population of whitefly and minimum temperature and minimum relative humidity with correlation coefficient (r) of -0.864 and -0.861 respectively. However temperature gradient (r = 0.923, p = 0.001), relative humidity gradient (r = 0.898, p = 0.001) and sun shine (r = 0.668, p

= 0.001) showed highly significant positive correlation with whitefly population. A significant negative correlation ($r = -0.558$, $p = 0.005$) was recorded between whitefly population and rainfall. Rest two parameter viz. maximum temperature and maximum relative humidity and one parameter wind speed exhibited non significant negative and positive correlation respectively (Table 4.26 and Fig 4.25-4.27).

There was highly significant negative correlation was noted with percent leaf curl incidence and minimum temperature and minimum relative humidity with correlation coefficient (r) of -0.948 and -0.833 respectively. However whitefly population ($r = 0.963$, $p = 0.001$), temperature gradient ($r = 0.927$, $p = 0.001$) and relative humidity gradient ($r = 0.842$, $p = 0.001$) illustrated highly significant positive correlation with percent leaf curl incidence. Rainfall ($r = -0.527$, $p = 0.005$) and maximum relative humidity (-0.540 , $p = 0.005$) indicated significant negative correlation while sun shine ($r = 0.572$, $p = 0.005$) showed significant positive correlation with percent leaf curl incidence. Rest two parameter viz. maximum temperature and wind speed exhibited non significant negative and positive correlation respectively (Table 4.26 and Fig 4.25-4.27).

There was highly significant positive correlation was noted with leaf curl PDI and incidence, whitefly population, temperature gradient and relative humidity gradient with correlation coefficient (r) of 0.998 , 0.955 , 0.933 and 0.839 respectively. However minimum temperature ($r = -0.963$, $p = 0.001$) and minimum relative humidity ($r = -0.840$, $p = 0.001$) indicated highly significant negative correlation with percent disease index of leaf curl. Rainfall ($r = -0.528$, $p = 0.005$) and maximum relative humidity (-0.572 , $p = 0.005$) showed significant negative correlation while sun shine ($r = 0.557$, $p = 0.001$) showed significant positive correlation with percent disease index of leaf curl. However two parameters viz. maximum temperature and wind speed exhibited non significant negative and positive correlation respectively (Table 4.26 and Fig 4.25-4.27).

4.3.7.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been presented in Table

Table 4.25: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Kharif 2017*)

Date	SMW	DAT	PDI	Incidence (%)	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
30 July – 5 Aug	31	7	0.00	0.00	0.00	32.7	26.2	6.5	2.5	85.1	65.9	19.3	3.1	5.5
06-12 Aug	32	14	0.24	1.00	0.00	30.8	24.9	5.9	6.4	89.0	72.3	16.7	3.4	1.8
13-19 Aug	33	21	1.00	2.33	0.00	32.1	25.1	6.9	6.3	91.9	69.4	22.4	2.0	2.4
20-26 Aug	34	28	2.00	4.67	0.30	31.8	25.1	6.7	5.1	91.4	69.1	22.3	1.4	5.5
27 Aug - 02 Sep	35	35	4.00	7.33	0.58	31.7	25.3	6.4	4.5	92.1	70.6	21.6	0.8	4.0
03-09 Sep	36	42	7.57	13.00	1.20	33.4	26.2	7.2	0.0	90.1	63.3	26.9	2.4	6.5
17-23 Sep	38	49	8.00	14.00	1.02	30.7	24.5	6.2	16.5	94.0	75.4	18.6	4.4	3.5
24-30 Sep	39	56	9.95	16.33	1.20	32.9	25.2	7.7	3.1	89.3	60.7	28.6	2.7	7.5
01-07 Oct	40	63	10.90	18.33	1.42	31.8	24.7	7.1	4.9	92.7	71.6	21.1	3.0	5.2
08-14 Oct	41	70	13.76	23.67	1.94	31.9	24.9	7.0	1.4	95.0	70.4	24.6	2.3	4.8
15-21 Oct	42	77	22.48	34.17	3.02	33.5	23.1	10.4	0.9	89.1	44.9	44.3	2.5	7.7
22-28 Oct	43	84	32.77	47.34	4.18	33.2	22.7	10.4	0.0	86.4	44.4	42.0	2.4	7.9
29 Oct - 04 Nov	44	91	46.40	60.58	4.80	31.2	18.5	12.7	0.0	86.9	39.0	47.9	2.3	7.8
12-18 Nov	46	98	50.49	68.63	4.26	28.5	18.3	10.2	0.1	88.4	55.4	33.0	3.7	5.2
19-25 Nov	47	105	52.38	70.99	3.88	30.3	17.5	12.8	0.0	82.1	38.3	43.9	2.2	6.9

SMW= Standard meteorological SMW

Table 4.26: Correlation of tomato leaf curl disease with its vector and weather parameters (Kharif 2017)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.920 ^{**}	1		
Incidence (%)	0.943 ^{**}	0.998 ^{**}	1	
Whitefly	0.942 ^{**}	0.955 ^{**}	0.963 ^{**}	1
T max (°C)	-0.309 ^{NS}	-0.464 ^{NS}	-0.443 ^{NS}	-0.266 ^{NS}
T min (°C)	-0.826 ^{**}	-0.963 ^{**}	-0.948 ^{**}	-0.864 ^{**}
T gr	0.852 ^{**}	0.933 ^{**}	0.927 ^{**}	0.923 ^{**}
Rainfall (mm)	-0.467 ^{NS}	-0.528 [*]	-0.527 [*]	-0.558 [*]
RH max (%)	-0.322 ^{NS}	-0.572 [*]	-0.540 [*]	-0.472 ^{NS}
RH min (%)	-0.753 ^{**}	-0.840 ^{**}	-0.833 ^{**}	-0.861 ^{**}
RH gr	0.815 ^{**}	0.839 ^{**}	0.842 ^{**}	0.898 ^{**}
WS (kmph)	0.081 ^{NS}	0.098 ^{NS}	0.101 ^{NS}	0.075 ^{NS}
SS (hr)	0.625 ^{**}	0.557 [*]	0.572 [*]	0.668 ^{**}

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.27: Regression equation of tomato leaf curl disease with its vector and weather parameters (Kharif 2017)

Variables / factors	Whitefly × weather (Wh×w)			Incidence × whitefly and weather (I×Wh ×w)			PDI × incidence, whitefly and weather (P×I×Wh×w)		
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence			PDI		
Intercept (a)	-1.804	-0.146	0.890	60.220	0.550	0.612	54.170	2.052	0.133
Incidence (X ₁)	-	-	-	-	-	-	0.459*	3.946	0.029*
Whitefly (X ₂)	-	-	-	3.578	0.904	0.417	1.196	1.185	0.321
T max (X ₃)	12.531	2.115	0.088	131.093	1.817	0.143	17.855	0.788	0.488
T min (X ₄)	-13.117	-2.183	0.081	-138.734	-1.867	0.135	-19.910	-0.843	0.461
T gr (X ₅)	-12.963	-2.160	0.083	-131.669	-1.784	0.149	-17.821	-0.775	0.495
Rainfall (X ₆)	-0.077	-1.771	0.137	-0.705	-1.440	0.223	-0.144	-1.030	0.379
RH max (X ₇)	-4.974	-1.421	0.215	-68.984	-1.880	0.133	-7.277	-0.622	0.578
RH min (X ₈)	5.151	1.456	0.205	70.442	1.886	0.132	7.258	0.608	0.586
RH gr (X ₉)	5.231	1.487	0.197	69.982	1.872	0.135	7.112	0.598	0.592
WS (X ₁₀)	0.430	2.531	0.052	2.988	1.315	0.259	0.295	0.466	0.673
SS (X ₁₁)	0.302	1.979	0.105	3.027	1.680	0.168	0.471	0.861	0.453
Relationship (Wh×w)	Regression equation								
	Y = -1.804 + 12.531X ₃ - 13.117X ₄ - 12.963X ₅ - 0.077X ₆ - 4.974X ₇ + 5.151X ₈ + 5.231X ₉ + 0.430X ₁₀ + 0.302X ₁₁								
(I×Wh ×w)	Y = 60.220 + 3.578X ₂ + 131.093X ₃ - 138.734X ₄ - 131.669X ₅ - 0.705X ₆ - 68.984X ₇ + 70.442X ₈ + 69.982X ₉ + 2.988X ₁₀ + 3.027X ₁₁								
(P×I×Wh×w)	Y = 54.170 + 0.459X ₁ + 1.196X ₂ + 17.855X ₃ - 19.910X ₄ - 17.821X ₅ - 0.144X ₆ - 7.277X ₇ + 7.258X ₈ + 7.112X ₉ + 0.295X ₁₀ + 0.471X ₁₁								
R²	R²								
	0.900								
	0.959								
	0.966								

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

4.27. None of the weather parameters independently indicated significant influence on population of whitefly but found to contribute around 90.0 percent ($R^2 = 0.900$) impact on population of whitefly (*B. tabaci*) when acted together.

None of the parameters independently indicated significant influence on percent leaf curl incidence but found to contribute around 95.90 percent ($R^2 = 0.959$) impact on percent incidence of leaf curl when acted together (Table 4.27).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 96.60 percent ($R^2 = 0.966$) effect on percent disease index of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 0.459$) percent disease index (Table 4.27).

4.3.8 Epidemiology of Tomato leaf curl disease during *Kharif* 2015-2017

4.3.8.1 Incidence of adult whitefly (*B. tabaci*) population and incidence and PDI of ToLCD

During *Kharif* 2015 to 2017 the first trace of adult whitefly (0.07) was recorded 14 days after transplanting (DAT) on tomato which declined to nil at 21 DAT. The whitefly population was first gradually increased up to 42 DAT (0.91) then slightly declined up to 0.72 at 49 DAT. From 56 to 91 DAT the whitefly population rapidly increased. The maximum whitefly population (4.33) was recorded at 91 DAT during this period maximum and minimum temperature was 30.6 and 19.2 °C respectively, whereas maximum and minimum relative humidity was 86.8 and 48.2 percent respectively, temperature and relative humidity gradient was 12.711.4 and 38.5 respectively. Further, wind velocity (speed) and sun shine was 2.8 kmph and 7.6 hours respectively. However, no rainfall was recorded during this period. The population then subsumed slowly up to 105 DAT (Table 4.28 and Fig 4.28-4.30).

The first trace of tomato leaf curl disease (ToLCD) was observed 14 days after transplanting with percent leaf curl incidence of 0.64 and index of 0.14 percent. From 14 to 63 DAT the extent of leaf curl infection was gradually increased from 0.64 and 0.14 to 16.48 and 8.60 percent disease incidence and PDI respectively. Thereafter percent leaf curl incidence and PDI were rapidly increased from 63 to 98 DAT from 16.48 and 8.60 to 65.39 and 47.56 percent disease

incidence and PDI respectively. The maximum incidence (68.09%) and PDI (49.91%) was recorded 105 days after transplanting (Table 4.28 and Fig 4.28-4.30).

4.3.8.2 Correlation of ToLCD with its vector and weather parameters

The correlation analysis between weather parameters and the mean population of whitefly has been presented in Table 4.29. There was highly significant negative correlation was noted with population of whitefly and minimum temperature, rainfall, minimum relative humidity and wind velocity with correlation coefficient (r) of -0.873, -0.746, -0.930 and -0.790 respectively. However temperature gradient ($r = 0.933$, $p = 0.001$), relative humidity gradient ($r = 0.931$, $p = 0.001$) and sun shine ($r = 0.838$, $p = 0.001$) displayed highly significant positive correlation with whitefly population. Rest two parameter viz. maximum temperature and maximum relative humidity exhibited non significant negative correlation (Table 4.29 and Fig 4.28-4.30).

There was highly significant negative correlation was noted with percent leaf curl incidence and minimum temperature, rainfall, minimum relative humidity and wind velocity with correlation coefficient (r) of -0.967, -0.700, -0.928 and -0.722 respectively. However whitefly population ($r = 0.963$, $p = 0.001$), temperature gradient ($r = 0.973$, $p = 0.001$) relative humidity gradient ($r = 0.916$, $p = 0.001$) and sun shine (0.768, $p = 0.001$) showed highly significant positive correlation with percent leaf curl incidence. A significant negative correlation was observed between percent leaf curl incidence and maximum relative humidity (-0.523, $p = 0.005$). However, one parameter viz. maximum temperature indicated non significant negative correlation (Table 4.29 and Fig 4.28-4.30).

There was highly significant positive correlation was noted with leaf curl percent disease index and incidence, whitefly population, temperature gradient, relative humidity gradient and sun shine with correlation coefficient (r) of 0.997, 0.948, 0.966, 0.895 and 0.739 respectively. However minimum temperature ($r = -0.977$, $p = 0.001$), rainfall ($r = -0.691$, $p = 0.001$), minimum relative humidity ($r = -0.916$, $p = 0.001$) and wind velocity ($r = -0.677$, $p = 0.001$) indicated highly

significant negative correlation with percent disease index of leaf curl (Table 4.29 and Fig 4.28-4.30).

4.3.8.3 Regression of ToLCD with its vector and weather parameters

The regression analysis of tomato leaf curl disease with its vector population and weather or meteorological parameters have been presented in Table 4.30. None of the weather parameters independently indicated significant influence on population of whitefly but found to contribute around 89.50 percent ($R^2 = 0.895$) impact on population of whitefly (*B. tabaci*) when acted together (Table 4.30).

Percent incidence of leaf curl and weather parameters were found to contribute around 94.90 percent ($R^2 = 0.949$) impact on percent incidence of leaf curl when acted together. Regression also expressed that with every unit increase in whitefly population there was significant positive increase ($b = 8.064$) of percent leaf curl incidence (Table 4.30).

Whereas percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 95.30 percent ($R^2 = 0.953$) effect on PDI of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase ($b = 0.805$) of percent disease index (Table 4.30).

It was depicted from the data that activity of whitefly, percent leaf curl incidence and PDI were more in *rabi* (winter) season transplanted crop than *kharif* (rainy) season transplanted crop. The results of the present study were in accordance with Singh, *et al.* 2015 who observed positive relation of ToLCV disease incidence with coefficient of infection (CI %) and climatic factors (temperature, rainfall and humidity). In rainy season of three years (2007-2010), average rainfall was 75.50 mm, minimum and maximum temperature ranged from 24.86 °C to 40.00 °C, respectively with relative humidity of 74.82 % and CI (%) of ToLCV disease was reached on 32.5%. Whereas, in winter season, rainfall was minimum and static on 1.78 mm, minimum and maximum temperature ranged from 7.14°C to 28.70°C, respectively coupled with 62.39% relative humidity and CI (%) of ToLCV disease increased and reached up to 42.62%. In present

Table 4.28: Incidence and percent disease index (PDI) of leaf curl in relation to vector population and weather parameters on tomato (*Kharif* 2015 to 2017)

DAT	PDI	Incidence	Whitefly	T max (°C)	T min (°C)	T gr	Rainfall (mm)	RH max (%)	RH min (%)	RH gr	WS (kmph)	SS (hr)
7	0.00	0.00	0.00	31.7	25.7	6.0	3.5	87.2	70.8	16.4	6.5	4.8
14	0.14	0.64	0.07	30.1	24.7	5.3	8.6	92.1	75.6	16.4	5.8	2.0
21	0.41	1.11	0.00	30.9	25.0	5.8	8.6	91.5	72.9	18.6	6.2	2.6
28	1.32	3.19	0.43	31.7	25.5	6.2	3.0	88.9	66.6	22.4	5.1	5.6
35	2.33	4.91	0.58	31.6	25.4	6.2	4.6	92.4	73.8	18.7	3.0	3.5
42	4.21	8.05	0.91	32.4	25.7	6.7	3.1	89.9	64.6	25.4	4.5	5.0
49	4.71	9.18	0.72	32.1	24.9	7.2	13.1	93.5	68.7	24.8	3.6	5.6
56	6.58	12.33	1.05	31.8	24.8	7.0	6.3	92.9	67.0	25.9	3.0	6.2
63	8.60	16.48	1.45	32.0	24.6	7.4	4.9	93.4	65.5	27.9	2.7	5.8
70	14.43	25.24	2.29	32.4	23.5	8.9	1.2	93.2	58.2	35.0	2.3	6.1
77	22.09	34.05	3.03	32.9	21.8	11.1	0.3	89.9	40.8	49.2	2.0	8.8
84	31.67	46.53	3.87	32.8	20.7	12.1	0.0	88.9	38.3	50.7	1.9	8.5
91	41.68	57.15	4.33	30.6	19.2	11.4	0.0	86.8	48.2	38.5	2.8	7.6
98	47.56	65.39	4.04	29.8	17.2	12.6	0.0	89.8	43.0	46.8	2.5	6.9
105	49.91	68.09	3.57	30.2	14.8	15.3	0.0	86.2	33.2	53.1	2.0	7.9

Table 4.29: Correlation of tomato leaf curl disease with its vector and weather parameters (Kharif 2015 to 2017)

Variables / factors	DAT	PDI	Incidence	Whitefly
DAT	1			
PDI	0.916**	1		
Incidence (%)	0.940**	0.997**	1	
Whitefly	0.946**	0.948**	0.963**	1
T max (°C)	-0.090 ^{NS}	-0.368 ^{NS}	-0.316 ^{NS}	-0.117 ^{NS}
T min (°C)	-0.861**	-0.977**	-0.967**	-0.873**
T gr	0.929**	0.966**	0.973**	0.933**
Rainfall (mm)	-0.630**	-0.691**	-0.700**	-0.746**
RH max (%)	-0.290 ^{NS}	-0.562*	-0.523*	-0.457 ^{NS}
RH min (%)	-0.897**	-0.916**	-0.928**	-0.930**
RH gr	0.927**	0.895**	0.916**	0.931**
WS (kmph)	-0.889**	-0.677**	-0.722**	-0.790**
SS (hr)	0.838**	0.739**	0.768**	0.838**

*Significant (at 5% d.f.), **Highly significant (at 1% d.f.)

DAT= Days after transplanting, gr= gradient, Max= Maximum, Min= Minimum, PDI= Percent disease index, RH= Relative humidity, SS= Sun shine, T= Temperature, WS= Wind speed

Table 4.30: Regression equation of tomato leaf curl disease with its vector and weather parameters (*Kharif* 2015 to 2017)

Variables / factors	Whitefly $\times$ weather (Wh $\times$ w)		Incidence $\times$ whitefly and weather (I $\times$ Wh $\times$ w)		PDI $\times$ incidence, whitefly and weather (P $\times$ I $\times$ Wh $\times$ w)	
	Coefficient (b)	t stat	p-value	Coefficient (b)	t stat	p-value
Dependant variable (Y)	Whitefly			Incidence		
						PDI
Intercept (a)	2.504	0.080	0.939	-9.720	-0.082	77.118
Incidence (X ₁)	-	-	-	-	-	0.805
Whitefly (X ₂)	-	-	-	8.064**	4.729	0.009**
T max (X ₃)	-11.813	-1.132	0.309	18.812	0.422	-0.498
T min (X ₄)	12.068	1.114	0.316	-23.391	-0.507	-0.001
T gr (X ₅)	12.154	1.108	0.318	-17.459	-0.374	-0.385
Rainfall (X ₆)	-0.046	-0.471	0.658	-0.318	-0.835	-1.071
RH max (X ₇)	10.950	1.229	0.274	-12.451	-0.321	0.181
RH min (X ₈)	-11.069	-1.237	0.271	13.773	0.353	-1.570
RH gr (X ₉)	-10.974	-1.228	0.274	13.103	0.337	0.901
WS (X ₁₀)	-0.133	-0.330	0.755	1.041	0.672	0.982
SS (X ₁₁)	-0.154	-0.391	0.712	1.871	1.230	-0.319
Relationship	Regression equation			R²		
(Wh $\times$ w)	Y = 2.504 - 11.813X ₃ + 12.068X ₄ + 12.154X ₅ - 0.046X ₆ + 10.950X ₇ - 11.069X ₈ - 10.974X ₉ - 0.133X ₁₀ - 0.154X ₁₁			0.895		
(I $\times$ Wh $\times$ w)	Y = -9.720 + 8.064X ₂ + 18.812X ₃ - 23.391X ₄ - 17.459X ₅ - 0.318X ₆ - 12.451X ₇ + 13.773X ₈ + 13.103X ₉ + 1.041X ₁₀ + 1.871X ₁₁			0.949		
(P $\times$ I $\times$ Wh $\times$ w)	Y = 77.118 + 0.805X ₁ - 0.498X ₂ - 0.018X ₃ - 0.385X ₄ - 1.071X ₅ + 0.181X ₆ - 1.570X ₇ + 0.901X ₈ + 0.982X ₉ - 0.319 X ₁₀ - 0.408 X ₁₁			0.953		

Significance: Highly significant (**) = less than 0.01 p-value (at 1%), Significant (*) = less than 0.05 p-value (at 5%)

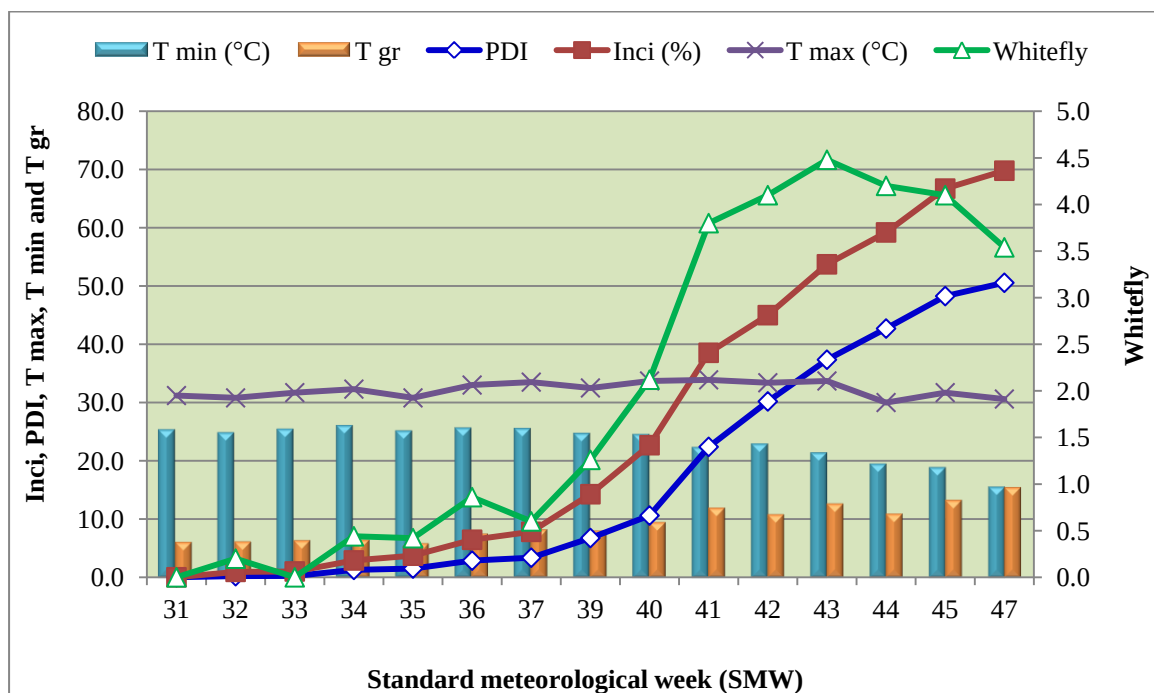


Fig. 4.19: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (Kharif 2015)

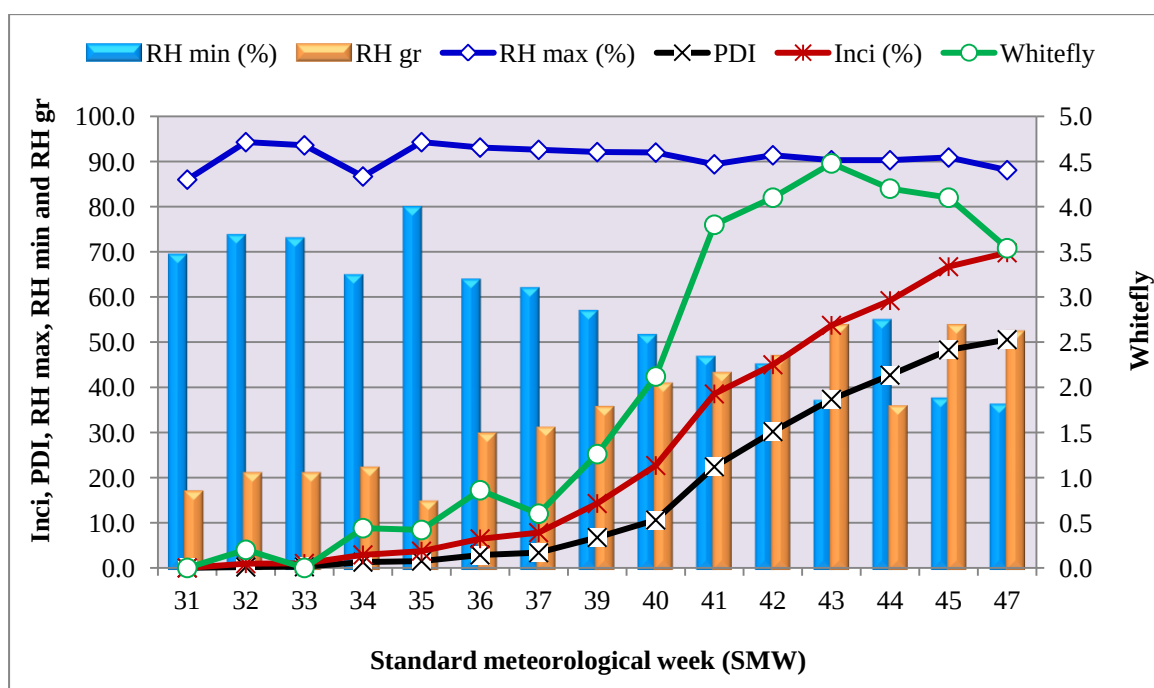


Fig. 4.20: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Kharif 2015)

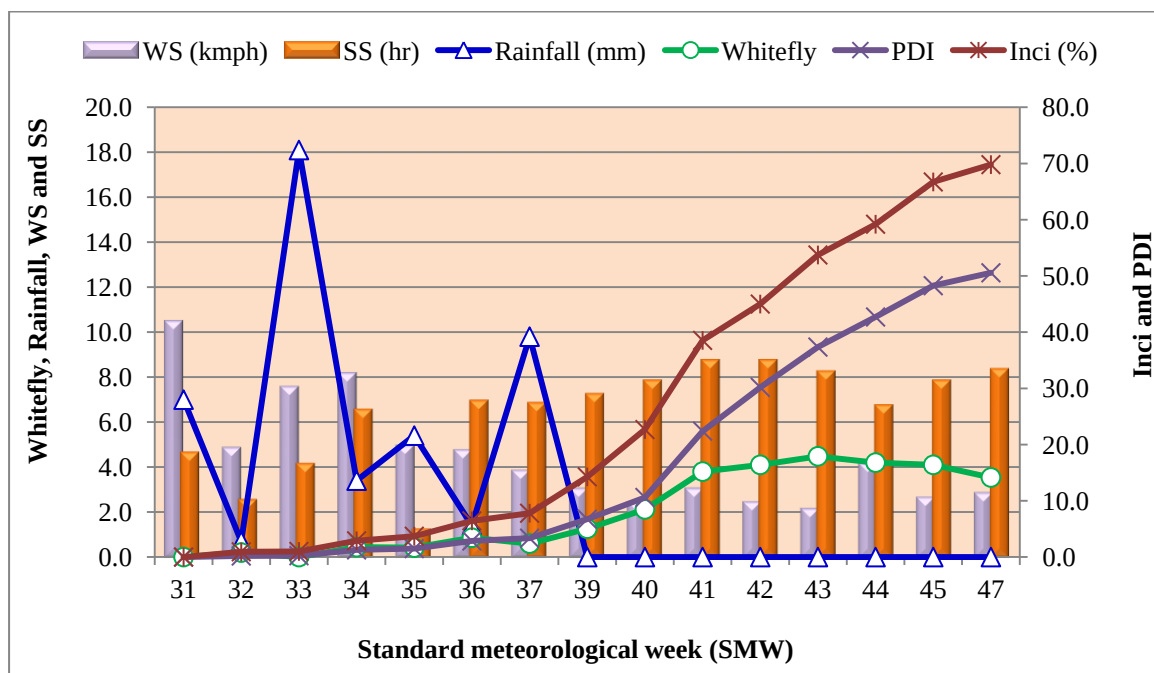


Fig. 4.21: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (*Kharif 2015*)

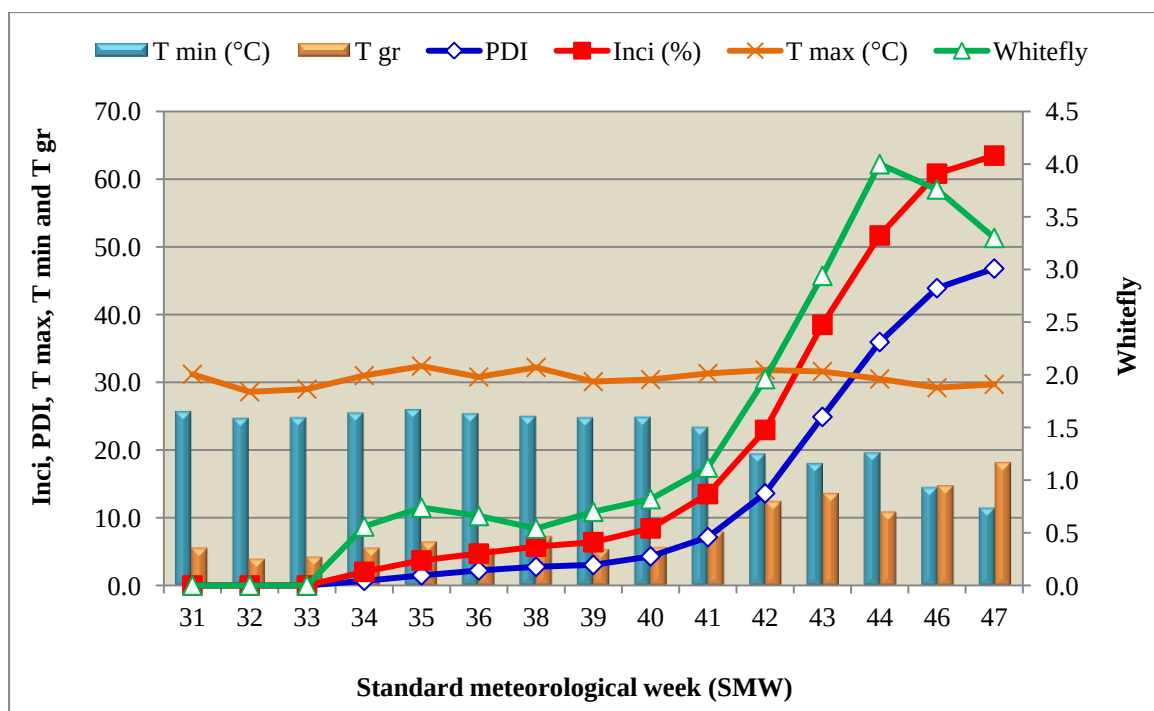


Fig. 4.22: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (*Kharif 2016*)

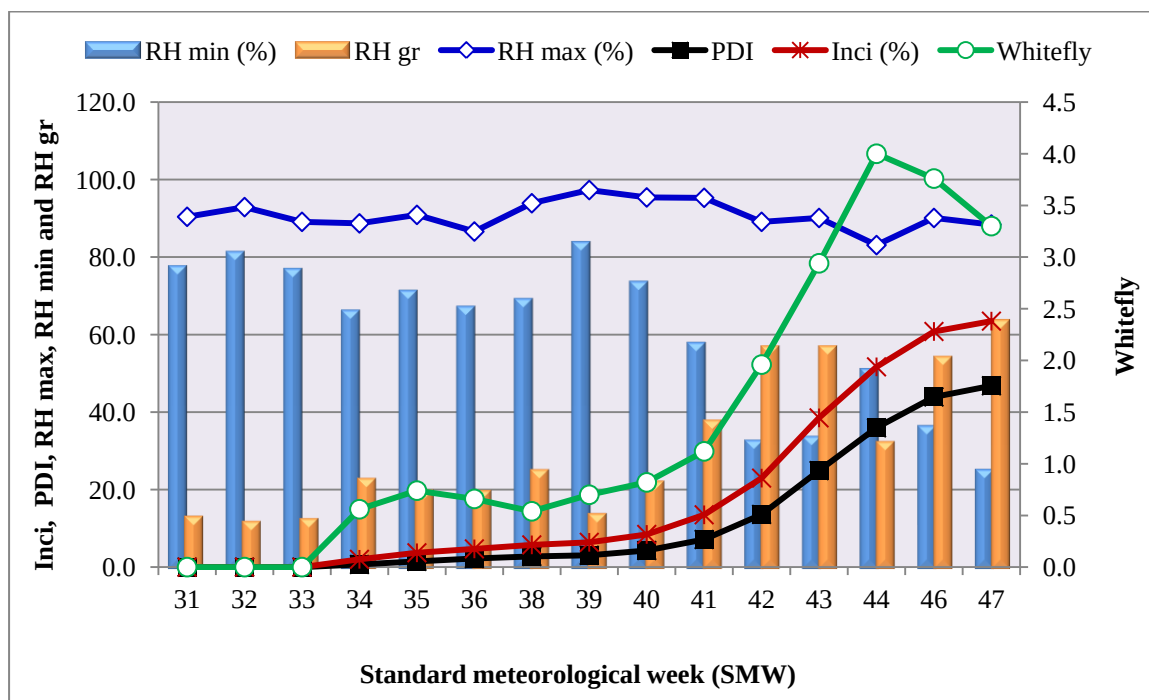


Fig. 4.23: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Kharif 2016)

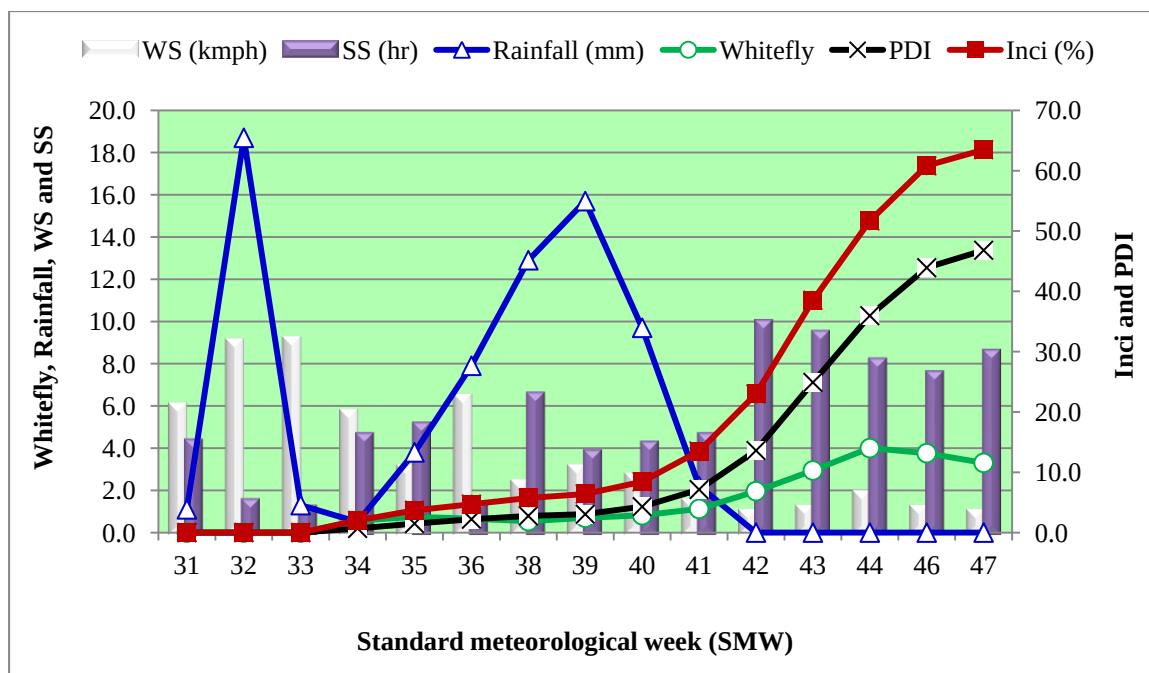


Fig. 4.24: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (Kharif 2016)

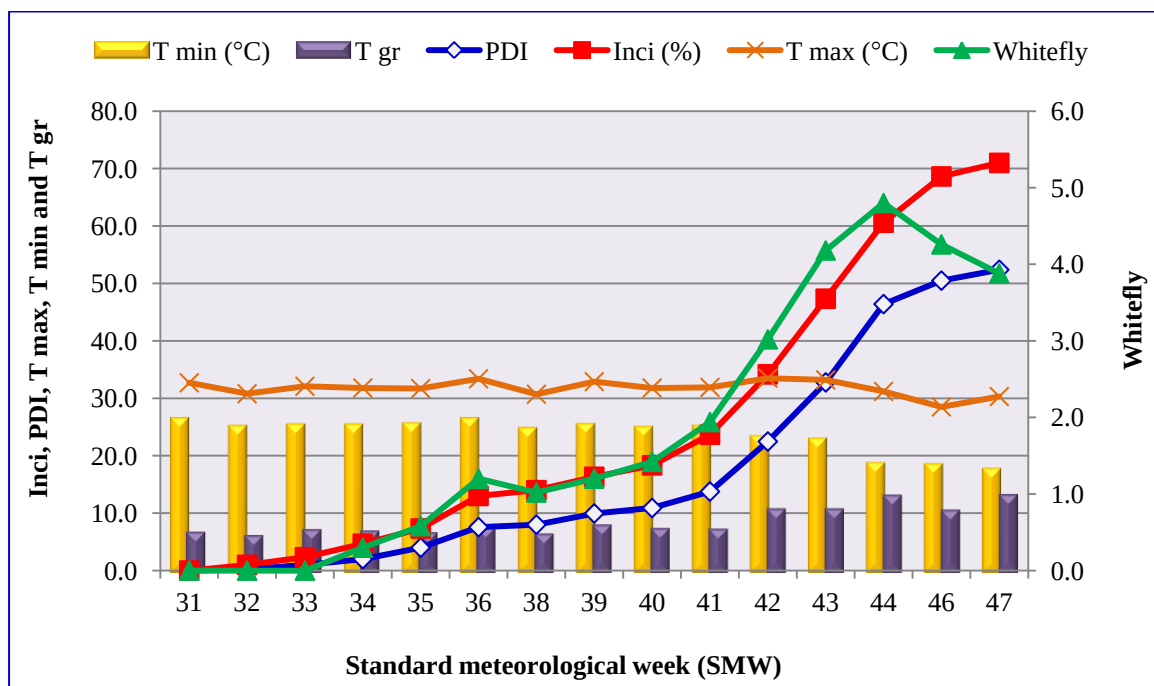


Fig. 4.25: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (Kharif 2017)

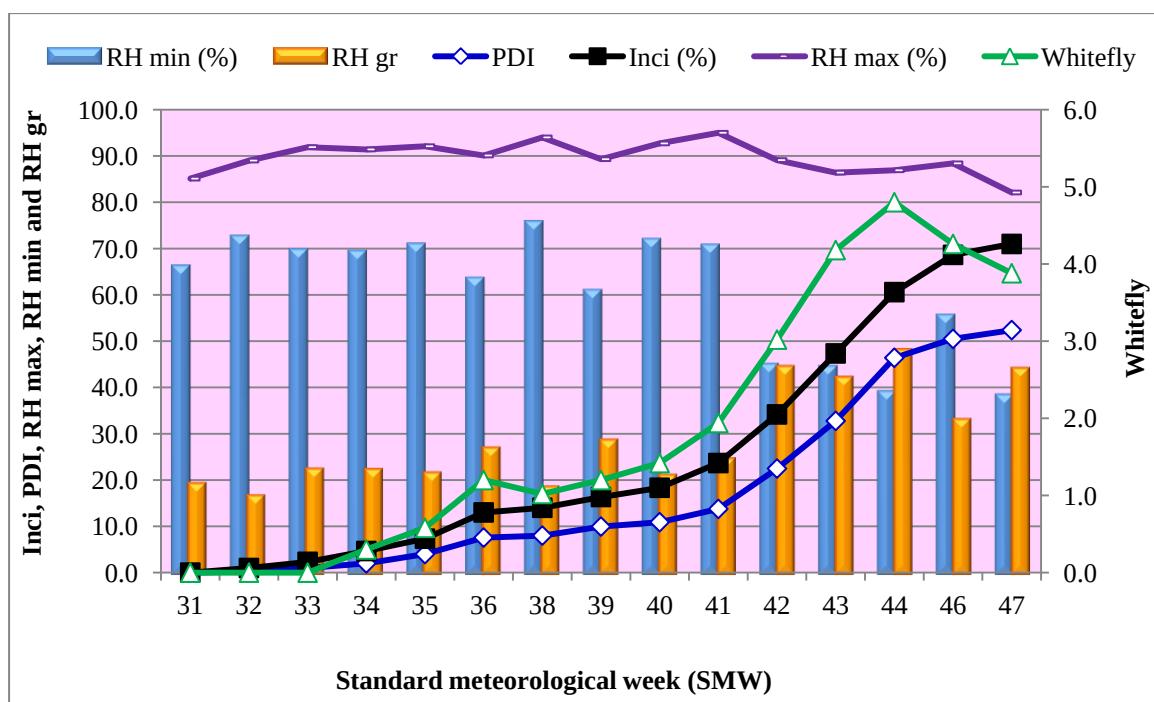


Fig. 4.26: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Kharif 2017)

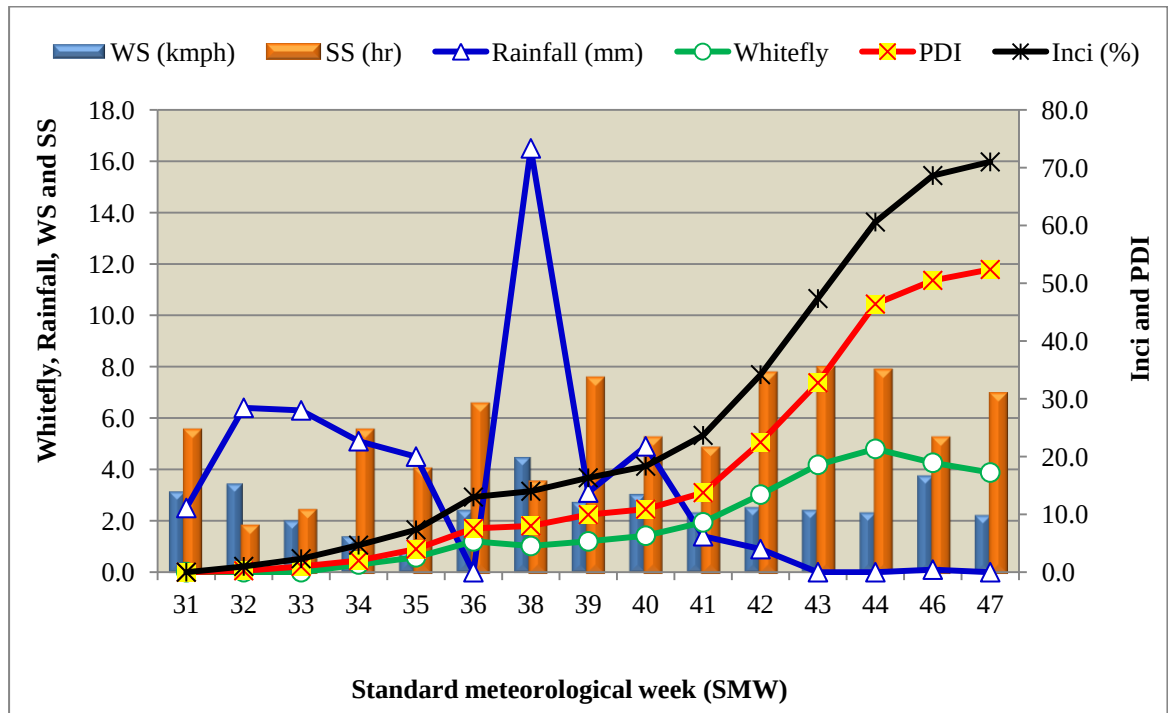


Fig. 4.27: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (Kharif 2017)

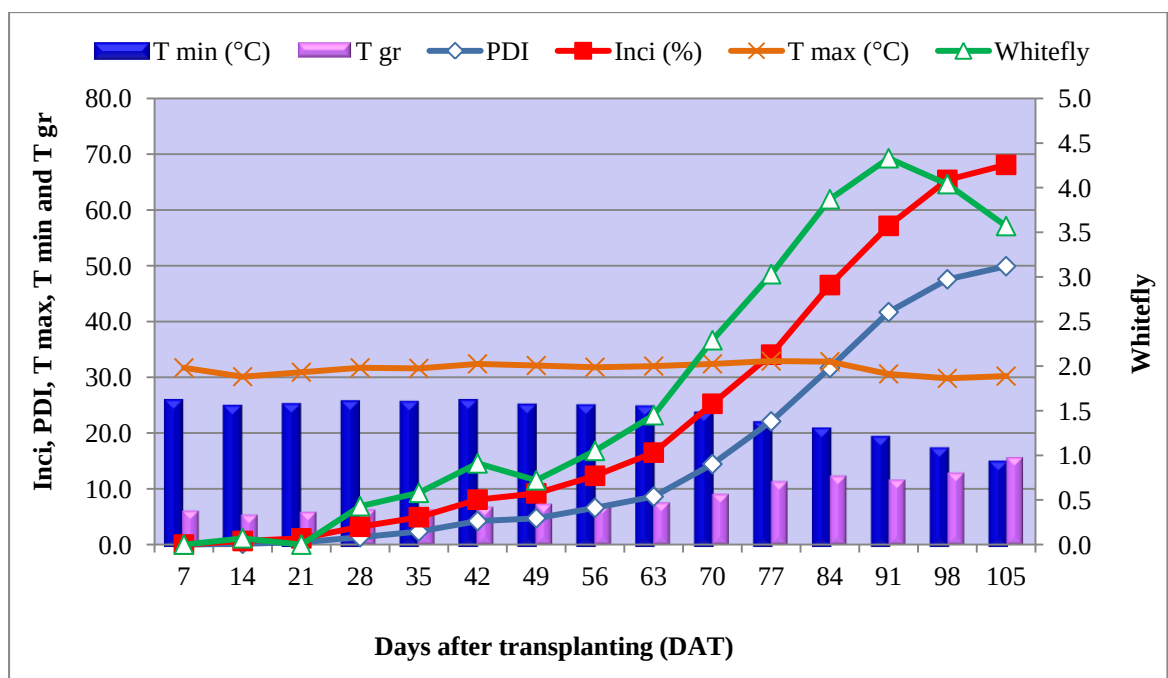


Fig. 4.28: Correlation of leaf curl disease with its vector and T max, T min, and T gradient (Kharif 2017)

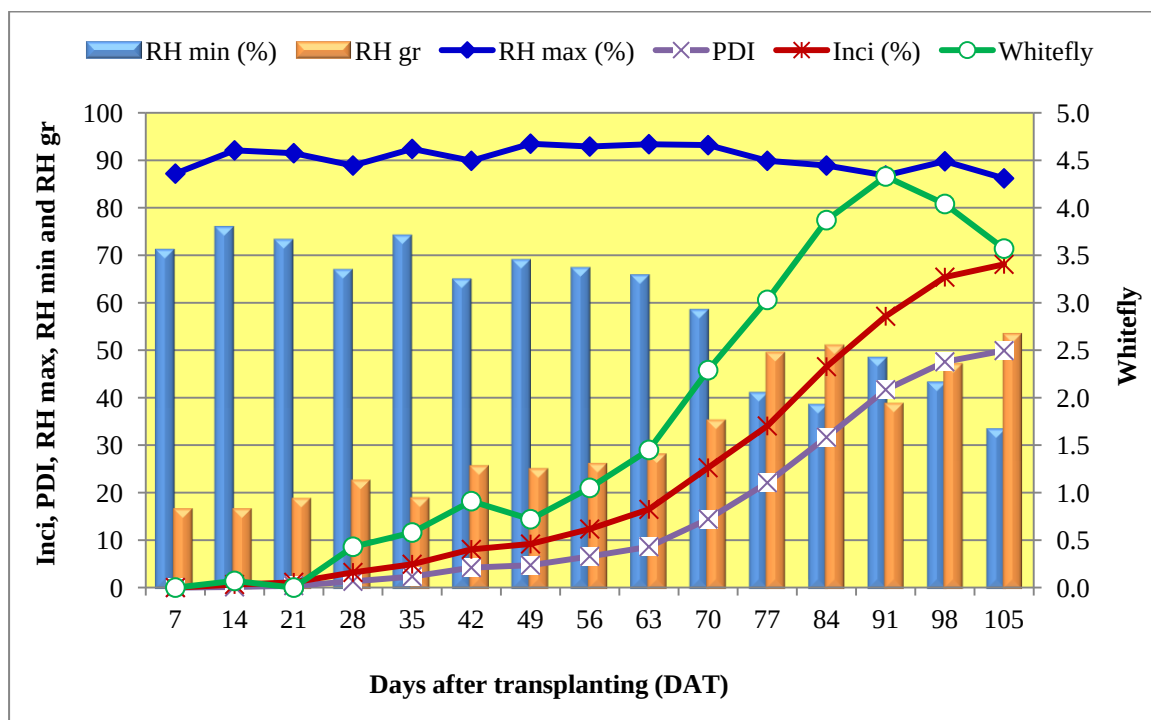


Fig. 4.29: Correlation of leaf curl disease with its vector and RH max, RH min, and RH gradient (Kharif 2015 to 2017)

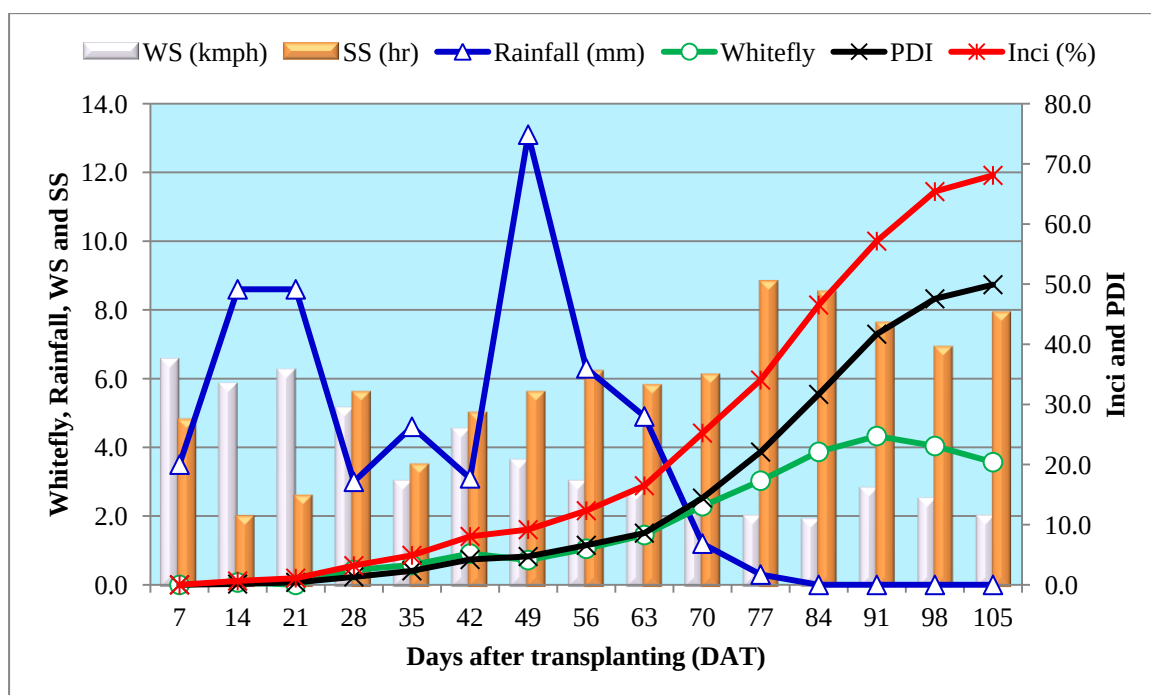


Fig. 4.30: Correlation of leaf curl disease with its vector and rainfall, wind speed and sun shine (Kharif 2015 to 2017)

investigation, ToLCV disease incidence increased in winter season (October - February) than rainy season (July -September) grown crop. This may be population of vector whiteflies did not survived and multiplied in rainy season due to high temperature whereas, winter season was more favourable for faster multiplication of whitefly population. Both whitefly and disease incidence was more in winter season transplanted crop than rainy season at eastern part of Uttar Pradesh in Varanasi (Singh, *et al.* 2010, Singh, *et al.* 2013).

Weather parameters played a key role in the development of whitefly (*B. tabaci*) population on tomato (Sharma *et al.*, 2017). The results of the present study were in accordance with Ashfaq *et al.* (2010) and Kaur *et al.* (2010) who also reported that the whitefly population was positively correlated with mean temperature and negatively correlated with mean relative humidity. The positive correlation between the temperature and whitefly population can be attributed to the enhanced rate of development and reproduction of whitefly. The relatively higher temperatures can be conducive for rapid multiplication and activity of whitefly. Sharma *et al.*, (2017) observed a positive correlation between adult population and abiotic factors viz. temperature (maximum and minimum) and sunshine hours, whereas humidity (maximum and minimum) and rainfall showed a negative correlation with it and these parameters together caused 89.00 percent contribution in whitefly population.

Temperature (maximum and minimum) had positively significant relationship for whitefly population and disease incidence. With increase in maximum temperature whitefly population showed 77 to 99 percent variability while minimum temperature it was 66 to 99 percent variability. Tomato leaf curl virus disease (TLCVD) incidence showed 84 to 96 percent variability with minimum temperature while 86 to 96 percent with maximum temperature. Relative humidity had negatively significant relationship with whitefly population and disease incidence. With increase in relative humidity whitefly population and TLCVD incidence decreased. Relative humidity showed 75 to 96 and 83 to 93 percent variability in case of whitefly population and disease incidence respectively (Haider *et al.*, 2017).

However in contrary to present results Jha and Kumar (2017) reported that maximum and minimum temperature and sun shine exhibited significant negative correlation whereas maximum and minimum relative humidity showed significant positive correlation with whitefly population. The weather parameters were found to contribute around 55.70 percent impact on population of whitefly when acted jointly ($R^2 = 0.5570$).

4.4 To evaluate the performance of popular commercial varieties/ hybrids and others (entries) against Tomato leaf curl disease

4.4.1. 2014/ToLCVRES entries/ variety

A sum of seven 2014/ToLCVRES entries/ variety with a susceptible check variety viz. Punjab Chhuhara were evaluated against tomato leaf curl disease (ToLCD) during *rabi* 2015-16 and 2016-17 and results were presented in Table 4.31a to 4.41 (Fig 4.31).

4.4.1.1 Disease incidence and percent disease index (PDI)

Substantial variability was found in incidence of all 2014/ToLCVRES entries/ variety evaluated under the study. During 2015-16 disease incidence varied from 0 to 4.84, 3.92 to 23.81, 9.80 to 48.04, 15.69 to 66.67, 18.63 to 77.45 and 25.49 to 91.18 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the calculated percent disease index (PDI) was also varied from 0 to 2.90, 2.24 to 14.83, 5.04 to 30.39, 11.34 to 45.38, 14.49 to 56.72 and 14.49 to 70.73 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The entries 2014/ToLCVRES-1, 2014/ToLCVRES-5 and variety H-24 were free from the disease up to 15 days after transplanting but in the rest other, symptoms of tomato leaf curl was appeared at 15 DAT (Table 4.31a – 4.32b).

While during 2016-17 disease incidence varied from 0 to 6.51, 1.67 to 16.94, 9.56 to 47.32, 11.85 to 82.42, 21.30 to 96.46 and 32.31 to 99.12 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the percent disease index (PDI) was also varied from 0 to 0.81, 0.48 to 9.44, 4.87 to 26.84, 7.75 to 59.12, 14.22 to 70.66 and 22.58 to 77.76 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Four entries 2014/ToLCVRES-1, 2014/ToLCVRES-2, 2014/ToLCVRES-3 and

2014/ToLCVRES-4 were free from the disease up to 15 days after transplanting but others showed first symptoms of tomato leaf curl disease at 15 days after transplanting (Table 4.31a – 4.32b).

The average incidence and PDI of leaf curl for both the years (2015-16 and 2016-17) displayed that disease incidence varied from 0 to 3.26, 3.23 to 14.42, 9.98 to 34.86, 13.77 to 60.70, 19.97 to 73.86 and 28.90 to 89.17 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the calculated percent disease index (PDI) varied from 0 to 1.63, 1.67 to 8.86, 4.96 to 20.11, 9.56 to 42.61, 14.36 to 52.75 and 24.46 to 68.91 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Only one entry viz. 2014/ToLCVRES-1 was free from the disease up to 15 days after transplanting whereas others were found infected with the leaf curl at 15 days after transplanting (Table 4.31a – 4.32b).

During 2015-16 at 90 DAT the lowest percent incidence and PDI was recorded in 2014/ToLCVRES-3 (25.49, 14.49 %) followed by 2014/ToLCVRES-1 (38.10, 17.28 %) and 2014/ToLCVRES-4 (47.62, 21.91 %) and highest in Punjab Chhuhara (91.18, 70.73 %) (Table 4.31a – 4.32b).

During 2016-17 at 90 DAT the percent incidence and PDI was also recorded lowest in 2014/ToLCVRES-3 (32.31, 22.58 %) followed by 2014/ToLCVRES-1 (45.34, 31.64 %) and 2014/ToLCVRES-4 (46.24, 33.03 %). However, the highest incidence and PDI was noted in H-24 (99.12, 77.76 %) (Table 4.31a – 4.32b).

The average incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) showed that at 90 DAT the lowest percent incidence of leaf curl was observed in 2014/ToLCVRES-3 (28.90%) followed by 2014/ToLCVRES-1 (41.72%) and 2014/ToLCVRES-4 (46.93%). Whereas, the lowest PDI was recorded from 2014/ToLCVRES-1 (24.46%) followed by 2014/ToLCVRES-3 (25.78%) and 2014/ToLCVRES-4 (27.47%). The highest mean percent incidence and PDI was recorded in Punjab Chhuhara (89.17, 68.91%) (Table 4.31a – 4.32b).

4.4.1.2 Reaction and level of resistance of 2014/ToLCVRES entries/ variety against ToLCD

Among the seven 2014/ToLCVRES entries/ variety evaluated during 2015-16, one entry viz. 2014/ToLCVRES-3 was regarded as resistant and fall under the grade 1. Of them two entries viz. 2014/ToLCVRES-1 and 2014/ToLCVRES-4 were categorized as moderately resistant with rating 3. However, two entries viz. 2014/ToLCVRES-2 and 2014/ToLCVRES-5 were kept in moderately susceptible category with rating 5. Two varieties viz. H-24 and Punjab Chhuhara were classified under the susceptible reaction with rating 7 (Table 4.33).

Out of seven 2014/ToLCVRES entries/ variety evaluated during 2016-17, none of the entry/ variety was found resistant against ToLCD. However, one entry viz. 2014/ToLCVRES-3 was regarded as moderately resistant with rating 3. Two entries viz. 2014/ToLCVRES-1 and 2014/ToLCVRES-4 were categorized as moderately susceptible and assigned with rating 5. Four entries/ varieties viz. 2014/ToLCVRES-2, 2014/ToLCVRES-5, H-24 and Punjab Chhuhara were shown as susceptible with rating 7 (Table 4.33).

The result of evaluation for both years (2015-16 and 2016-17) displayed that the performance of two varieties viz. H-24 and Punjab Chhuhara were constant with susceptible reaction but none of the entry was found constant with resistant, moderately resistant or moderately susceptible reaction (Table 4.33).

4.4.1.3 Yield parameters of 2014/ToLCVRES entries/ variety

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out for both the years (2015-16 and 2016-17) and presented in Table 4.34.

The number of fruits plant⁻¹ is an important attribute that contributes to the final productivity of tomato plant (Table 4.634). During 2015-16 the number of fruits plant⁻¹ significantly ranged from 34.17 (Punjab Chhuhara) to 65.00 (H-24). The significant maximum number of fruits plant⁻¹ was recorded in H-24 (65.00) followed by 2014/ToLCVRES-2 (50.90) and 2014/ToLCVRES-4 (41.10). However, the lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (34.17). During 2016-17 the number of fruits plant⁻¹ significantly ranged from

Table 4.31a: Percent incidence of tomato leaf curl disease in 2014/ToLCVRES entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)						
	15			30			45
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16
2014/ToLCVRES-1	0.00	0.00	0.00	4.76	1.69	3.23	11.43
2014/ToLCVRES-2	1.91	0.00	0.96	13.33	4.17	8.75	21.90
2014/ToLCVRES-3	0.98	0.00	0.49	3.92	2.54	3.23	9.80
2014/ToLCVRES-4	1.90	0.00	0.95	6.67	1.67	4.17	13.33
2014/ToLCVRES-5	0.00	1.80	0.90	9.52	4.53	7.03	20.95
H-24	0.00	6.51	3.25	9.52	16.94	13.23	22.41
Punjab Chhuhara	4.84	1.67	3.26	23.81	5.02	14.42	48.04
							15.10
							31.57

Table 4.31b: Percent incidence of tomato leaf curl disease in 2014/ToLCVRES entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)						
	60			75			90
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16
2014/ToLCVRES-1	21.91	14.80	18.36	27.62	34.03	30.83	38.10
2014/ToLCVRES-2	39.05	24.17	31.61	44.76	83.49	64.13	62.86
2014/ToLCVRES-3	15.69	11.85	13.77	18.63	21.30	19.97	25.49
2014/ToLCVRES-4	24.76	16.77	20.77	33.33	32.78	33.06	47.62
2014/ToLCVRES-5	34.29	21.47	27.88	46.67	78.99	62.83	60.95
H-24	38.98	82.42	60.70	51.26	96.46	73.86	63.39
Punjab Chhuhara	66.67	40.74	53.71	77.45	69.89	73.67	91.18
							87.16
							89.17

Table 4.32a: Evaluation of 2014/ToLCVRES entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)									
	15					30				
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2016-17
2014/ToLCVRES-1	0.00	0.00	0.00	3.13	0.97	2.05	6.80	5.58	6.19	6.19
2014/ToLCVRES-2	0.54	0.00	0.27	7.62	2.03	4.83	13.20	6.66	9.93	9.93
2014/ToLCVRES-3	0.14	0.00	0.07	2.24	1.09	1.67	5.04	4.87	4.96	4.96
2014/ToLCVRES-4	0.27	0.00	0.14	4.49	0.48	2.49	8.16	5.50	6.83	6.83
2014/ToLCVRES-5	0.00	0.75	0.38	6.26	2.47	4.37	12.79	8.22	10.51	10.51
H-24	0.00	0.81	0.41	5.99	9.44	7.71	12.52	26.84	19.68	19.68
Punjab Chhuhara	2.90	0.36	1.63	14.83	2.89	8.86	30.39	9.82	20.11	20.11

Table 4.32b: Evaluation of 2014/ToLCVRES entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)										Reaction (at final observation)				
	60			75			90								
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Constant
2014/ToLCVRES-1	16.46	7.58	12.02	17.28	15.56	16.42	17.28	31.64	24.46	MR	MS				
2014/ToLCVRES-2	24.22	16.07	20.15	29.79	56.41	43.10	29.79	69.81	49.80	MS	S				
2014/ToLCVRES-3	11.34	7.75	9.56	14.49	14.22	14.36	14.49	22.58	25.78	R	MR				
2014/ToLCVRES-4	17.01	9.59	13.30	21.91	17.89	19.90	21.91	33.03	27.47	MR	MS				
2014/ToLCVRES-5	23.40	14.58	18.99	31.70	52.41	42.06	31.70	67.15	49.43	MS	S				
H-24	26.10	59.12	42.61	34.85	70.66	52.75	47.62	77.76	62.69	S	S				S
Punjab Chhuhara	45.38	27.91	36.65	56.72	48.57	52.65	70.73	67.10	68.91	S	S				S

Table 4.33: Classification of 2014/ToLCVRES entries in different reaction categories

Year	Reaction category	No. of entry/ variety	Name of entry/ variety
Entries/ varieties with constant reaction in both the years	Resistant	-	
	Moderately resistant	-	
	Moderately susceptible	-	
	Susceptible	2	H-24, Punjab Chhuhara
2015-16	Resistant	1	2014/ToLCVRES-3
	Moderately resistant	2	2014/ToLCVRES-1, 2014/ToLCVRES-4
	Moderately susceptible	2	2014/ToLCVRES-2, 2014/ToLCVRES-5
	Susceptible	2	H-24, Punjab Chhuhara
	Resistant	-	
2016-17	Moderately resistant	1	2014/ToLCVRES-3
	Moderately susceptible	2	2014/ToLCVRES-1, 2014/ToLCVRES-4
	Susceptible	4	2014/ToLCVRES-2, 2014/ToLCVRES-5, H-24, Punjab Chhuhara,

34.13 (2014/ToLCVRES-1) to 64.47 (H-24). The significant maximum number of fruits plant⁻¹ was recorded in H-24 (64.47) followed by 2014/ToLCVRES-2 (50.73) and 2014/ToLCVRES-4 (42.45). The lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (34.25). The mean number of fruits plant⁻¹ of both years (2015-16 and 2016-17) exhibited that the number of fruits plant⁻¹ significantly ranged from 34.25 (Punjab Chhuhara) to 64.73 (H-24). The maximum number of fruits plant⁻¹ was observed in H-24 (64.73) followed by 2014/ToLCVRES-2 (50.82) and 2014/ToLCVRES-4 (42.45). However, the lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (34.25).

Fruit yield plant⁻¹ is an important character that contributes the yield potential of tomato plant. The significant difference was observed among 2014/ToLCVRES entries/ varieties for fruit yield plant⁻¹ (Table 4.34). During 2015-16, it ranged from 1.40 (Punjab Chhuhara) to 3.02 kg (2014/ToLCVRES-2). The maximum fruit yield plant⁻¹ was observed in 2014/ToLCVRES-2 (3.02 kg) followed by 2014/ToLCVRES-5 (2.81 kg) and 2014/ToLCVRES-1 (2.53 kg) and the minimum was in Punjab Chhuhara (1.40 kg). During 2016-17, the fruit yield plant⁻¹ ranged from 1.36 (Punjab Chhuhara) to 2.95 kg (2014/ToLCVRES-2). The maximum fruit yield plant⁻¹ was recorded in 2014/ToLCVRES-2 (2.95 kg) followed by 2014/ToLCVRES-5 (2.73 kg) and 2014/ToLCVRES-4 (2.56 kg) and minimum was observed in Punjab Chhuhara (1.36 kg). The mean fruit yield plant⁻¹ of both years (2015-16 and 2016-17) displayed that the fruit yield plant⁻¹ significantly ranged from 1.38 kg (Punjab Chhuhara) to 2.99 kg (2014/ToLCVRES-2). The maximum fruit yield plant⁻¹ was noted in 2014/ToLCVRES-2 (2.99 kg) followed by 2014/ToLCVRES-5 (2.77 kg) and 2014/ToLCVRES-4 (2.50 kg) and the minimum was observed in Punjab Chhuhara (1.38 kg).

Average fruit weight is an important yield contributing parameter that contributes the yield of tomato. The significant variation was observed in average fruit weight of commercial varieties evaluated during 2015-16 and 2016-17 (Table 4.34). In both the years (2015-16 and 2016-17) the maximum average fruit weight was recorded in 2014/ToLCVRES-1 (73.40 and 71.64 g) followed by 2014/ToLCVRES-5 (68.92 and 66.80 g) and 2014/ToLCVRES-3 (63.99 and 63.46

g). However 2014/ToLCVRES-5 was at par with 2014/ToLCVRES-1. The lowest average fruit weight was observed from Punjab Chhuhara (41.05 and 40.39 g). The pooled mean data of average fruit weight also expressed that average fruit weight was recorded maximum in 2014/ToLCVRES-1 (72.52 g) followed by 2014/ToLCVRES-5 (67.86 g) and 2014/ToLCVRES-3 (63.73 g). However the lowest weight was noted in Punjab Chhuhara (40.72 g).

4.4.1.4 Yield of 2014/ToLCVRES entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or variety. Marketable yield ha^{-1} , Unmarketable yield ha^{-1} and Total yield ha^{-1} were computed for all the 2014/ToLCVRES entries/ varieties evaluated in both the years (2015-16 and 2016-17) and depicted in Table 4.35.

Marketable yield ha^{-1} directly influences the economic yield of tomato. The significant difference was observed in marketable yield ha^{-1} of 2014/ToLCVRES entries/ varieties evaluated during 2015-16 and 2016-17 (Table 4.35). In both the years the highest marketable yield ha^{-1} was recorded in 2014/ToLCVRES-5 (554.74 and 545.17 q). This was followed by 2014/ToLCVRES-1 (438.22 q) and 2014/ToLCVRES-2 (413.98 q) in 2015-16 and 2014/ToLCVRES-1 (412.04 q) and 2014/ToLCVRES-4 (407.54 q) in 2016-17. However in both the years the lowest marketable yield ha^{-1} was observed in Punjab Chhuhara (145.24 and 140.61 q). The pooled mean data also exhibited the significant maximum marketable yield ha^{-1} in 2014/ToLCVRES-5 (549.96 q) followed by 2014/ToLCVRES-1 (425.13 q) and 2014/ToLCVRES-2 (407.19 q). The minimum yield was recorded in Punjab Chhuhara (142.92 q).

Unmarketable yield ha^{-1} directly influences the yield of tomato. In 2015-16 the unmarketable yield was ranged between 4.39 to 26.52 q (Table 4.68). The minimum unmarketable yield was recorded in 2014/ToLCVRES-3 (4.39 q) followed by H-24 (5.18 q) and 2014/ToLCVRES-4 (12.96 q). The maximum unmarketable yield was obtained from Punjab Chhuhara (26.52 q). During 2016-17 it ranged from 7.81 to 22.75 q and the minimum was recorded in Punjab Chhuhara (6.62 q) followed by 2014/ToLCVRES-4 (7.81 q) and 2014/ToLCVRES-5 (8.86 q). The maximum unmarketable yield ha^{-1} was observed in 2014/ToLCVRES-3

Table 4.34: Yield parameters of 2014/ToLCVRES entries

Entry/ variety	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/ToLCVRES-1	34.43	34.13	34.28	2.53	2.43	2.48	73.40	71.64	72.52
2014/ToLCVRES-2	50.90	50.73	50.82	3.02	2.95	2.99	59.40	59.35	59.38
2014/ToLCVRES-3	38.40	37.40	37.90	2.46	2.37	2.41	63.99	63.46	63.73
2014/ToLCVRES-4	41.10	43.80	42.45	2.44	2.56	2.50	59.46	57.59	58.52
2014/ToLCVRES-5	40.80	40.93	40.87	2.81	2.73	2.77	68.92	66.80	67.86
H-24	65.00	64.47	64.73	2.37	2.30	2.33	36.46	36.52	36.49
Punjab Chhuhara	34.17	34.33	34.25	1.40	1.36	1.38	41.05	40.39	40.72
Sem±	2.693	3.621	2.197	0.082	0.101	0.066	1.935	2.237	1.502
CD (p=0.05)	8.299*	11.158*	6.770*	0.251*	0.310*	0.204*	5.961*	6.894*	4.629*
CV	10.714	14.357	8.726	5.805	7.317	4.763	5.825	6.854	4.563

Table 4.35: Yield performance of 2014/ToL CVRES entries

Entry/ variety	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/ToL CVRES-1	438.22	412.04	425.13	13.71	14.42	14.06	451.93	426.46	439.19
2014/ToL CVRES-2	413.98	400.40	407.19	13.44	22.36	17.90	427.42	422.75	425.09
2014/ToL CVRES-3	354.16	344.58	349.37	4.39	22.75	13.57	358.55	367.33	362.94
2014/ToL CVRES-4	401.35	407.54	404.44	12.96	7.81	10.39	414.31	415.34	414.83
2014/ToL CVRES-5	554.74	545.17	549.96	21.93	8.86	15.40	576.67	554.04	565.35
H-24	357.96	349.34	353.65	5.18	14.68	9.93	363.15	364.02	363.59
Punjab Chhuhara	145.24	140.61	142.92	26.52	6.62	16.57	171.76	147.22	159.49
Sem±	6.708	7.151	5.737	1.852	2.132	1.561	6.713	7.926	6.018
CD (p=0.05)	20.670*	22.033*	17.678*	5.706*	6.570*	4.809*	20.685*	24.422*	18.542*
CV	3.051	3.335	2.642	22.881	26.515	19.346	2.945	3.563	2.672

(22.75 q). However it is visible from mean of both the years that the lowest unmarketable yield ha^{-1} was obtained from H-24 (9.93 q) followed by 2014/ToLCVRES-4 (10.39 q) and 2014/ToLCVRES-3 (13.57 q). The maximum unmarketable yield ha^{-1} was recorded in 2014/ToLCVRES-2 (17.90 q).

Total yield ha^{-1} directly contributes the final yield of the crop. In both the years (2015-16 and 2016-17) significant difference was observed in total yield ha^{-1} among the 2014/ToLCVRES entries/ varieties evaluated under the study (Table 4.35). During 2015-16, the total yield ha^{-1} ranged from 171.76 q (Punjab Chhuhara) to 576.67 q (2014/ToLCVRES-5). The maximum marketable yield ha^{-1} was noted in 2014/ToLCVRES-5 (576.67 q) followed by 2014/ToLCVRES-1 (451.93 q) and 2014/ToLCVRES-2 (427.42 q). The minimum marketable yield ha^{-1} was observed in Punjab Chhuhara (171.76 q). During 2016-17, the highest total yield ha^{-1} was recorded in 2014/ToLCVRES-5 (554.04 q) followed by 2014/ToLCVRES-1 (426.46 q) and 2014/ToLCVRES-2 (422.75 q). However 2014/ToLCVRES-4 (415.34 q) and 2014/ToLCVRES-2 were at par with 2014/ToLCVRES-1. The minimum total yield ha^{-1} was observed in Punjab Chhuhara (147.22 q). Whereas, mean total yield ha^{-1} for both years (2015-16 and 2016-17) exhibited that total yield ha^{-1} ranged from 159.49 q (Punjab Chhuhara) to 565.35 q (2014/ToLCVRES-5). The maximum total yield ha^{-1} was observed in 2014/ToLCVRES-5 (565.35 q) followed by 2014/ToLCVRES-1 (439.19 q), and 2014/ToLCVRES-2 (425.09 q). However, the minimum total yield ha^{-1} was noted in Punjab Chhuhara (159.49 q).

4.4.1.5 Quality parameters of 2014/ToLCVRES entries/ varieties

The selection of any variety/ entry depends on yield and yield depends on various parameters of yield contributing factors along with resistance. The resistance of entry/ variety to the disease and its yield and quality parameters of fruit may also influence the selection of entry/ variety by affecting the market value of produce (fruits). Therefore quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each variety were also evaluated during 2015-16 and 2016-17 and mentioned in (Table 4.36a and 4.36b).

The equatorial diameter indicates the globosity of fruit that directly affects the value of produce. In both the years (2015-16 and 2016-17) the significant largest fruit was observed for 2014/ToLCVRES-1 with equatorial diameter of 53.67 and 54.34 mm. This was followed by 2014/ToLCVRES-3 (51.63 and 51.06 mm) and 2014/ToLCVRES-5 (51.36 and 52.53 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (36.42 and 41.67 mm). The mean equatorial diameter of both the years ranged from 39.04 to 54.00 mm. The largest fruit was obtained from 2014/ToLCVRES-1 (54.00 mm) followed by 2014/ToLCVRES-5 (51.95 mm) and 2014/ToLCVRES-3 (51.35 mm). The minimum equatorial diameter was measured in Punjab Chhuhara (39.04 mm).

The polar diameter represents the length/ height of fruit that determines the fruit shape and size. In both the years the significant the longest fruit was obtained from Punjab chhuhara with polar diameter of 53.07 and 58.15 mm (Table 4.36a). This was followed by 2014/ToLCVRES-4 (51.70 and 54.52 mm) and 2014/ToLCVRES-1 (49.97 and 52.58 mm). The fruit height of H-24 was found lowest (39.58 and 38.47 mm). The mean data also showed longest fruit in Punjab Chhohara with polar diameter of 55.61 mm which was followed by 2014/ToLCVRES-4 (53.11 mm) and 2014/ToLCVRES-1 (51.27 mm). The fruit height of H-24 was lowest (39.03 mm).

In 2015-16 the number of locules ranged from 2.60 to 4.87. The maximum number of locules was observed in 2014/ToLCVRES-1 (4.87) followed by 2014/ToLCVRES-3 (4.67) and 2014/ToLCVRES-5 (4.47). The minimum number of locules was recorded Punjab Chhuhara (2.60). In 2016-17 the maximum number of locules was observed in H-24 (4.53) followed by 2014/ToLCVRES-3 (4.27) and 2014/ToLCVRES-1 (3.93). The minimum number of locules was recorded in Punjab Chhuhara (2.33). The mean data of both the years (2015-16 and 2016-17) exhibited significant variation in number of locules among entries/ varieties and ranged between 2.47 to 4.47 mm (Table 4.36a). The maximum number of locules was observed in 2014/ToLCVRES-3 (4.47) followed by 2014/ToLCVRES-1 (4.40) and H-24 (4.27). The minimum number of locules was recorded in Punjab Chhuhara (2.47).

The significant variation was observed on pericarp thickness among the entries/ varieties evaluated in the year 2015-16 and 2016-17 (Table 4.36b). In both the years the fruits of 2014/ToLCVRES-4 had the maximum (6.63 mm) pericarp thickness. This was followed by 2014/ToLCVRES-1 (5.83 mm) and 2014/ToLCVRES-3 (4.93) in 2015-16 and 2014/ToLCVRES-1 (5.07 mm) and H-24 (4.53 mm) in 2016-17. The minimum pericarp thickness was measured in 2014/ToLCVRES-2 (4.10 mm) and Punjab Chhuhara (2.33) in 2015-16 and 2016-17 respectively. The mean data of 2015-16 and 2016-17 also showed that the maximum pericarp thickness was recorded in 2014/ToLCVRES-4 (6.23 mm) followed by 2014/ToLCVRES-1 (5.45 mm) and 2014/ToLCVRES-3 (4.60 mm). The thinnest pericarp was measured in Punjab Chhuhara (3.61 mm).

Among the seven 2014/ToLCVRES entries/ varieties evaluated in both the years the maximum total soluble solids content (4.43 and 4.99 °Brix) was found in 2014/ToLCVRES-1 (Table 4.36b). This was followed by 2014/ToLCVRES-3 (4.33 °Brix) and Punjab Chhuhara (4.27 °Brix) in 2015-16 and 2014/ToLCVRES-3 (4.72 °Brix) and 2014/ToLCVRES-4 (4.48 °Brix) in 2016-17. The minimum total soluble solids content was recorded in H-24 (3.17 °Brix) Punjab Chhuhara (4.08 °Brix) in 2015-16 and 2016-17 respectively. The mean data of 2015-16 and 2016-17 also showed significant variation in total soluble solids (TSS) among the seven entries/ varieties and ranged from 3.74 to 4.71 °Brix. The maximum total soluble solids content was recorded in 2014/ToLCVRES-1 (4.71 °Brix) followed by 2014/ToLCVRES-3 (4.53 °Brix) and 2014/ToLCVRES-4 (4.21 °Brix). The minimum total soluble solids content was recorded in H-24 (3.74 °Brix).

Out of seven 2014/ToLCVRES entries/ varieties evaluated in 2015-16 and 2016-17, one was pear shaped (Punjab Chhuhara) and another one was oval shaped (2014/ToLCVRES-4) and rest others were either round or flattish round in shape (Table 4.69b). Among the seven 2014/ToLCVRES entries/ varieties evaluated entry 2014/ToLCVRES-5 and 2014/ToLCVRES-1 produced light red to deep red and deep red fruits respectively. However remaining four entries (2014/ToLCVRES-2, 2014/ToLCVRES-3, 2014/ToLCVRES-4) and one variety (Punjab Chhuhara) were produced red to deep red fruits (Table 4.36b).

Table 4.36a: Quality parameters of 2014/ToLCVRES entries

Entry/ variety	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/ToLCVRES-1	53.67	54.34	54.00	49.97	52.58	51.27	4.87	3.93	4.40
2014/ToLCVRES-2	47.40	47.87	47.63	42.47	44.51	43.49	3.60	2.73	3.17
2014/ToLCVRES-3	51.63	51.06	51.35	46.53	45.44	45.99	4.67	4.27	4.47
2014/ToLCVRES-4	46.40	48.29	47.34	51.70	54.52	53.11	3.00	2.60	2.80
2014/ToLCVRES-5	51.36	52.53	51.95	43.39	45.90	44.64	4.47	3.27	3.87
H-24	46.10	44.91	45.50	39.58	38.47	39.03	4.00	4.53	4.27
Punjab Chhuhara	36.42	41.67	39.04	53.07	58.15	55.61	2.60	2.33	2.47
Sem±	1.629	1.607	1.191	1.563	1.612	0.894	0.089	0.079	0.054
CD (p=0.05)	5.018*	4.951*	3.671*	4.817*	4.968*	2.756*	0.275*	0.243*	0.168*
CV	5.930	5.718	4.288	5.802	5.756	3.255	3.971	4.048	2.595

Table 4.36b: Quality parameters of 2014/ToLCVRES entries

Entry/ variety	Pericarp thickness (mm)			TSS (Brix %)		Fruit shape	Fruit colour
	2015-16	2016-17	Mean	2015-16	2016-17		
2014/ToLCVRES-1	5.83	5.07	5.45	4.43	4.99	Round	Deep red
2014/ToLCVRES-2	4.10	3.87	3.98	3.77	4.23	Round	Red-Deep red
2014/ToLCVRES-3	4.93	4.27	4.60	4.33	4.72	Round	Red-Deep red
2014/ToLCVRES-4	6.63	5.83	6.23	3.93	4.48	Oval	Red-Deep red
2014/ToLCVRES-5	4.33	4.00	4.16	3.52	4.12	Round	Light red-Deep red
H-24	4.37	4.53	4.45	3.17	4.31	Round	Red-Deep red
Punjab Chhuhara	4.89	2.33	3.61	4.27	4.08	Pear	Red-Deep red
Sem±	0.136	0.120	0.091	0.112	0.098		
CD (p=0.05)	0.420*	0.371*	0.280*	0.345*	0.301*		0.213*
CV	4.712	4.881	3.388	4.948	3.827		2.877

4.4.1.6 Other parameters of 2014/ToLCVRES entries/ varieties

Some other parameters such as plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering, days to 50% flowering and days to first fruiting were also recorded for all the entries/ varieties during 2015-16 and 2016-17 and presented in Table 4.37a and 4.37b.

In both the years the highest plant height was recorded in 2014/ToLCVRES-1 (129.74 and 125.07 cm) followed by 2014/ToLCVRES-4 (74.13 and 73.75 cm) and 2014/ToLCVRES-3 (69.07 and 68.22 cm). The minimum plant height was measured in Punjab Chhuhara (49.11 cm) and H-24 (46.86 cm) in 2015-16 and 2016-17 respectively (Table 4.37a). The mean plant height of all the entries/ varieties in both the years (2015-16 and 2016-17) significantly ranged from 48.07 to 127.40 cm. The highest plant height was recorded in 2014/ToLCVRES-1 (127.40 cm) followed by 2014/ToLCVRES-4 (73.94 cm) and 2014/ToLCVRES-3 (68.64 cm). The lowest (50.11 cm) plant height was noted in H-24 (48.07 cm).

In both the years (2015-16 and 2016-17) the maximum number of branches plant⁻¹ was observed in H-24 (10.60 and 10.20) followed by 2014/ToLCVRES-1 (10.13 and 9.80) and 2014/ToLCVRES-5 (7.53 and 7.20). The least number of branches were recorded in Punjab Chhuhara (8.93 and 8.87). It was also revealed from the mean data presented in table 4.37a that among all the 2014/ToLCVRES entries/ varieties evaluated the significant highest number of primary branches plant⁻¹ was found in H-24 (10.40) followed by 2014/ToLCVRES-1 (9.97) and 2014/ToLCVRES-5 (7.37). The minimum number of primary branches was recorded from Punjab Chhuhara (8.90).

In 2015-16 and 2016-17 the number of secondary branches plant⁻¹ showed non significant variation among the entries/ varieties evaluated (Table 4.37a). However the pooled mean of number of secondary branches plant⁻¹ significantly ranged from 4.67 to 5.17. The maximum number of secondary branches plant⁻¹ was counted in 2014/ToLCVRES-2 (5.17) followed by Punjab Chhuhara (5.13) and 2014/ToLCVRES-5 (4.93). The minimum number of branches was recorded in 2014/ToLCVRES-3 (4.67).

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.37b. In 2015-16 the days to first flowering significantly varied from 23.67 to 30.00 days. The minimum (23.67 days) days to first flowering were observed in 2014/ToLCVRES-4 followed by 2014/ToLCVRES-3 (24.00 days), and 2014/ToLCVRES-5 (25.00 days). The maximum (30.00 days) days to first flowering were observed in 2014/ToLCVRES-1. In 2016-17 the days to first flowering significantly ranged with minimum (24.33 days) days to first flowering in 2014/ToLCVRES-3, 2014/ToLCVRES-5 to maximum (30.33 days) 2014/ToLCVRES-1. The mean data shows that among all the 2014/ToLCVRES entries/ varieties evaluated the significant lowest (24.17) days to first flowering were recorded in 2014/ToLCVRES-3 followed by 2014/ToLCVRES-4 (24.33) and 2014/ToLCVRES-5 (24.67 days). The maximum (30.17 days) days to first flowering were observed in 2014/ToLCVRES-1.

In 2015-16 the days to 50% flowering significantly ranged from 35.67 to 43.33 days (Table 4.37b). The minimum (35.67 days) days to 50% flowering were observed in 2014/ToLCVRES-3 followed by Punjab Chhuhara (37.00 days) and 2014/ToLCVRES-5 (37.67 days). The maximum (43.33 days) days to 50% flowering were observed in 2014/ToLCVRES-1. In 2016-17 the minimum (36.33 days) days to 50% flowering were recorded in 2014/ToLCVRES-5 followed by 2014/ToLCVRES-3 (37.00 days) and Punjab Chhuhara (28.00 days). The maximum (44.33 days) days to first flowering were observed in 2014/ToLCVRES-1. It was revealed from the pooled mean of 2015-16 and 2016-17 that among all the 2014/ToLCVRES entries/ varieties evaluated the significant least (36.33) days to 50% flowering were observed in 2014/ToLCVRES-3 followed by 2014/ToLCVRES-5 (37.00) and Punjab Chhuhara (37.50 days). The maximum days to 50% flowering were observed in 2014/ToLCVRES-1 (43.83 days).

In 2015-16 the days to first fruiting significantly varied from 33.00 to 45.67 days (Table 4.37b). The minimum days to first fruiting were observed in 2014/ToLCVRES-3 (33.00 days) followed by 2014/ToLCVRES-5 (34.00 days) and 2014/ToLCVRES-4 (35.00 days). However the maximum (45.67 days) days to first fruiting were observed in Punjab Chhuhara. In 2016-17 the significant least (36.67 days) number of days for first fruiting were recorded in 2014/ToLCVRES-3

Table 4.37a: Other parameters of 2014/ToLCVRES entries

Entry/ variety	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/ToLCVRES-1	129.74	125.07	127.40	10.13	9.80	9.97	4.93	4.67	4.80
2014/ToLCVRES-2	56.06	55.04	55.55	8.13	7.80	7.97	5.27	5.07	5.17
2014/ToLCVRES-3	69.07	68.22	68.64	8.60	8.00	8.30	4.80	4.53	4.67
2014/ToLCVRES-4	74.13	73.75	73.94	8.07	8.07	8.07	4.60	4.80	4.70
2014/ToLCVRES-5	54.92	51.94	53.43	7.53	7.20	7.37	5.00	4.87	4.93
H-24	49.28	46.86	48.07	10.60	10.20	10.40	4.87	4.93	4.90
Punjab Chhuhara	49.11	47.99	48.55	8.93	8.87	8.90	5.07	5.20	5.13
Sem±	4.307	3.801	2.815	0.462	0.530	0.438	0.122	0.136	0.105
CD (p=0.05)	13.272*	11.713*	8.673*	1.424*	1.632*	1.350*	0.376 NS	0.419 NS	0.323*
CV	10.828	9.830	7.176	9.037	10.713	8.715	4.289	4.843	3.704

Table 4.37b: Other parameters of 2014/ToLCVRES entries

Entry/ variety	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/ToLCVRES-1	30.00	30.33	30.17	43.33	44.33	43.83	40.67	42.00	41.33
2014/ToLCVRES-2	26.33	25.00	25.67	39.67	40.33	40.00	39.67	38.67	39.17
2014/ToLCVRES-3	24.00	24.33	24.17	35.67	37.00	36.33	33.00	36.67	34.83
2014/ToLCVRES-4	23.67	25.00	24.33	43.00	42.33	42.67	35.00	39.33	37.17
2014/ToLCVRES-5	25.00	24.33	24.67	37.67	36.33	37.00	34.00	36.67	35.33
H-24	26.33	25.00	25.67	39.67	40.67	40.17	35.00	39.00	37.00
Punjab Chhuhara	27.00	25.33	26.17	37.00	38.00	37.50	45.67	39.33	42.50
Sem±	0.595	0.707	0.432	0.839	0.825	0.637	1.031	0.644	0.533
CD (p=0.05)	1.835*	2.179*	1.331*	2.585*	2.541*	1.962*	3.178*	1.986*	1.643*
CV	3.959	4.781	2.896	3.685	3.583	2.782	4.754	2.876	2.419

and 2014/ToLCVRES-5 followed by 2014/ToLCVRES-2 (38.67 days). The maximum days to first fruiting were observed in 2014/ToLCVRES-1 (42.00 days). The pooled mean data showed that the least (34.83 days) number of days for first fruiting were noted in 2014/ToLCVRES-3 followed by 2014/ToLCVRES-5 (35.33 days) and H-24 (37.00 days). The maximum days to first fruiting were observed in Punjab Chhuhara (42.50 days).

4.4.1.7 Overall performance of 2014/ToLCVRES entries/ varieties

The overall performance of all the 2014/ToLCVRES entries/ varieties were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.38 to 4.40.

It was clearly visible from Table 4.38 that in 2015-16 2014/ToLCVRES-1 gave best overall rank followed by 2014/ToLCVRES-3 and 2014/ToLCVRES-5. Though these three entries showed commendable overall rank with moderately resistant, resistant and moderately susceptible reaction but 2014/ToLCVRES-5 recorded maximum per ha total yield (576.67 q) and exhibited moderately susceptible reaction followed by 2014/ToLCVRES-1 (451.93 q) and 2014/ToLCVRES-2 (427.42 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2014/ToLCVRES-1 with average fruit weight of 73.40 g followed by 2014/ToLCVRES-5 (68.92 g) and 2014/ToLCVRES-3 (63.99 g). However largest round fruits were recorded in 2014/ToLCVRES-1 with equatorial diameter of 53.67 mm followed by 2014/ToLCVRES-3 (51.63 mm) and 2014/ToLCVRES-5 (51.36 mm). Punjab Chhuhara was recorded for the longest fruit with polar diameter of 53.07 mm followed by 2014/ToLCVRES-4 (51.70 mm) and 2014/ToLCVRES-1 (49.97 mm). However 2014/ToLCVRES-4 had the maximum (6.63 mm) pericarp thickness followed by 2014/ToLCVRES-1 (5.83 mm) and 2014/ToLCVRES-3 (4.93 mm). In case of TSS the maximum total soluble solids content (4.43 °Brix) was found in 2014/ToLCVRES-1 followed by 2014/ToLCVRES-3 (4.33 °Brix) and Punjab Chhuhara (4.29 °Brix). Whereas, the minimum (33.00 days) days to first fruiting were observed in 2014/ToLCVRES-3 followed by 2014/ToLCVRES-5 (34.00) and Punjab Chhuhara (35.00 days).

It was revealed from the experimental data presented in Table 4.39 that in 2016-17 2014/ToLCVRES-1 provided best overall performance followed by 2014/ToLCVRES-3 and 2014/ToLCVRES-4. Though these varieties were superfine in overall performance with moderately susceptible and moderately resistant reaction but maximum (469.63 q) per ha total yield was recorded in 2014/ToLCVRES-5 that showed susceptible reaction. This was followed by 2014/ToLCVRES-1 (426.46 q) and 2014/ToLCVRES-2 (422.75 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2014/ToLCVRES-1 with average fruit weight of 71.64 g followed by 2014/ToLCVRES-5 (66.80 g) and 2014/ToLCVRES-3 (63.46 g). However the largest round fruits were recorded in 2014/ToLCVRES-1 with equatorial diameter of 54.34 mm followed by 2014/ToLCVRES-5 (52.53 mm) and 2014/ToLCVRES-3 (51.06 mm). Punjab Chhuhara was recorded for the longest fruit with polar diameter of 58.15 mm followed by 2014/ToLCVRES-4 (54.52 mm) and 2014/ToLCVRES-1 (52.58 mm). However 2014/ToLCVRES-4 had the maximum (5.83 mm) pericarp thickness followed by 2014/ToLCVRES-1 (5.07 mm) and H-24 (4.53 mm). In case of TSS the maximum total soluble solids content (4.99 °Brix) was found in 2014/ToLCVRES-1 followed by 2014/ToLCVRES-3 (4.72 °Brix) and 2014/ToLCVRES-4 (4.48 °Brix). However the least (36.7 days) number of days required for first fruiting were recorded in 2014/ToLCVRES-3 and 2014/ToLCVRES-5 followed by 2014/ToLCVRES- 2 (38.67 days).

It was revealed from the average data of both the years (2015-16 and 2016-17) that the overall performance of 2014/ToLCVRES-1 was best which was followed by 2014/ToLCVRES-3 and 2014/ToLCVRES-4 (Table 4.40). Though these varieties were superfine in overall performance with moderately resistant and moderately susceptible reaction but maximum (565.35 q) per ha total yield was recorded in 2014/ToLCVRES-5 that showed susceptible reaction. This was followed by 2014/ToLCVRES-1 (439.19 q) and 2014/ToLCVRES-2 (425.09 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2014/ToLCVRES-1 with average fruit weight of 72.52 g followed by 2014/ToLCVRES-5 (67.86 g) and

Table 4.38: Overall performance of 2014/ToLCVRES entries in 2015-16

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/ToLCVRES-1	38.10	17.28	MR	73.40	451.93	53.67	49.97	5.83	4.43	40.67
2014/ToLCVRES-2	62.86	29.79	MS	59.40	427.42	47.40	42.47	4.10	3.77	39.67
2014/ToLCVRES-3	25.49	14.49	R	63.99	358.55	51.63	46.53	4.93	4.33	33.00
2014/ToLCVRES-4	47.62	21.91	MR	59.46	414.31	46.40	51.70	6.63	3.93	35.00
2014/ToLCVRES-5	60.95	31.70	MS	68.92	576.67	51.36	43.39	4.33	3.52	34.00
H-24	63.39	47.62	S	36.46	363.15	46.10	39.58	4.37	3.17	35.00
Punjab Chhuhara	91.18	70.73	S	41.05	171.76	36.42	53.07	4.89	4.27	45.67
Sem±				1.935	6.713	1.629	1.563	0.136	0.112	1.031
CD (p=0.05)				5.961*	20.685*	5.018*	4.817*	0.420*	0.345*	3.178*
CV				5.825	2.945	5.930	5.802	4.712	4.948	4.754

Table 4.39: Overall performance of 2014/ToLCVRES entries in 2016-17

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/ToLCVRES-1	45.34	31.64	MS	71.64	426.46	54.34	52.58	5.07	4.99	42.00
2014/ToLCVRES-2	93.91	69.81	S	59.35	422.75	47.87	44.51	3.87	4.23	38.67
2014/ToLCVRES-3	32.31	22.58	MR	63.46	367.33	51.06	45.44	4.27	4.72	36.67
2014/ToLCVRES-4	46.24	33.03	MS	57.59	415.34	48.29	54.52	5.83	4.48	39.33
2014/ToLCVRES-5	88.65	67.15	S	66.80	554.04	52.53	45.90	4.00	4.12	36.67
H-24	99.12	77.76	S	36.52	364.02	44.91	38.47	4.53	4.31	39.00
Punjab Chhuhara	87.16	67.10	S	40.39	147.22	41.67	58.15	2.33	4.08	39.33
Sem±				2.237	7.926	1.607	1.612	0.120	0.098	0.644
CD (p=0.05)				6.894*	24.422*	4.951*	4.968*	0.371*	0.301*	1.986*
CV				6.854	3.563	5.718	5.756	4.881	3.827	2.876

Table 4.40: Overall performance of 2014/ToLCVRES entries in both the years (2015-16 and 2016-17)

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/ToLCVRES-1	41.72	24.46		72.52	439.19	54.00	51.27	5.45	4.71	41.33
2014/ToLCVRES-2	78.39	49.80		59.38	425.09	47.63	43.49	3.98	4.00	39.17
2014/ToLCVRES-3	28.90	25.78		63.73	362.94	51.35	45.99	4.60	4.53	34.83
2014/ToLCVRES-4	46.93	27.47		58.52	414.83	47.34	53.11	6.23	4.21	37.17
2014/ToLCVRES-5	74.80	49.43		67.86	565.35	51.95	44.64	4.16	3.82	35.33
H-24	81.26	62.69	S	36.49	363.59	45.50	39.03	4.45	3.74	37.00
Punjab Chhuhara	89.17	68.91	S	40.72	159.49	39.04	55.61	3.61	4.17	42.50
Sem±				1.502	6.018	1.191	0.894	0.091	0.069	0.533
CD (p=0.05)				4.629*	18.542*	3.671*	2.756*	0.280*	0.213*	1.643*
CV				4.563	2.672	4.288	3.255	3.388	2.877	2.419

2014/ToLCVRES-3 (63.73 g). However the largest round fruits were recorded in 2014/ToLCVRES-1 with equatorial diameter of 54.00 mm followed by 2014/ToLCVRES-5 (51.95 mm) and 2014/ToLCVRES-3 (51.35 mm). Punjab Chhuhara was recorded for the longest fruit with polar diameter of 55.61 mm followed by 2014/ToLCVRES-4 (53.11 mm) and 2014/ToLCVRES-1 (51.27 mm). However 2014/ToLCVRES-4 had the maximum (6.23 mm) pericarp thickness followed by 2014/ToLCVRES-1 (5.45 mm) and 2014/ToLCVRES- (4.60 mm). In case of TSS the maximum total soluble solids content (4.71 °Brix) was found in 2014/ToLCVRES-1 followed by 2014/ToLCVRES-3 (4.53 °Brix) and 2014/ToLCVRES-4 (4.21 °Brix). However the least (34.83 days) number of days for first fruiting were noted in 2014/ToLCVRES-3 followed by 2014/ToLCVRES-5 (35.33 days) and H-24 (35.33 days).

4.4.1.8 Correlation of leaf curl disease with different parameters of 2014/ToLCVRES entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2014/ToLCVRES entries/ varieties for the year 2015-16 and 2016-17 and presented in table 4.41. Percent disease index of leaf curl indicated significant negative correlation with average fruit weight ($r = -0.784$, $p = 0.005$), equatorial diameter of fruit ($r = -0.760$, $p = 0.005$), thickness of pericarp ($r = -0.770$, $p = 0.005$), TSS ($r = -0.733$, $p = 0.005$) and plant height ($r = -0.739$, $p = 0.005$). There was significant positive correlation was observed between percent disease index of leaf curl and number of secondary branches plant⁻¹. However rest other parameters showed either non significant positive or negative correlation with percent disease index.

4.4.2 2015/ToLCVRES entries/ variety

A sum of seven 2015/ToLCVRES entries/ variety with a susceptible check variety viz. Punjab Chhuhara were evaluated against tomato leaf curl disease (ToLCD) during *Rabi* 2015-16 and 2016-17 and results were depicted in Table 4.42a to 4.52 (Fig 4.32).

Table 4.41: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2014/ToLCVRES entries

Parameters	Mean	
	Disease incidence	PDI
PDI	0.953 ^{**}	-
No of fruits plant⁻¹	0.413 ^{NS}	0.411 ^{NS}
Fruit yield plant⁻¹ (kg)	-0.256 ^{NS}	-0.442 ^{NS}
Average fruit weight (g)	-0.644 ^{NS}	-0.784 [*]
Marketable yield q ha⁻¹	-0.266 ^{NS}	-0.448 ^{NS}
Unmarketable yield q ha⁻¹	0.337 ^{NS}	0.257 ^{NS}
Total yield (q ha⁻¹)	-0.259 ^{NS}	-0.443 ^{NS}
Equatorial diameter of fruit (mm)	-0.672 [*]	-0.760 [*]
Polar diameter of fruit (mm)	-0.189 ^{NS}	-0.206 ^{NS}
Number of locules fruit⁻¹	-0.477 ^{NS}	-0.388 ^{NS}
Thickness of pericarp (mm)	-0.689 [*]	-0.770 [*]
TSS (% Brix)	-0.783 [*]	-0.733 [*]
Plant height (cm)	-0.667 [*]	-0.739 [*]
No. of primary branches plant⁻¹	0.039 ^{NS}	0.149 ^{NS}
No. of secondary branches plant⁻¹	0.866 ^{**}	0.785 [*]
First flowering (DAT)	-0.076 ^{NS}	-0.139 ^{NS}
50 per cent flowering (DAT)	-0.241 ^{NS}	-0.402 ^{NS}
First fruiting (DAT)	0.333 ^{NS}	0.286 ^{NS}

4.4.2.1 Disease incidence and percent disease index (PDI)

Considerable variability was observed in incidence of all 2015/ToLCVRES entries/ variety evaluated under the study. During 2015-16 disease incidence was varied from 0.0 to 1.67, 1.59 to 14.29, 5.56 to 35.34, 13.49 to 64.79, 19.05 to 89.17 and 30.95 to 94.17 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the calculated percent disease index (PDI) was also varied from 0.0 to 0.95, 0.68 to 7.81, 2.72 to 20.68, 8.05 to 47.73, 12.70 to 69.71 and 12.70 to 69.71 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The entries 2015/ToLCVRES-1, 2015/ToLCVRES-2, 2015/ToLCVRES-4, 2015/ToLCVRES-5 and variety H-24 were free from the disease up to 15 days after transplanting while remaining two entry and variety were found infected with the disease at 15 DAT (Table 4.42a – 4.43b).

During 2016-17 disease incidence was varied from 0.0 to 2.52, 0.0 to 15.32, 2.61 to 37.79, 11.48 to 74.23, 24.22 to 96.32 and 35.91 to 99.10 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the percent disease index (PDI) of leaf curl was also varied from 0.0 to 0.60, 0.0 to 7.76, 1.35 to 20.26, 6.55 to 52.52, 15.32 to 67.50, 25.65 to 79.67 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Only one entry 2015/ToLCVRES-1 was free from the disease up to 30 days after transplanting while others showed first symptoms of tomato leaf curl disease at 15 days after transplanting (Table 4.42a – 4.43b).

The average incidence and PDI of leaf curl for both the years (2015-16 and 2016-17) displayed that disease incidence was varied from 0.0 to 2.10, 1.19 to 14.81, 4.09 to 36.57, 12.49 to 69.51, 21.64 to 92.75 and 33.43 to 96.64 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the calculated percent disease index (PDI) was varied from 0.0 to 0.78, 0.63 to 7.79, 2.09 to 20.47, 7.30 to 50.13, 14.01 to 68.61 and 19.18 to 74.69 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Four entries 2015/ToLCVRES-1, 2015/ToLCVRES-2, 2015/ToLCVRES-4, 2015/ToLCVRES-5 and variety H-24 were free from the disease up to 15 days after transplanting but in others the disease was first appeared at 15 days after transplanting (Table 4.42a – 4.43b).

During 2015-16 at 90 DAT the lowest percent incidence and PDI was recorded in 2015/ToLCVRES-5 (30.95, 12.70 %) followed by 2015/ToLCVRES-4 (44.79, 23.21 %) and 2015/ToLCVRES-1 (53.17, 25.28 %) and highest in Punjab Chhuhara (94.17, 69.71 %) (Table 4.42a – 4.43b).

During 2016-17 at 90 DAT the percent incidence and PDI was also observed lowest in 2015/ToLCVRES-5 (35.91, 25.65 %) followed by 2015/ToLCVRES-4 (53.70, 39.08 %) and 2015/ToLCVRES-1 (65.51, 48.67 %) and highest in Punjab Chhuhara (99.10, 79.67 %) (Table 4.42a – 4.43b).

The average incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) also showed that at 90 DAT the percent incidence and PDI was also observed lowest in 2015/ToLCVRES-5 (33.43, 19.18 %) followed by 2015/ToLCVRES-4 (49.25, 31.15 %) and 2015/ToLCVRES-1 (59.34, 36.98 %) and highest in Punjab Chhuhara (96.64, 74.69 %) (Table 4.42a – 4.43b).

4.4.2.2 Reaction and level of resistance of 2015/ToLCVRES entries/ variety against ToLCD

Among the seven 2015/ToLCVRES entries/ variety evaluated during 2015-16, one entry viz. 2015/ToLCVRES-5 was regarded as resistant and fall under the grade 1. Of them two entries viz. 2015/ToLCVRES-1 and 2015/ToLCVRES-4 were categorized as moderately resistant with rating 3. Four entries/ varieties (2015/ToLCVRES-2, 2015/ToLCVRES-3, H-24 and Punjab Chhuhara) were classified under the susceptible reaction with rating 7 (Table 4.44). However none of them was moderately susceptible.

Out of seven 2015/ToLCVRES entries/ variety evaluated during 2016-17, none of the entry/ variety was found resistant against ToLCD. However, one entry viz. 2015/ToLCVRES-5 was regarded as moderately resistant with rating 3 and rest others (2015/ToLCVRES-1, 2015/ToLCVRES-2, 2015/ToLCVRES-3, 2015/ToLCVRES-4, H-24 and Punjab Chhuhara) were shown susceptible reaction with rating 7 (Table 4.44).

The result of evaluation for both years (2015-16 and 2016-17) indicated that the performance of four entries/ varieties viz. 2015/ToLCVRES-2, 2015/ToLCVRES-3, H-24 and Punjab Chhuhara were constant with susceptible

Table 4.42a: Percent incidence of tomato leaf curl disease in 2015/ToLCVRES entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)								
	15			30			45		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	0.00	0.00	0.00	2.38	0.00	1.19	5.56	2.61	4.09
2015/ToLCVRES-2	0.00	0.00	0.00	3.27	1.74	2.51	12.30	10.47	11.39
2015/ToLCVRES-3	0.79	0.79	0.79	5.65	2.54	4.10	14.53	12.04	13.29
2015/ToLCVRES-4	0.00	0.00	0.00	2.38	0.79	1.59	10.31	9.80	10.06
2015/ToLCVRES-5	0.00	0.00	0.00	1.59	0.81	1.20	6.35	7.34	6.85
H-24	0.00	0.00	0.00	8.23	4.39	6.31	20.51	14.53	17.52
Punjab Chhuhara	1.67	2.52	2.10	14.29	15.32	14.81	35.34	37.79	36.57

Table 4.42b: Percent incidence of tomato leaf curl disease in 2015/ToLCVRES entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)								
	60			75			90		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	17.46	17.46	17.46	37.30	51.84	44.57	53.17	65.51	59.34
2015/ToLCVRES-2	37.20	40.58	38.89	74.37	84.84	79.61	81.00	88.65	84.83
2015/ToLCVRES-3	36.18	37.49	36.84	56.39	66.14	61.27	69.30	78.64	73.97
2015/ToLCVRES-4	19.26	19.08	19.17	34.42	41.78	38.10	44.79	53.70	49.25
2015/ToLCVRES-5	13.49	11.48	12.49	19.05	24.22	21.64	30.95	35.91	33.43
H-24	33.46	29.99	31.73	71.59	76.99	74.29	82.92	90.60	86.76
Punjab Chhuhara	64.79	74.23	69.51	89.17	96.32	92.75	94.17	99.10	96.64

Table 4.43a: Evaluation of 2015/ToLCVRES entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)											
	15			30			45					
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean			
2015/ToLCVRES-1	0.00	0.00	0.00	1.47	0.00	0.74	2.83	1.35	2.09			
2015/ToLCVRES-2	0.00	0.00	0.00	2.10	0.48	1.29	7.38	5.71	6.55			
2015/ToLCVRES-3	0.34	0.34	0.34	3.35	1.34	2.35	7.15	5.88	6.52			
2015/ToLCVRES-4	0.00	0.00	0.00	1.70	0.57	1.14	5.55	5.60	5.58			
2015/ToLCVRES-5	0.00	0.00	0.00	0.68	0.58	0.63	2.72	3.61	3.17			
H-24	0.00	0.00	0.00	4.70	2.38	3.54	12.07	7.71	9.89			
Punjab Chhuhara	0.95	0.60	0.78	7.81	7.76	7.79	20.68	20.26	20.47			

Table 4.43b: Evaluation of 2015/ToLCVRES entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)										Reaction	
	60					75					(at final observation)	
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Constant
2015/ToLCVRES-1	10.88	10.47	10.68	25.28	34.12	29.70	25.28	48.67	36.98	MR	S	S
2015/ToLCVRES-2	26.09	27.48	26.79	52.89	58.23	55.56	52.89	67.00	59.95	S	S	S
2015/ToLCVRES-3	25.37	26.77	26.07	38.91	44.44	41.68	38.91	58.97	48.94	S	S	S
2015/ToLCVRES-4	12.38	11.98	12.18	23.21	27.38	25.30	23.21	39.08	31.15	MR	S	S
2015/ToLCVRES-5	8.05	6.55	7.30	12.70	15.32	14.01	12.70	25.65	19.18	R	MR	
H-24	23.91	20.06	21.99	48.57	50.84	49.71	48.57	70.00	59.29	S	S	S
Punjab Chhuhara	47.73	52.52	50.13	69.71	67.50	68.61	69.71	79.67	74.69	S	S	S

Table 4.44: Classification of 2015/ToLCVRES entries in different reaction categories

Year	Reaction category	No. of entry/ variety	Name of entry/ variety
Entries/	Resistant	0	
varieties with	Moderately resistant	0	
constant	Moderately susceptible	0	
reaction in	Susceptible	4	2015/ToLCVRES-2, 2015/ToLCVRES-3, Punjab Chhuhara , H-24
both the years			
2015-16	Resistant	1	2015/ToLCVRES-5
	Moderately resistant	2	2015/ToLCVRES-1, 2015/ToLCVRES-4
	Moderately susceptible	0	
	Susceptible	4	2015/ToLCVRES-2, 2015/ToLCVRES-3, Punjab Chhuhara , H-24
2016-17	Resistant	0	
	Moderately resistant	1	2015/ToLCVRES-5
	Moderately susceptible	0	
	Susceptible	6	2015/ToLCVRES-1, 2015/ToLCVRES-2, 2015/ToLCVRES-3, 2015/ToLCVRES-4, Punjab Chhuhara , H-24

reaction but none of the entry was found constant with resistant, moderately resistant or moderately susceptible reaction (Table 4.44).

4.4.2.3 Yield parameters of 2015/ToLCVRES entries/ variety

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out for both the years (2015-16 and 2016-17) and presented in Table 4.45.

In both the years the significant maximum number of fruits plant⁻¹ was recorded in H-24 (87.07 and 86.66). This was followed by 2015/ToLCVRES-3 (48.27) and 2015/ToLCVRES-5 (41.40) in 2015-16 and 2015/ToLCVRES-3 (46.07) and 2015/ToLCVRES-2 (40.47) in 2016-17 (Table 4.45). However, the lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (31.97 and 32.67). The mean number of fruits plant⁻¹ of both years (2015-16 and 2016-17) exhibited that the number of fruits plant⁻¹ significantly ranged from 32.32 (Punjab Chhuhara) to 86.70 (H-24). The maximum number of fruits plant⁻¹ was obtained from H-24 (86.70) followed by 2015/ToLCVRES-3 (47.17) and 2015/ToLCVRES-5 (40.23). However, the lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (32.32).

The significant difference was observed among 2015/ToLCVRES entries/ varieties for fruit yield plant⁻¹ (Table 4.45). In 2015-16, it ranged from 1.47 (Punjab Chhuhara) to 2.80 kg (2015/ToLCVRES-5). The maximum fruit yield plant⁻¹ was observed in 2015/ToLCVRES-5 (2.80 kg) followed by 2015/ToLCVRES-1 (2.72 kg) and 2015/ToLCVRES-3 (2.71 kg) and the minimum was in Punjab Chhuhara (1.47 kg). In 2016-17, the fruit yield plant⁻¹ ranged from 1.49 (Punjab Chhuhara) to 2.79 kg (2015/ToLCVRES-3). The maximum fruit yield plant⁻¹ was recorded in 2015/ToLCVRES-3 (2.79 kg) followed by 2015/ToLCVRES-5 and H-24 (2.72 kg) and minimum was observed in Punjab Chhuhara (1.49 kg). The mean fruit yield plant⁻¹ of both years (2015-16 and 2016-17) displayed that the fruit yield plant⁻¹ significantly ranged from 1.48 kg (Punjab Chhuhara) to 2.76 kg (2015/ToLCVRES-5). The maximum fruit yield plant⁻¹ was noted in 2015/ToLCVRES-5 (2.76 kg) followed by 2015/ToLCVRES-3 (2.75 kg) and H-24 (2.50 kg) and the minimum was observed in Punjab Chhuhara (1.48 kg).

In both the years (2015-16 and 2016-17) the maximum average fruit weight was recorded in 2015/ToLCVRES-1 (74.86 and 77.43 g) followed by 2015/ToLCVRES-5 (67.73 and 72.35 g) and 2015/ToLCVRES-4 (65.01 and 63.88 g) (Table 4.45). The lowest average fruit weight was observed from Punjab Chhuhara (31.09 and 31.63 g). The pooled mean data of average fruit weight also expressed that average fruit weight was recorded maximum in 2015/ToLCVRES-1 (76.14 g) followed by 2015/ToLCVRES-5 (70.04 g) and 2015/ToLCVRES-4 (64.45 g). However the lowest weight was noted in Punjab Chhuhara (31.36 g).

4.4.2.4 Yield of 2015/ToLCVRES entries/ varieties

The significant difference was observed in marketable yield ha^{-1} of 2015/ToLCVRES entries/ varieties evaluated during 2015-16 and 2016-17 (Table 4.46). In both the years the highest marketable yield ha^{-1} was recorded in 2015/ToLCVRES-5 (637.41 and 623.81 q). This was followed by 2015/ToLCVRES-1 (546.03 q) and 2015/ToLCVRES-2 (531.48 q) in 2015-16 and 2015/ToLCVRES-2 (534.68 q) and 2015/ToLCVRES-1 (532.81 q) in 2016-17. However in both the years the lowest marketable yield ha^{-1} was observed in Punjab Chhuhara (257.80 and 255.56 q). The pooled mean data also exhibited the significant maximum marketable yield ha^{-1} in 2015/ToLCVRES-5 (630.61 q) followed by 2015/ToLCVRES-1 (539.42 q) and 2015/ToLCVRES-2 (533.08 q). The minimum yield was recorded in Punjab Chhuhara (256.68 q).

In 2015-16 the unmarketable yield was ranged from 7.41 to 10.31 q (Table 4.46). The minimum unmarketable yield was recorded in 2015/ToLCVRES-5 (7.41 q) followed by 2015/ToLCVRES-1 (10.31 q) and 2015/ToLCVRES-4 (11.11 q). The maximum unmarketable yield was obtained from Punjab Chhuhara (27.51 q). In 2016-17 it ranged from 1.59 to 23.94 q and the minimum was recorded in Punjab Chhuhara (1.59 q) followed by 2015/ToLCVRES-5 (3.44 q) and 2015/ToLCVRES-3 (8.73 q). The maximum unmarketable yield ha^{-1} was observed in 2015/ToLCVRES-4 (23.94 q). However it is visible from mean of both the years that the lowest unmarketable yield ha^{-1} was obtained from 2015/ToLCVRES-4 (5.43 q) followed by 2015/ToLCVRES-3 (11.38 q) and 2015/ToLCVRES-1 (12.17

Table 4.45: Yield parameters of 2015/ToLCVRES entries

Entry/ variety	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	36.30	34.20	35.25	2.72	2.62	2.67	74.86	77.43	76.14
2015/ToLCVRES-2	39.67	40.47	40.07	2.24	2.21	2.23	56.59	54.63	55.61
2015/ToLCVRES-3	48.27	46.07	47.17	2.71	2.79	2.75	56.20	61.41	58.81
2015/ToLCVRES-4	38.27	38.80	38.53	2.49	2.47	2.48	65.01	63.88	64.45
2015/ToLCVRES-5	41.40	39.07	40.23	2.80	2.72	2.76	67.73	72.35	70.04
H-24	87.07	86.33	86.70	2.71	2.72	2.71	31.09	31.63	31.36
Punjab Chhuhara	31.97	32.67	32.32	1.47	1.49	1.48	46.17	45.81	45.99
Sem±	2.004	1.529	1.014	0.072	0.088	0.057	1.694	2.425	1.483
CD (p=0.05)	6.176*	4.713*	3.124*	0.222*	0.271*	0.176*	5.219*	7.472*	4.570*
CV	7.526	5.839	3.838	5.097	6.273	4.055	5.164	7.221	4.469

Table 4.46: Yield performance of 2015/ToLCVRES entries

Entry/ variety	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	546.03	532.81	539.42	10.31	14.02	12.17	556.34	546.83	551.59
2015/ToLCVRES-2	531.48	534.68	533.08	20.10	13.76	16.93	551.59	548.44	550.01
2015/ToLCVRES-3	483.60	473.41	478.51	14.02	8.73	11.38	497.62	482.14	489.88
2015/ToLCVRES-4	451.56	453.31	452.44	11.11	23.94	17.53	462.67	477.25	469.96
2015/ToLCVRES-5	637.41	623.81	630.61	7.41	3.44	5.43	644.82	627.25	636.04
H-24	522.88	527.64	525.26	22.49	10.10	16.30	545.37	537.75	541.56
Punjab Chhuhara	257.80	255.56	256.68	27.51	1.59	14.55	285.31	257.14	271.23
Sem±	9.267	8.224	6.205	0.996	0.688	0.586	9.250	8.342	6.258
CD (p=0.05)	28.553*	25.341*	19.119*	3.068*	2.119*	1.806*	28.503	25.704	19.283
CV	3.275	2.932	2.202	10.686	11.029	7.537	3.165	2.909	2.161

q). The maximum unmarketable yield ha^{-1} was recorded in 2015/ToLCVRES-4 (17.53 q).

In both the years the maximum total yield ha^{-1} was recorded in 2015/ToLCVRES-5 (644.82 and 627.25 q). This was followed by 2015/ToLCVRES-1 (556.34 q) and 2015/ToLCVRES-2 (551.59 q) in 2015-16 and 2015/ToLCVRES-2 (548.44 q) and 2015/ToLCVRES-1 (546.83 q) in 2016-17. However, the minimum marketable yield ha^{-1} was observed in Punjab Chhuhara (285.31 and 257.14 q). Whereas, mean total yield ha^{-1} for both years (2015-16 and 2016-17) exhibited that total yield ha^{-1} ranged from 271.23 q (Punjab Chhuhara) to 636.04 q (2015/ToLCVRES-5). The maximum total yield ha^{-1} was observed in 2015/ToLCVRES-5 (636.04 q) followed by 2015/ToLCVRES-1 (551.59 q) and 2015/ToLCVRES-2 (550.01 q). However, the minimum total yield ha^{-1} was noted in Punjab Chhuhara (271.23 q) (Table 4.46).

4.4.2.5 Quality parameters of 2015/ToLCVRES entries/ varieties

In both the years (2015-16 and 2016-17) the significant largest fruit was observed for 2015/ToLCVRES-5 with equatorial diameter of 58.43 and 60.71 mm (Table 4.47a). This was followed by 2015/ToLCVRES-4 (51.43 mm) and 2015/ToLCVRES-2 (51.20 mm) in 2015-16 and 2015/ToLCVRES-4 (54.57 mm) and 2015/ToLCVRES-3 (50.91 mm) in 2016-17. The minimum equatorial diameter was recorded in Punjab Chhuhara (36.42 and 35.80 mm). The mean equatorial diameter of both the years ranged from 36.11 to 59.57 mm. The largest fruit was obtained from 2015/ToLCVRES-5 (59.57 mm) followed by 2015/ToLCVRES-4 (53.00 mm) and 2015/ToLCVRES-2 (50.30 mm). The minimum equatorial diameter was measured in Punjab Chhuhara (36.11 mm).

In both the years the significant longest fruit was obtained from 2015/ToLCVRES-1 with polar diameter of 55.57 and 55.78 mm (Table 4.47a) followed by Punjab chhuhara (53.07 and 52.32 mm) and 2015/ToLCVRES-4 (50.63 and 51.21 mm). The fruit height of H-24 was found lowest (39.57 and 39.48 mm). The mean data also showed longest fruit in 2015/ToLCVRES-1 (55.68 mm) followed by Punjab chhuhara (52.69 mm) and 2015/ToLCVRES-4 (50.92 mm). However the minimum polar diameter was recorded in H-24 (39.52 mm).

In both years the maximum number of locules was recorded in 2015/ToLCVRES-5 (4.80 and 4.73) followed by 2015/ToLCVRES-2 (4.27 and 4.40) and 2015/ToLCVRES-5 (4.13 and 4.00). The minimum number of locules was recorded Punjab Chhuhara (2.60 and 2.73). The mean data also exhibited significant variation in number of locules among entries/ varieties and ranged between 2.67 to 4.77 mm (Table 4.47a). The maximum number of locules was observed in 2015/ToLCVRES-5 (4.77) followed by 2015/ToLCVRES-1 (4.33) and H-24 (4.07). The minimum number of locules was recorded in Punjab Chhuhara (2.67).

The significant variation was observed on pericarp thickness among the entries/ varieties evaluated in the year 2015-16 and 2016-17 (Table 4.47b). In both the years the fruits of 2015/ToLCVRES-3 had the maximum (5.77 and 5.66 mm) pericarp thickness. This was followed by 2015/ToLCVRES-1 (5.73 and 5.60 mm) and 2015/ToLCVRES-4 (5.43 and 5.41). The minimum pericarp thickness was measured in H-24 (4.37 and 4.31 mm). The mean data of 2015-16 and 2016-17 also showed that the maximum pericarp thickness was recorded in 2015/ToLCVRES-3 (5.71 mm) followed by 2015/ToLCVRES-1 (5.67 mm) and 2015/ToLCVRES-4 (5.42 mm). The variety H-24 produced fruits with thin pericarp (4.34 mm).

Among the seven 2015/ToLCVRES entries/ varieties evaluated in both the years the maximum total soluble solids content (4.25 and 4.17 °Brix) was found in Punjab Chhuhara (Table 4.47b). This was followed by 2015/ToLCVRES-3 (4.00 and 3.90 °Brix) and 2015/ToLCVRES-4 (3.83 and 3.87 °Brix). The minimum total soluble solids content was recorded in H-24 (3.03 and 2.99 °Brix) The mean data of 2015-16 and 2016-17 also indicated significant variation in total soluble solids (TSS) among the seven entries/ varieties and ranged from 3.01 to 4.21 °Brix. The maximum total soluble solids content was recorded in Punjab Chhuhara (4.21 °Brix) followed by 2015/ToLCVRES-3 (3.95 °Brix) and 2015/ToLCVRES-4 (3.85 °Brix). The minimum total soluble solids content was recorded in H-24 (3.01 °Brix).

Out of seven 2015/ToLCVRES entries/ varieties evaluated in 2015-16 and 2016-17, one was pear shaped (Punjab Chhuhara) and another one was oval shaped

Table 4.47a: Quality parameters of 2015/ToLCVRES entries

Entry/ variety	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	44.81	45.32	45.07	55.57	55.78	55.68	2.80	3.00	2.90
2015/ToLCVRES-2	51.20	49.40	50.30	46.80	46.51	46.65	4.27	4.40	4.33
2015/ToLCVRES-3	49.07	50.91	49.99	43.33	44.23	43.78	4.00	3.93	3.97
2015/ToLCVRES-4	51.43	54.57	53.00	50.63	51.21	50.92	3.40	3.47	3.43
2015/ToLCVRES-5	58.43	60.71	59.57	47.33	47.02	47.18	4.80	4.73	4.77
H-24	46.23	47.37	46.80	39.57	39.48	39.52	4.13	4.00	4.07
Punjab Chhuhara	36.42	35.80	36.11	53.07	52.32	52.69	2.60	2.73	2.67
Sem±	1.822	1.692	1.529	1.895	1.521	1.280	0.111	0.118	0.073
CD (p=0.05)	5.613*	5.213*	4.711*	5.840*	4.688*	3.943*	0.341*	0.364*	0.226*
CV	6.542	5.961	5.438	6.833	5.481	4.611	5.167	5.455	3.400

Table 4.47b: Quality parameters of 2015/ToLCVRES entries

Entry/ variety	Pericarp thickness (mm)			TSS (Brix %)		Fruit shape	Fruit colour
	2015-16	2016-17	Mean	2015-16	2016-17		
2015/ToLCVRES-1	5.73	5.60	5.67	3.60	3.80	Oval	Red
2015/ToLCVRES-2	4.41	4.65	4.53	3.73	3.67	Round	Deep red
2015/ToLCVRES-3	5.77	5.66	5.71	4.00	3.90	Round	Red
2015/ToLCVRES-4	5.43	5.41	5.42	3.83	3.87	Round	Red-Deep red
2015/ToLCVRES-5	5.23	5.10	5.17	3.67	3.70	Round	Red-Deep red
H-24	4.37	4.31	4.34	3.03	2.99	Round	Red
Punjab Chhuhara	4.89	4.95	4.92	4.25	4.17	Pear	Red-Deep red
Sem±	0.150	0.096	0.083	0.107	0.130		
CD (p=0.05)	0.464*	0.295*	0.255*	0.329*	0.399*		0.266*
CV	5.091	3.255	2.809	4.962	6.022		4.004

(2015/ToLCVRES-1) and rest others were either round or flattish round in shape (Table 4.47b). Among the seven 2015/ToLCVRES entries/ varieties evaluated three entries/ variety 2015/ToLCVRES-1, 2015/ToLCVRES-3 and H-24 produced red fruits and another three entries/ variety (2015/ToLCVRES-4, 2015/ToLCVRES-5 and Punjab Chhuhara) produced red to deep red colour fruits. However remaining one entry (2015/ToLCVRES-2) were produced deep red fruits.

4.4.2.6 Other parameters of 2015/ToLCVRES entries/ varieties

Some other parameters such as plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering, days to 50% flowering and days to first fruiting were also recorded for all the entries/ varieties during 2015-16 and 2016-17 and presented in Table 4.48a and 4.48b.

In both the years the highest plant height was recorded in 2015/ToLCVRES-5 (75.52 and 68.28 cm) followed by 2015/ToLCVRES-1 (70.47 and 61.80 cm) and 2015/ToLCVRES-4 (52.60 and 49.99 cm). The minimum plant height was measured in Punjab Chhuhara (46.92 and 43.89 cm) in 2015-16 and 2016-17 respectively (Table 4.48a). The mean plant height of all the entries/ varieties in both the years (2015-16 and 2016-17) significantly ranged from 45.41 to 71.90 cm. The highest plant height was recorded in 2015/ToLCVRES- (71.90 cm) followed by 2015/ToLCVRES-1 (66.13 cm) and 2015/ToLCVRES-4 (51.30 cm). The lowest (45.41 cm) plant height was noted in Punjab Chhuhara (48.07 cm).

In 2015-16 the number of primary branches plant⁻¹ significantly ranged from 6.00 to 8.87. The maximum number of primary branches was observed in H-24 (8.87) followed by Punjab Chhuhara (8.47) and 2015/ToLCVRES-5 (7.93). The least number of branches were recorded in 2015/ToLCVRES-2 (6.00). In 2016-17 the maximum number of primary branches was observed in Punjab Chhuhara (8.07) followed by H-24 (7.67) and 2015/ToLCVRES-4 (7.47). However, the minimum number of branches was recorded in 2015/ToLCVRES-2 (5.53). It was also revealed from the mean data presented in table 4.48a that among all the 2015/ToLCVRES entries/ varieties evaluated the significant highest number of

primary branches plant⁻¹ was found in H-24 and Punjab Chhuhara (8.27) with minimum in 2015/ToLCVRES-2 (5.77).

In both the years number of secondary branches plant⁻¹ showed significant variation among the entries/ varieties evaluated under the study (Table 4.48a). The maximum number of secondary branches was observed in 2015/ToLCVRES-5 (5.33 and 5.20). This was followed by 2015/ToLCVRES-4 (4.87) and 2015/ToLCVRES-2 (4.80) in 2015-16 and 2015/ToLCVRES-4 (4.87), 2015/ToLCVRES-1 and 2015/ToLCVRES-3 (4.73). The least number of secondary branches was observed in Punjab Chhuhara (3.93 and 3.80). However the pooled mean of number of secondary branches plant⁻¹ significantly ranged from 3.87 to 5.27. The maximum number of secondary branches plant⁻¹ was counted in 2015/ToLCVRES-5 (5.27) followed by 2015/ToLCVRES-4 (4.87) and 2015/ToLCVRES-4 (4.70). The minimum number of branches was recorded in Punjab Chhuhara (3.87).

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.48b. In 2015-16 the days to first flowering significantly varied from 23.67 to 31.67 days. The minimum (23.67 days) days to first flowering were observed in 2015/ToLCVRES-2, 2015/ToLCVRES-5 and Punjab Chhuhara (23.67 days) with maximum (31.67 days) days to first flowering were observed in Punjab Chhuhara.

In 2016-17 the minimum days to first flowering were recorded in 2015/ToLCVRES-2 (22.33 days) followed 2015/ToLCVRES-5 and H-24 (23.00) (Table 4.48b). The maximum (32.67 days) days to first flowering were observed in Punjab Chhuhara. The mean data shows that among all the 2015/ToLCVRES entries/ varieties evaluated the significant lowest (23..) days to first flowering were recorded in 2015/ToLCVRES-2 followed by 2015/ToLCVRES-5 and H-24 (23.33 days). The maximum (32.17 days) days to first flowering were observed in Punjab Chhuhara.

In both the years the minimum days to 50% flowering days to 50% flowering were observed in H-24 (29.00 and 28.33 days). This was followed by 2015/ToLCVRES-5 (32.67 days) and 2015/ToLCVRES-2 (33.33 days) in 2015-16 and 2015/ToLCVRES-2 (32.67 days) and 2015/ToLCVRES-5 (34.00 days) in

Table 4.48a: Other parameters of 2015/ToLCVRES entries

Entry/ variety	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	70.47	61.80	66.13	7.20	6.80	7.00	4.53	4.73	4.63
2015/ToLCVRES-2	48.33	45.67	47.00	6.00	5.53	5.77	4.80	4.53	4.67
2015/ToLCVRES-3	48.81	45.01	46.91	7.87	7.20	7.53	4.67	4.73	4.70
2015/ToLCVRES-4	52.60	49.99	51.30	7.87	7.47	7.67	4.87	4.87	4.87
2015/ToLCVRES-5	75.52	68.28	71.90	7.93	7.40	7.67	5.33	5.20	5.27
H-24	52.33	49.27	50.80	8.87	7.67	8.27	4.20	4.40	4.30
Punjab Chhuhara	46.92	43.89	45.41	8.47	8.07	8.27	3.93	3.80	3.87
Sem±	2.793	3.385	1.745	0.239	0.340	0.161	0.168	0.170	0.093
CD (p=0.05)	8.607*	10.431*	5.377*	0.738*	1.047*	0.497*	0.519*	0.524*	0.286*
CV	8.575	11.279	5.576	5.357	8.221	3.748	6.315	6.387	3.486

Table 4.48b: Other parameters of 2015/ToLCVRES entries

Entry/ variety	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/ToLCVRES-1	25.00	26.33	25.67	38.33	39.67	39.00	31.67	33.67	32.67
2015/ToLCVRES-2	23.67	22.33	23.00	33.33	32.67	33.00	32.00	31.33	31.67
2015/ToLCVRES-3	26.00	25.00	25.50	34.00	35.00	34.50	35.33	33.67	34.50
2015/ToLCVRES-4	25.00	25.67	25.33	35.33	34.67	35.00	29.33	29.67	29.50
2015/ToLCVRES-5	23.67	23.00	23.33	32.67	34.00	33.33	33.67	34.33	34.00
H-24	23.67	23.00	23.33	29.00	28.33	28.67	34.00	33.33	33.67
Punjab Chhuhara	31.67	32.67	32.17	37.67	36.33	37.00	37.67	37.00	37.33
Sem±	0.624	0.544	0.482	0.552	0.593	0.366	0.842	0.922	0.752
CD (p=0.05)	1.922*	1.677*	1.487*	1.700*	1.828*	1.129*	2.595*	2.839*	2.317*
CV	4.232	3.708	3.280	2.783	2.988	1.847	4.369	4.795	3.907

2016-17. The maximum (38.33 and 39.67 days) days to first flowering were observed in 2015/ToLCVRES-1. It was revealed from the pooled mean of 2015-16 and 2016-17 that among all the 2015/ToLCVRES entries/ varieties evaluated the significant least (28.67 days) days to 50% flowering were observed in H-24 followed by 2015/ToLCVRES-2 (33.00) and 2015/ToLCVRES-5 (33.33 days). The maximum days to 50% flowering were observed in 2015/ToLCVRES-1 (39.00 days) (Table 4.48b).

In 2015-16 the days to first fruiting significantly varied from 29.33 to 37.67 days (Table 4.48b). The minimum days to first fruiting were observed in 2015/ToLCVRES-4 (29.33 days) followed by 2015/ToLCVRES-1 (31.67 days) and 2015/ToLCVRES-2 (32.00 days). However the maximum (37.67 days) days to first fruiting were observed in Punjab Chhuhara. In 2016-17 the significant least (29.67 days) number of days for first fruiting were recorded in 2015/ToLCVRES-4 followed by 2015/ToLCVRES-2 (31.33 days) and H-24 (33.33). The maximum days to first fruiting were observed in Punjab Chhuhara (37.00 days). The pooled mean data showed that the least (29.50 days) number of days for first fruiting were noted in 2015/ToLCVRES-4 followed by 2015/ToLCVRES-2 (31.67 days) and 2015/ToLCVRES-1 (32.67 days). The maximum days to first fruiting were observed in Punjab Chhuhara (37.33 days).

4.4.2.7 Overall performance of 2015/ToLCVRES entries/ varieties

The overall performance of all the 2015/ToLCVRES entries/ varieties were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.49 to 4.51.

It was clearly visible from Table 4.49 that in 2015-16, 2015/ToLCVRES-5 gave best overall rank followed by 2015/ToLCVRES-1 and 2015/ToLCVRES-4. Though these three entries showed commendable overall rank with resistant, and moderately resistant reaction. The maximum per ha total yield was recorded in 2015/ToLCVRES-5 (644.82 q) and exhibited resistant reaction followed by 2015/ToLCVRES-1 (556.34 q) and 2015/ToLCVRES-2 (551.59 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2015/ToLCVRES-1 with average fruit weight of

74.86 g followed by 2015/ToLCVRES-5 (67.73 g) and 2015/ToLCVRES-4 (65.01 g). However the largest round fruits were recorded in 2015/ToLCVRES-5 with equatorial diameter of 58.43 mm followed by 2015/ToLCVRES-4 (51.43 mm) and 2015/ToLCVRES-2 (51.20 mm). 2015/ToLCVRES-1 was recorded for the longest fruit with polar diameter of 55.57 mm followed by Punjab Chhuhara (53.07 mm) and 2015/ToLCVRES-4 (50.63 mm). However 2015/ToLCVRES-3 had the maximum (5.77 mm) pericarp thickness followed by 2015/ToLCVRES-1 (5.73 mm) and 2015/ToLCVRES-4 (5.43 mm). In case of TSS the maximum total soluble solids content (4.25 °Brix) was found in Punjab Chhuhara followed by 2015/ToLCVRES-3 (4.00 °Brix) and 2015/ToLCVRES-4 (3.83 °Brix). However the minimum (29.33 days) days to first fruiting were observed in 2015/ToLCVRES-4 followed by 2015/ToLCVRES-1 (31.67) and 2015/ToLCVRES-2 (32.00 days).

It was revealed from the experimental data presented in Table 4.50 that in 2016-17, 2015/ToLCVRES-5 provided best overall performance followed by 2015/ToLCVRES-1 and 2015/ToLCVRES-2. These varieties were superfine in overall performance with moderately resistant and susceptible reaction. The maximum (627.25 q) per ha total yield was recorded in 2015/ToLCVRES-5 followed by 2015/ToLCVRES-2 (548.44 q) and 2015/ToLCVRES-1 (546.83 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2015/ToLCVRES-1 with average fruit weight of 77.43 g followed by 2015/ToLCVRES-5 (72.35 g) and 2015/ToLCVRES-4 (63.88 g). However the largest round fruits were recorded in 2015/ToLCVRES-5 with equatorial diameter of 60.71 mm followed by 2015/ToLCVRES-4 (54.57 mm) and 2015/ToLCVRES-3 (50.91 mm). 2015/ToLCVRES-1 was recorded for the longest fruit with polar diameter of 55.78 mm followed by Punjab Chhuhara (52.32 mm) and 2015/ToLCVRES-4 (51.21 mm). However 2015/ToLCVRES-3 had the maximum (5.66 mm) pericarp thickness followed by 2015/ToLCVRES-1 (5.60 mm) and 2015/ToLCVRES-4 (5.41 mm). In case of TSS the maximum total soluble solids content (4.17 °Brix) was found in Punjab Chhuhara followed by 2015/ToLCVRES-3 (3.90 °Brix) and 2015/ToLCVRES-4 (3.87 °Brix). However the least (29.67 days) number of days

Table 4.49: Overall performance of 2015/ToLCVRES entries in 2015-16

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/ToLCVRES-1	53.17	25.28	MR	74.86	556.34	44.81	55.57	5.73	3.60	31.67
2015/ToLCVRES-2	81	52.89	S	56.59	551.59	51.20	46.80	4.41	3.73	32.00
2015/ToLCVRES-3	69.3	38.91	S	56.20	497.62	49.07	43.33	5.77	4.00	35.33
2015/ToLCVRES-4	44.79	23.21	MR	65.01	462.67	51.43	50.63	5.43	3.83	29.33
2015/ToLCVRES-5	30.95	12.7	R	67.73	644.82	58.43	47.33	5.23	3.67	33.67
H-24	82.92	48.57	S	31.09	545.37	46.23	39.57	4.37	3.03	34.00
Punjab Chhuhara	94.17	69.71	S	46.17	285.31	36.42	53.07	4.89	4.25	37.67
Sem±				1.694	9.250	1.822	1.895	0.150	0.107	0.842
CD (p=0.05)				5.219*	28.503	5.613*	5.840*	0.464*	0.329*	2.595*
CV				5.164	3.165	6.542	6.833	5.091	4.962	4.369

Table 4.50: Overall performance of 2015/ToLCVRES entries in 2016-17

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/ToLCVRES-1	65.51	48.67	S	77.43	546.83	45.32	55.78	5.60	3.80	33.67
2015/ToLCVRES-2	88.65	67	S	54.63	548.44	49.40	46.51	4.65	3.67	31.33
2015/ToLCVRES-3	78.64	58.97	S	61.41	482.14	50.91	44.23	5.66	3.90	33.67
2015/ToLCVRES-4	53.7	39.08	S	63.88	477.25	54.57	51.21	5.41	3.87	29.67
2015/ToLCVRES-5	35.91	25.65	MR	72.35	627.25	60.71	47.02	5.10	3.70	34.33
H-24	90.6	70	S	31.63	537.75	47.37	39.48	4.31	2.99	33.33
Punjab Chhuhara	99.1	79.67	S	45.81	257.14	35.80	52.32	4.95	4.17	37.00
Sem±				2.425	8.342	1.692	1.521	0.096	0.130	0.922
CD (p=0.05)				7.472*	25.704	5.213*	4.688*	0.295*	0.399*	2.839*
CV				7.221	2.909	5.961	5.481	3.255	6.022	4.795

Table 4.51: Overall performance of 2015/ToLCVRES entries in both the years (2015-16 and 2016-17)

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/ToLCVRES-1	59.34	36.98		76.14	551.59	45.07	55.68	5.67	3.70	32.67
2015/ToLCVRES-2	84.83	59.95	S	55.61	550.01	50.30	46.65	4.53	3.70	31.67
2015/ToLCVRES-3	73.97	48.94	S	58.81	489.88	49.99	43.78	5.71	3.95	34.50
2015/ToLCVRES-4	49.25	31.15		64.45	469.96	53.00	50.92	5.42	3.85	29.50
2015/ToLCVRES-5	33.43	19.18		70.04	636.04	59.57	47.18	5.17	3.68	34.00
H-24	86.76	59.29	S	31.36	541.56	46.80	39.52	4.34	3.01	33.67
Punjab Chhuhara	96.64	74.69	S	45.99	271.23	36.11	52.69	4.92	4.21	37.33
Sem±				1.483	6.258	1.529	1.280	0.083	0.086	0.752
CD (p=0.05)				4.570*	19.283	4.711*	3.943*	0.255*	0.266*	2.317*
CV				4.469	2.161	5.438	4.611	2.809	4.004	3.907

for first fruiting were recorded in 2015/ToLCVRES-4 followed by 2015/ToLCVRES-2 (31.33 days) and H-24 (33.33 days).

It was revealed from the average data of both the years (2015-16 and 2016-17) that the overall performance of 2015/ToLCVRES-5 was best which was followed by 2015/ToLCVRES-1 and 2015/ToLCVRES-4 (Table 4.51). Though these varieties were superfine in overall performance with variation in their reaction but maximum (636.04 q) per ha total yield was recorded in 2015/ToLCVRES-5 followed by 2015/ToLCVRES-1 (551.59 q) and 2015/ToLCVRES-2 (550.01 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from 2015/ToLCVRES-1 with average fruit weight of 76.14 g followed by 2015/ToLCVRES-5 (70.04 g) and 2015/ToLCVRES-4 (64.45 g). However the largest round fruits were recorded in 2015/ToLCVRES-5 with equatorial diameter of 59.57 mm followed by 2015/ToLCVRES-4 (53.00 mm) and 2015/ToLCVRES-2 (50.30 mm). 2015/ToLCVRES-1 was recorded for the longest fruit with polar diameter of 55.68 mm followed by Punjab Chhuhara (52.69 mm) and 2015/ToLCVRES-4 (50.92 mm). However 2015/ToLCVRES-3 had the maximum (5.71 mm) pericarp thickness followed by 2015/ToLCVRES-1 (5.67 mm) and 2015/ToLCVRES-4 (5.42 mm). In case of TSS the maximum total soluble solids content (4.21 °Brix) was found in Punjab Chhuhara followed by 2015/ToLCVRES-3 (3.95 °Brix) and 2015/ToLCVRES-4 (3.85 °Brix). However the least (29.50 days) number of days for first fruiting were noted in 2015/ToLCVRES-4 followed by 2015/ToLCVRES-2 (31.67 days) and 2015/ToLCVRES-1 (32.67 days).

4.4.2.8 Correlation of leaf curl disease with different parameters of 2015/ToLCVRES entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2015/ToLCVRES entries/ varieties for the year 2015-16 and 2016-17 and presented in table 4.52. Percent disease index of leaf curl indicated significant negative correlation with fruit yield plant⁻¹ ($r = -0.696$, $p = 0.005$), average fruit weight ($r = -0.750$, $p = 0.005$), Marketable yield q ha⁻¹ ($r = -0.693$, $p = 0.005$), Total yield q ha⁻¹ ($r = -0.683$, $p = 0.005$), equatorial diameter of fruit ($r = -0.$

Table 4.52: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2015/ToLCVRES entries

Parameters	Mean	
	Disease incidence	PDI
PDI	0.991 ^{**}	-
No of fruits plant⁻¹	0.281 ^{NS}	0.202 ^{NS}
Fruit yield plant⁻¹ (kg)	-0.599 ^{NS}	-0.696 [*]
Average fruit weight (g)	-0.760 [*]	-0.750 [*]
Marketable yield q ha⁻¹	-0.625 ^{NS}	-0.693 [*]
Unmarketable yield q ha⁻¹	0.591 ^{NS}	0.567 ^{NS}
Total yield (q ha⁻¹)	-0.614 ^{NS}	-0.683 [*]
Equatorial diameter of fruit (mm)	-0.794 [*]	-0.816 ^{**}
Polar diameter of fruit (mm)	-0.221 ^{NS}	-0.158 ^{NS}
Number of locules fruit⁻¹	-0.341 ^{NS}	-0.372 ^{NS}
Thickness of pericarp (mm)	-0.528 ^{NS}	-0.536 ^{NS}
TSS (% Brix)	0.016 ^{NS}	0.100 ^{NS}
Plant height (cm)	-0.799 ^{**}	-0.794 [*]
No. of primary branches plant⁻¹	0.027 ^{NS}	0.061 ^{NS}
No. of secondary branches plant⁻¹	-0.890 ^{**}	-0.909 ^{**}
First flowering (DAT)	0.428 ^{NS}	0.512 ^{NS}
50 per cent flowering (DAT)	-0.156 ^{NS}	-0.112 ^{NS}
First fruiting (DAT)	0.463 ^{NS}	0.513 ^{NS}



Fig 4.31: Experimental plots of 2014/ToLCVRES entries



Fig 4.32: Experimental plots of 2015/ToLCVRES entries

816, $p = 0.001$), plant height ($r = -0.794$, $p = 0.005$) and No. of secondary branches plant⁻¹ ($r = -0.909$, $p = 0.001$). However rest other parameters showed either non significant positive or negative correlation with percent disease index.

4.4.3 2016/ToLCVRES entries/ varieties

Seven 2016/ToLCVRES entries/ varieties including were evaluated against tomato leaf curl disease (ToLCD) during *rabi* 2016-17 and 2017-18 and results were presented in Table 4.53a to 4.63 (Fig 4.33).

4.4.3.1 Disease incidence and percent disease index (PDI)

Considerable variability was found in incidence and PDI of all 2016/ToLCVRES entries/ varieties evaluated. During 2016-17, disease incidence was varied from 0 to 3.33, 0.83 to 9.84, 4.96 to 25.29, 10.92 to 49.32, 20.61 to 77.12 and 29.08 to 87.69 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. However, the calculated percent disease index (PDI) was also varied from 0 to 1.65, 0.12 to 5.99, 3.31 to 16.72, 7.08 to 32.72, 13.02 to 49.94 and 19.54 to 63.42 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. The entries 2016/ToLCVRES-1, 2016/ToLCVRES-4 and 2016/ToLCVRES-5 were free from the disease up to 15 days after transplanting (DAT) but in the rest other, symptoms of tomato leaf curl was appeared either at 15 DAT (Table 4.53a – 4.54b).

While during 2017-18 disease incidence was varied from 0 to 1.63, 2.70 to 11.96, 10.08 to 39.64, 16.23 to 67.41, 24.19 to 90.15 and 33.08 to 96.45 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. However, the calculated percent disease index (PDI) was also varied from 0 to 0.70, 1.16 to 6.64, 6.46 to 25.25, 10.97 to 51.14, 16.11 to 69.90 and 24.90 to 76.38 percent 15, 30, 45, 60, 75 and 90 DAT respectively. All the entries were free from the disease up to 15 days after transplanting (DAT) but in one entry 2016/ToLCVRES-4 the disease was appeared at 15 DAT (Table 4.53a – 4.54b).

However the average incidence and PDI of both years (2016-17 and 2017-18) depicted that disease incidence was varied from 0 to 1.67, 2.11 to 10.90, 7.52 to 32.47, 13.58 to 58.36, 22.40 to 80.60 and 31.08 to 88.39 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. However, the calculated percent disease index

(PDI) was varied from 0 to 0.83, 1.04 to 6.32, 4.89 to 20.98, 9.02 to 41.93, 14.56 to 59.57 and 22.22 to 67.93 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. Two entries 2016/ToLCVRES-1 and 2016/ToLCVRES-5 were free from the disease up to 15 DAT whereas others were found infected with the leaf curl at 15 days after transplanting (Table 4.53a – 4.54b).

During 2016-17 at 90 DAT the lowest percent incidence and percent disease index (PDI) was recorded in 2016/ToLCVRES-1 (29.08, 19.54 %) followed by 2016/ToLCVRES-5 (58.08, 39.76 %) and 2016/ToLCVRES-4 (66.03, 45.30 %) and highest in 2016/ToLCVRES-6 (87.69, 63.42 %) (Table 4.53a – 4.54b).

During 2017-18 at 90 DAT the percent incidence and percent disease index (PDI) was also observed lowest in 2016/ToLCVRES-1 (33.08, 24.90 %) followed by 2016/ToLCVRES-4 (83.38, 60.97 %) and 2016/ToLCVRES-5 (85.09, 62.47 %). However, the highest leaf curl incidence and percent disease index was recorded in 2016/ToLCVRES-2 (96.45, 76.38 %) (Table 4.53a – 4.54b).

The average percent incidence and PDI of both years (2016-17 and 2017-18) also showed that lowest percent incidence and PDI of leaf curl was observed in 2016/ToLCVRES-1 (31.08, 22.22 %) followed by 2016/ToLCVRES-5 (71.59, 51.12%) and 2016/ToLCVRES-4 (74.71, 53.14%). Whereas the highest infection of leaf curl was recorded in 2016/ToLCVRES-6 with 88.39 percent incidence and PDI of 67.93 percent (Table 4.53a – 4.54b).

4.4.3.2 Response of 2016/ToLCVRES entries/ varieties of tomato against ToLCD

In both the years none of the entry was found resistant among the seven entries/ varieties evaluated against tomato leaf curl disease (ToLCD) in 2016-17 and 2017-18. However one entry (2016/ToLCVRES-1) was moderately resistant and remaining six (2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES-4, 2016/ToLCVRES-5, 2016/ToLCVRES-6 and 2016/ToLCVRES-7) were susceptible to ToLCD with constant reaction in both the years (Table 4.55).

Table 4.53a: Percent incidence of tomato leaf curl disease in 2016/ToLCVRES entries

Entry	Percent disease incidence at 15-day intervals (DAT)								
	15			30			45		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	0.00	0.00	0.00	0.83	3.38	2.11	4.96	10.08	7.52
2016/ToLCVRES-2	3.33	0.00	1.67	9.84	11.96	10.90	25.29	39.64	32.47
2016/ToLCVRES-3	2.68	0.00	1.34	7.15	4.98	6.07	15.27	19.87	17.57
2016/ToLCVRES-4	0.00	1.63	0.81	4.51	4.96	4.74	10.89	22.30	16.60
2016/ToLCVRES-5	0.00	0.00	0.00	2.91	8.76	5.84	9.12	31.19	20.15
2016/ToLCVRES-6	1.52	0.00	0.76	7.63	2.70	5.17	21.24	16.27	18.76
2016/ToLCVRES-7	2.68	0.00	1.34	8.16	2.38	5.27	15.79	15.29	15.54

Table 4.53b: Percent incidence of tomato leaf curl disease in 2016/ToLCVRES entries

Entry	Percent disease incidence at 15-day intervals (DAT)								
	60			75			90		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	10.92	16.23	13.58	20.61	24.19	22.40	29.08	33.08	31.08
2016/ToLCVRES-2	49.32	67.41	58.36	71.06	90.15	80.60	78.96	96.45	87.71
2016/ToLCVRES-3	33.48	38.95	36.22	62.26	64.07	63.16	78.69	88.59	83.64
2016/ToLCVRES-4	23.99	29.90	26.95	46.01	62.30	54.16	66.03	83.38	74.71
2016/ToLCVRES-5	20.30	37.22	28.76	39.15	69.81	54.48	58.08	85.09	71.59
2016/ToLCVRES-6	46.97	42.72	44.84	77.12	76.25	76.68	87.69	89.09	88.39
2016/ToLCVRES-7	33.42	27.63	30.53	65.26	65.06	65.16	78.85	86.23	82.54

Table 4.54a: Evaluation of 2016/ToLCVRES entries against tomato leaf curl disease

Entry	Percent disease index at 15-day intervals (DAT)									
	15					30				
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17
2016/ToLCVRES-1	0.00	0.00	0.00	0.12	1.95	1.04	3.31	6.46	4.89	20.98
2016/ToLCVRES-2	1.65	0.00	0.83	5.99	6.64	6.32	16.72	25.25	11.58	10.51
2016/ToLCVRES-3	0.91	0.00	0.46	3.84	2.84	3.34	10.13	14.03	11.97	11.97
2016/ToLCVRES-4	0.00	0.70	0.35	2.46	3.07	2.77	6.98	18.26	10.07	9.59
2016/ToLCVRES-5	0.00	0.00	0.00	1.54	4.99	3.26	13.86	10.10	9.09	9.59
2016/ToLCVRES-6	0.65	0.00	0.33	5.00	1.16	3.08	10.07	9.09	9.59	9.59
2016/ToLCVRES-7	0.39	0.00	0.19	3.86	1.25	2.55	10.10	9.09	9.59	9.59

Table 4.54b: Evaluation of 2016/ToLCVRES entries against tomato leaf curl disease

Entry	Percent disease index at 15-day intervals (DAT)									
	60					75				
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17
2016/ToLCVRES-1	7.08	10.97	9.02	13.02	16.11	14.56	19.54	24.90	22.22	MR
2016/ToLCVRES-2	32.72	51.14	41.93	49.24	69.90	59.57	59.47	76.38	67.93	MR
2016/ToLCVRES-3	22.60	24.56	23.58	40.53	45.50	43.02	55.17	65.40	60.28	S
2016/ToLCVRES-4	15.03	19.70	17.37	27.44	44.25	35.85	45.30	60.97	53.14	S
2016/ToLCVRES-5	13.06	23.33	18.20	24.57	49.49	37.03	39.76	62.47	51.12	S
2016/ToLCVRES-6	30.98	28.17	29.58	49.94	54.99	52.47	63.42	65.72	64.57	S
2016/ToLCVRES-7	22.16	17.46	19.81	41.82	46.71	44.26	54.67	63.22	58.95	S

Table 4.55: Classification of 2016/ToLCVRES entries in different reaction categories

Year	Reaction category	No. of Entry	Name of entry
Entries with constant reaction in both the years	Resistant	0	
	Moderately resistant	1	2016/ToLCVRES-1
	Moderately susceptible	0	
	Susceptible	6	2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES-4, 2016/ToLCVRES-5, 2016/ToLCVRES-6, 2016/ToLCVRES-7
2016-17	Resistant	0	
	Moderately resistant	1	2016/ToLCVRES-1
	Moderately susceptible	0	
	Susceptible	6	2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES-4, 2016/ToLCVRES-5, 2016/ToLCVRES-6, 2016/ToLCVRES-7
2017-18	Resistant	0	
	Moderately resistant	1	2016/ToLCVRES-1
	Moderately susceptible	0	
	Susceptible	6	2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES-4, 2016/ToLCVRES-5, 2016/ToLCVRES-6, 2016/ToLCVRES-7

4.4.3.3 Yield parameters of 2016/ToLCVRES entries/ varieties

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out during 2016-17 and 2017-18 and presented in Table 4.56.

During 2016-17 the number of fruits plant⁻¹ significantly ranged from 22.60 to 66.98 (Table 4.56). The significant maximum number of fruits plant⁻¹ (66.98) was recorded in 2016/ToLCVRES-3 followed by H-24 (58.21) and Punjab Chhuhara (38.03). However 2016/ToLCVRES-6 (32.75), 2016/ToLCVRES-4 (33.00) and 2016/ToLCVRES-7 (34.47) were at par with Punjab Chhuhara (38.03). The lowest number of fruits plant⁻¹ (22.60) was recorded in 2016/ToLCVRES-2. During 2017-18 the number of fruits plant⁻¹ significantly ranged from 15.24 to 58.48. The significant maximum number of fruits plant⁻¹ (58.48) was recorded in H-24 followed by 2016/ToLCVRES-3 (47.52) and Punjab Chhuhara (37.93). However 2016/ToLCVRES-6 (32.80) and Punjab Chhuhara (37.93) were at par with each other. The lowest number of fruits plant⁻¹ (15.24) was recorded in 2016/ToLCVRES-4. The mean number of fruits plant⁻¹ of both years (2016-17 and 2017-18) exhibited that the number of fruits plant⁻¹ significantly ranged from 21.46 to 58.35. The significant maximum number of fruits plant⁻¹ (58.35) was observed in H-24 followed by 2016/ToLCVRES-3 (57.25) and Punjab Chhuhara (37.98). However 2016/ToLCVRES-3 and H-24 were at par with each other. The lowest number of fruits plant⁻¹ (21.46) was recorded in 2016/ToLCVRES-2.

There was significant variation was noted among 2016/ToLCVRES entries for fruit yield plant⁻¹ (Table 4.56). During 2016-17, the fruit yield plant⁻¹ significantly ranged from 1.13 to 2.84 kg. The significant maximum fruit yield plant⁻¹ (2.84 kg) was registered in 2016/ToLCVRES-3 followed by 2016/ToLCVRES-4 (2.66 kg) and 2016/ToLCVRES-7 (2.62 kg) and minimum (1.13 kg) was observed in 2016/ToLCVRES-2. However H-24 (2.30 kg), 2016/ToLCVRES-6 (2.40 kg), 2016/ToLCVRES-7 (2.62) and 2016/ToLCVRES-4 (2.66 kg) were at par with 2016/ToLCVRES3-3. During 2017-18, the fruit yield plant⁻¹ significantly ranged from 0.68 to 2.40 kg. The significant maximum fruit yield plant⁻¹ (2.40 kg) was recorded in 2016/ToLCVRES-6 followed by 2016/ToLCVRES-1 (2.20 kg) and H-24 (2.16 kg) however these three entries were

at par with each other. The lowest (0.68 kg) fruit yield was observed in 2016/ToLCVRES-2. The pooled mean of fruit yield plant⁻¹ displayed that the fruit yield plant⁻¹ significantly ranged from 0.91 to 2.40. The significant maximum fruit yield plant⁻¹ (2.40 kg) was noted in 2016/ToLCVRES-6 followed by 2016/ToLCVRES-1 (2.31 kg) and H-24 (2.23 kg) and minimum (0.91 kg) was observed in 2016/ToLCVRES-2. Whereas 2016/ToLCVRES-3 (2.21 kg), H-24, and 2016/ToLCVRES-1 were at par with 2016/ToLCVRES-6.

The significant variation was observed in average fruit weight of 2016/ToLCVRES entries evaluated during 2016-17 and 2017-18 (Table 4.56). During 2016-17, the average fruit weight significantly ranged from 36.52 to 86.67 g. The significant maximum average fruit weight (86.67 g) was recorded in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-4 (83.90 g) and 2016/ToLCVRES-7 (75.83 g) and minimum (36.52 g) was observed in Punjab Chhuhara. However 2016/ToLCVRES-1 and 2016/ToLCVRES-4 were at par with each other. During 2017-18, the average fruit weight significantly ranged 34.33 to 84.17 g. The significant maximum average fruit weight (84.17 g) was recorded in 2016/ToLCVRES-4 followed by 2016/ToLCVRES-1 (75.89 g) and 2016/ToLCVRES-6 (73.33 g) and minimum (34.33 g) was observed in 2016/ToLCVRES-3. However 2016/ToLCVRES-1 and 2016/ToLCVRES-4 were at par with each other. The mean average fruit weight of both years (2016-17 and 2017-18) expressed that the average fruit weight significantly ranged from 35.51 to 84.03 g. The significant maximum average fruit weight (84.03 g) was observed in 2016/ToLCVRES-4 followed by 2016/ToLCVRES-1 (81.28 g) and 2016/ToLCVRES-6 (73.27 g) and minimum (35.51 g) was recorded in Punjab Chhuhara. However 2016/ToLCVRES-1 and 2016/ToLCVRES-4 were at par with each other.

4.4.3.4 Yield of 2016/ToLCVRES entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or entry. Marketable yield ha⁻¹, Unmarketable yield ha⁻¹ and Total yield ha⁻¹ were computed for all the 2016/ToLCVRES entries evaluated in both the years (2016-17 and 2017-18) and depicted in Table 4.57.

The significant difference was observed in marketable yield ha^{-1} of entries evaluated during 2016-17 and 2017-18 (Table 4.57). During 2016-17, the marketable yield ha^{-1} significantly ranged from 140.61 to 643.20 q. The significant maximum marketable yield ha^{-1} (643.20 q) was noted in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-3 (521.35 q) and 2016/ToLCVRES-4 (506.85 q) however these both entries were at par with each other. The minimum marketable yield ha^{-1} (140.61 q) was observed in Punjab Chhuhara. During 2017-18, the marketable yield ha^{-1} significantly ranged from 107.94 to 613.57 q. The significant maximum marketable yield ha^{-1} (613.57 q) was recorded in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-6 (460.03 q) and 2016/ToLCVRES-4 (382.01 q). The minimum marketable yield ha^{-1} (107.94 q) was found in 2016/ToLCVRES-2. Whereas the mean marketable yield ha^{-1} of both years (2016-17 and 2017-18) displayed that the marketable yield ha^{-1} significantly ranged from 134.47 to 628.39 q. The significant maximum marketable yield ha^{-1} (628.39 q) was obtained from 2016/ToLCVRES-1 followed by 2016/ToLCVRES-4 (444.43 q) and 2016/ToLCVRES-6 (443.65 q) however these both entries were at par with each other. The minimum marketable yield ha^{-1} (134.47 q) was noted in Punjab Chhuhara.

During 2016-17, the unmarketable yield ha^{-1} significantly ranged from 4.71 to 15.85 q (Table 4.57). The minimum unmarketable yield ha^{-1} (4.71 q) was recorded in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-5 (5.93 q) and 2016/ToLCVRES-4 (6.43 q). However Punjab Chhuhara (6.61 q), 2016/ToLCVRES-7 (6.61 q), 2016/ToLCVRES-4 (6.43 q) and 2016/ToLCVRES-5 (5.93 q) were at par with 2016/ToLCVRES-1 (4.71 q). The maximum unmarketable yield ha^{-1} (15.85 q) was noted in 2016/ToLCVRES-2. Whereas during 2017-18, the unmarketable yield ha^{-1} ranged from 0 to 30.03 q. The unmarketable yield ha^{-1} was nil in 2016/ToLCVRES-2, 2016/ToLCVRES-5 and 2016/ToLCVRES-6. The maximum unmarketable yield ha^{-1} (30.03 q) was recorded in 2016/ToLCVRES-4. The mean unmarketable yield ha^{-1} from both years (2016-17 and 2017-18) showed that unmarketable yield ha^{-1} significantly ranged from 2.96 to 18.23 q. The minimum unmarketable yield ha^{-1} (2.96 q) was found in 2016/ToLCVRES-5 followed by 2016/ToLCVRES-1 (3.43 q) and

Table 4.56: Yield parameters of 2016/ToLCVRES entries

Entry	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	27.89	30.05	28.97	2.41	2.20	2.31	86.67	75.89	81.28
2016/ToLCVRES-2	22.60	20.32	21.46	1.13	0.68	0.91	50.00	38.15	44.08
2016/ToLCVRES-3	66.98	47.52	57.25	2.84	1.57	2.21	43.33	34.33	38.83
2016/ToLCVRES-4	33.00	15.24	24.12	2.66	1.29	1.98	83.90	84.17	84.03
2016/ToLCVRES-5	23.53	22.88	23.21	1.54	1.56	1.55	65.61	68.33	66.97
2016/ToLCVRES-6	32.75	32.80	32.78	2.40	2.40	2.40	73.21	73.33	73.27
2016/ToLCVRES-7	34.47	29.04	31.76	2.62	1.78	2.20	75.83	61.18	68.51
Sem±	1.909	2.328	1.570	0.229	0.102	0.119	2.400	3.323	2.151
CD (p=0.05)	5.884*	7.173*	4.837*	0.707*	0.313*	0.367*	7.396*	10.238*	6.626*
CV	9.597	14.266	8.669	17.832	10.743	10.672	6.081	9.253	5.706

Table 4.57: Yield performance of 2016/ToLCVRES entries

Entry	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	643.20	613.57	628.39	4.71	2.14	3.43	647.91	615.71	631.81
2016/ToLCVRES-2	172.88	107.94	140.41	15.85	0.00	7.93	188.73	107.94	148.34
2016/ToLCVRES-3	521.35	244.84	383.10	10.61	5.71	8.16	531.96	250.56	391.26
2016/ToLCVRES-4	506.85	382.01	444.43	6.43	30.03	18.23	513.28	412.04	462.66
2016/ToLCVRES-5	336.93	256.06	296.50	5.93	0.00	2.96	342.86	256.06	299.46
2016/ToLCVRES-6	427.27	460.03	443.65	8.60	0.00	4.30	435.87	460.03	447.95
2016/ToLCVRES-7	481.22	303.44	392.33	6.61	3.15	4.88	487.83	306.59	397.21
Sem±	6.604	6.037	5.098	1.009	0.732	0.633	6.768	6.314	5.378
CD (p=0.05)	20.350*	18.603*	15.707*	3.109*	2.254*	1.951*	20.854*	19.454*	16.572*
CV	2.592	3.091	2.265	20.825	21.616	15.385	2.606	3.178	2.347

2016/ToLCVRES-6 (4.30 q). The maximum unmarketable yield ha^{-1} (18.23 q) was registered in 2016/ToLCVRES-4. However 2016/ToLCVRES-7 (4.88 q), 2016/ToLCVRES-6 and 2016/ToLCVRES-1 were at par with 2016/ToLCVRES-5.

The significant variation was remarked in total yield ha^{-1} of entries evaluated during 2016-17 and 2017-18 (Table 4.57). During 2016-17, the total yield ha^{-1} significantly ranged from 147.22 to 647.91 q. The significant maximum total yield ha^{-1} (647.91 q) was noted in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-3 (531.96 q) and 2016/ToLCVRES-4 (513.28 q). The minimum total yield ha^{-1} (147.22 q) was observed in Punjab Chhuhara. However 2016/ToLCVRES-3 and 2016/ToLCVRES-4 were at par with each other. During 2017-18, the total yield ha^{-1} significantly ranged from 107.94 to 615.71 q. The significant maximum total yield ha^{-1} (615.71 q) was recorded in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-6 (460.03 q) and 2016/ToLCVRES-4 (412.04 q). The minimum total yield ha^{-1} (107.94 q) was found in 2016/ToLCVRES-2. Whereas the mean total yield ha^{-1} of both years (2016-17 and 2017-18) displayed that the total yield ha^{-1} significantly ranged from 141.64 to 631.81 q. The significant maximum total yield ha^{-1} (631.81 q) was obtained from 2016/ToLCVRES-1 followed by 2016/ToLCVRES-4 (462.66 q) and 2016/ToLCVRES-6 (447.95 q) however these both entries were at par with each other. The minimum total yield ha^{-1} (141.64 q) was noted in Punjab Chhuhara.

4.4.3.5 Quality parameters of 2016/ToLCVRES entries/ varieties

Quality parameters of fruit are one of the important factors that directly or indirectly influence the market value of yield. quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each entry were studied during 2016-17 and 2017-18 and mentioned in Table 4.58a and 4.58b.

During 2016-17 the significant difference was noticed in equatorial diameter which ranged from 41.67 to 55.96 mm (Table 4.58a). The largest fruit was gained from 2016/ToLCVRES-4 with equatorial diameter of 55.96 mm followed by 2016/ToLCVRES -1 (55.28 mm) and 2016/ToLCVRES-5 (53.63 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (41.67

mm). 2016/ToLCVRES-7 (53.23 mm), 2016/ToLCVRES-5 and 2016/ToLCVRES-1 were at par with 2016/ToLCVRES-4. However during 2017-18 the equatorial diameter was ranged from 38.98 to 54.28 mm. The largest fruit was observed in 2016/ToLCVRES-4 with equatorial diameter of 54.28 mm followed by 2016/ToLCVRES-5 (52.84 mm) and 2016/ToLCVRES-6 (51.26 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (38.98 mm). However 2016/ToLCVRES-1 (51.01 mm), 2016/ToLCVRES-7 (51.11 mm), 2016/ToLCVRES-6 (51.26 mm) and 2016/ToLCVRES-5 (52.84 mm) were at par with 2016/ToLCVRES-4 (54.28 mm). The mean equatorial diameter from both years (2016-17 and 2016-17) significantly ranged from 40.32 to 55.12 mm. The largest fruit was observed in 2016/ToLCVRES-4 with equatorial diameter of 55.12 mm followed by 2016/ToLCVRES-5 (53.24 mm) and 2016/ToLCVRES-1 (53.14 mm) however these three entries were at par with each other. The minimum equatorial diameter was recorded in Punjab Chhuhara (40.32 mm).

The significant variation was observed in polar diameter of entries evaluated. The polar diameter ranged from 38.47 to 65.92 mm in 2016-17 and 38.20 to 55.40 mm in 2017-18 (Table 4.58a). In both years the fruits with maximum polar diameter were obtained from 2016/ToLCVRES-2 with polar diameter of 65.92 and 55.40 mm in 2016-17 and 2017-18 respectively. This was followed by Punjab Chhuhara (58.15) and 2016/ToLCVRES-1 (56.27 mm) in 2016-17 and Punjab Chhuhara (54.90) and 2016/ToLCVRES-5 (54.82 mm) in 2017-18. 2016/ToLCVRES-5 (54.95 mm), 2016/ToLCVRES-1 and Punjab Chhuhara were at par with each other in 2016-17 whereas 2016/ToLCVRES-1 (53.28 mm), 2016/ToLCVRES-5 and Punjab Chhuhara were at par with 2016/ToLCVRES-2 in 2017-18. In both years the minimum polar diameter (38.47 and 38.20 mm) was obtained from H-24. The pooled mean of polar diameter significantly ranged from 38.34 to 60.66 mm (Table 4.58a). The maximum polar diameter (60.66 mm) was recorded in 2016/ToLCVRES-2 followed by Punjab Chhuhara (56.53 mm) and 2016/ToLCVRES-5 (54.88 mm). The fruits with lowest polar diameter (38.34 mm) were obtained from H-24. However 2016/ToLCVRES-1 (54.77 mm), 2016/ToLCVRES-5 and Punjab Chhuhara were at par with each other.

The locules are directly derived from the carpels in the flower. Locule number affects fruit shape and can increase fruit size by as much as fifty percent. Thus, the increase in locule number is an important factor for development of large tomato fruit (Lippman and Tanksley, 2001, Muños *et al.*, 2011 and Clevenger, 2013). A significant variation was observed in the number of locules among evaluated entries in both the years 2016-17 and 2017-18 (Table 4.58a). In 2016-17 the number of locules ranged from 2.33 to 5.00. The maximum number of locules (5.00) was observed in 2016/ToLCVRES-6 followed by H-24 (4.53) and 2016/ToLCVRES-4 (4.07). However 2016/ToLCVRES-1 (3.53), 2016/ToLCVRES-5 (3.60) were at par with 2016/ToLCVRES-7 (3.87). The minimum number of locules (2.33) was recorded in Punjab Chhuhara. In 2017-18 the number of locules ranged from 2.00 to 4.50. The maximum number of locules (4.50) was observed in 2016/ToLCVRES-7 followed by H-24 (4.40) and 2016/ToLCVRES-4 (4.33) however these were at par with each other. The minimum number of locules (2.00) was recorded in 2016/ToLCVRES-2. The pooled mean of locules exhibited significant variation in number of locules among entries and ranged from 2.33 to 4.47 (Table 4.58a). The maximum number of locules (4.47) was observed in H-24 followed by 2016/ToLCVRES-4 (4.20) and 2016/ToLCVRES-6 (4.20) however these were at par with each other. The minimum number of locules (2.33) was found in Punjab Chhuhara.

A significant variation was observed on pericarp thickness among evaluated entries in both the years 2016-17 and 2017-18 (Table 4.58b). In 2016-17 the pericarp thickness ranged from 2.33 to 5.61 mm. Among the 2016/ToLCVRES entries, 2016/ToLCVRES-1 produced fruits with maximum pericarp thickness (5.61 mm) followed by 2016/ToLCVRES-4 (5.21 mm) and 2016/ToLCVRES-5 (5.17 mm). However 2016/ToLCVRES-7 (4.87 mm), 2016/ToLCVRES-2 (4.94 mm) and 2016/ToLCVRES-5 were at par with 2016/ToLCVRES-4. In 2017-18 the pericarp thickness ranged from 2.33 to 6.31 mm. The fruits of 2016/ToLCVRES-5 had the maximum pericarp thickness (6.31 mm) followed by 2016/ToLCVRES-1 (5.49 mm) and 2016/ToLCVRES-2 (5.25) and both of these entries were at par with each other. In both years the fruits of Punjab Chhuhara had the thinnest pericarp (2.33 mm) among all entries. The mean data of 2016-17 and 2017-18 also

showed significant variation in pericarp thickness among the entries and ranged from 2.33 to 5.74 mm. The maximum (5.74 mm) pericarp thickness was recorded in 2016/ToLCVRES-5 followed by 2016/ToLCVRES-1 (5.55 mm) and 2016/ToLCVRES-2 (5.09 mm). The minimum pericarp thickness (2.33 mm) was recorded in Punjab Chhuhara.

In 2016-17 the TSS ranged from 3.17 to 5.45 °Brix. Among the nine entries evaluated, the significant maximum total soluble solids content (5.45 °Brix) was found in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-6 (4.99 °Brix) and 2016/ToLCVRES-2 (4.67 °Brix) however both of these entries were at par with each other. In 2017-18 the TSS ranged from 2.79 to 4.56 °Brix. Among the nine 2016/ToLCVRES entries evaluated, the maximum total soluble solids content (4.56 °Brix) was found in 2016/ToLCVRES-2 followed by H-24 (4.19 °Brix) and Punjab Chhuhara (4.18 °Brix). However 2016/ToLCVRES-6 (4.06 °Brix), H-24 and Punjab Chhuhara were at par with each other. In both years the minimum total soluble solids content (3.17 and 2.79 °Brix) was recorded in 2016/ToLCVRES-4. The pooled mean data of 2016-17 and 2017-18 also showed significant variation in total soluble solids (TSS) among the entries and ranged from 2.98 to 4.61 °Brix. The maximum total soluble solids content (4.61 °Brix) was obtained in 2016/ToLCVRES-2 followed by 2016/ToLCVRES-6 (4.53 °Brix) and 2016/ToLCVRES-1 (4.49 °Brix) and these were at par with each other. The minimum total soluble solids content (2.98 °Brix) was recorded in 2016/ToLCVRES-4 (Table 4.58b).

Among the nine entries evaluated the fruits of one entry 2016/ToLCVRES-2) was oval shaped and another one (Punjab Chhuhara) was pear shaped and rest of the 2016/ToLCVRES entries produced either round or flattish round fruits. In case of fruit colour one entry (Punjab Chhuhara) produced red to deep red fruits whereas the fruits of two entries (2016/ToLCVRES-5 and 2016/ToLCVRES-7) were deep red and remaining six entries (2016/ToLCVRES-1, 2016/ToLCVRES-2, 2016/ToLCVRES-3, 2016/ToLCVRES -4, 2016/ToLCVRES-6 and H-24) were found to produce red coloured fruits (Table 4.58b).

Table 4.58a: Quality parameters of 2016/ToLCVRES entries

Entry	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	55.28	51.01	53.14	56.27	53.28	54.77	3.53	3.67	3.60
2016/ToLCVRES-2	42.14	39.25	40.70	65.92	55.40	60.66	2.80	2.00	2.40
2016/ToLCVRES-3	45.19	45.28	45.23	43.00	38.65	40.83	3.47	3.20	3.33
2016/ToLCVRES-4	55.96	54.28	55.12	51.19	48.93	50.06	4.07	4.33	4.20
2016/ToLCVRES-5	53.63	52.84	53.24	54.95	54.82	54.88	3.60	2.67	3.13
2016/ToLCVRES-6	51.39	51.26	51.33	44.35	46.34	45.34	5.00	3.40	4.20
2016/ToLCVRES-7	53.23	51.11	52.17	47.72	43.25	45.49	3.87	4.50	4.18
Sem±	0.929	1.515	0.778	1.443	1.735	1.080	0.136	0.143	0.099
CD (p=0.05)	2.863*	4.669*	2.396*	4.447*	5.345*	3.328*	0.418*	0.441*	0.304*
CV	3.157	5.324	2.687	4.816	6.173	3.720	6.248	7.309	4.782

Table 4.58b: Quality parameters of 2016/ToLCVRES entries

Entry	Pericarp thickness (mm)			TSS (Brix %)		Fruit shape	Fruit colour	
	2016-17	2017-18	Mean	2016-17	2017-18			Mean
2016/ToLCVRES-1	5.61	5.49	5.55	5.45	3.52	4.49	Round	Red
2016/ToLCVRES-2	4.94	5.25	5.09	4.67	4.56	4.61	Oval	Red
2016/ToLCVRES-3	4.38	4.43	4.41	4.38	3.12	3.75	Round	Red
2016/ToLCVRES-4	5.21	4.94	5.07	3.17	2.79	2.98	Round	Red
2016/ToLCVRES-5	5.17	6.31	5.74	4.37	3.63	4.00	Round	Deep Red
2016/ToLCVRES-6	4.57	4.79	4.68	4.99	4.06	4.53	Round	Red
2016/ToLCVRES-7	4.87	4.38	4.62	3.95	3.14	3.54	Round	Deep Red
Sem±	0.147	0.074	0.074	0.088	0.124	0.063		
CD (p=0.05)	0.453*	0.228*	0.228*	0.272*	0.381*	0.195*		
CV	5.130	2.520	2.546	3.451	6.041	2.744		

4.4.3.6 Other parameters of 2016/ToLCVRES entries/ varieties

Some other parameters such as Plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF) were recorded for each and every entry during 2016-17 and 2017-18 and presented in Table 4.59a and 4.59b.

In 2016-17 plant height was ranged from 46.30 to 69.73 cm (Table 4.59a). The significantly highest (69.73 cm) plant height was recorded in 2016/ToLCVRES-5 followed by 2016/ToLCVRES-1 (64.41 cm) and 2016/ToLCVRES-6 (62.82 cm). However 2016/ToLCVRES-7 (61.99 cm), 2016/ToLCVRES-6 and 2016/ToLCVRES-1 were at par with 2016/ToLCVRES-5. In 2017-18 the plant height was significantly ranged from 41.35 to 61.89 cm during. The highest (61.89 cm) plant height was recorded in 2016/ToLCVRES-6 followed by 2016/ToLCVRES-5 (60.27 cm) and 2016/ToLCVRES-7 (57.86 cm). However 2016/ToLCVRES-4 (54.76 cm), 2016/ToLCVRES-1 (57.22 cm), 2016/ToLCVRES-7 and 2016/ToLCVRES-5 were at par with 2016/ToLCVRES-6. In both years the lowest (46.30 and 41.35 cm) plant height was noted in 2016/ToLCVRES-2. The pooled mean data of plant height exhibited significant variation among the entries and ranged from 43.83 to 65.00 cm. The highest (65.00 cm) plant height was recorded in 2016/ToLCVRES-5 followed by 2016/ToLCVRES-6 (62.36 cm) and 2016/ToLCVRES-1 (60.82 cm). The lowest (43.83 cm) plant height was noted in 2016/ToLCVRES-2. However 2016/ToLCVRES-7 (59.93 mm), 2016/ToLCVRES-1 and 2016/ToLCVRES-6 were at par with 2016/ToLCVRES-5.

In 2016-17 the number of primary branches plant⁻¹ varied significantly (Table 4.59a). The highest (10.20) number of branches was observed in H-24 followed by 2016/ToLCVRES-2, 2016/ToLCVRES-3 and 2016/ToLCVRES-6 (9.27). The least number of branches (7.07) were observed in 2016/ToLCVRES-4. In 2017-18 there was significant difference was observed in number of primary branches plant⁻¹ among entries and varied from 6.27 to 9.93 (Table 4.59a). The highest (9.93) number of branches was observed in H-24 followed by 2016/ToLCVRES-6 (9.33) and Punjab Chhuhara (8.60). Whereas

2016/ToLCVRES-6 and H-24 were at par with each other. The least (6.27) number of branches were noticed in 2016/ToLCVRES-5. It was revealed from pooled mean of 2016-17 and 2017-18 that among all the 2016/ToLCVRES entries evaluated the significant highest (10.07) number of primary branches plant⁻¹ was found in H-24 followed by 2016/ToLCVRES-6 (9.30) and 2016/ToLCVRES-3 (8.83). The least number of branches (6.83) were recorded from 2016/ToLCVRES-4. Whereas 2016/ToLCVRES-6 and H-24 were at par with each other.

In 2016-17 the number of secondary branches plant⁻¹ varied significantly (Table 4.59a). The highest (5.20) number of secondary branches was observed in Punjab Chhuhara followed by H-24 (4.93) and 2016/ToLCVRES-7 (3.93) whereas Punjab Chhuhara and H-24 were at par with each other. The least number of branches were recorded in 2016/ToLCVRES-3 (3.20). In 2017-18 there was significant difference was observed in number of secondary branches plant⁻¹ among the entries and varied from 2.80 to 4.87 (Table 4.59a). The highest (4.87) number of branches was observed in H-24 followed by Punjab Chhuhara (4.80) and 2016/ToLCVRES-4 and 2016/ToLCVRES-7 (3.47) whereas Punjab Chhuhara and H-24 were at par with each other. The least number of branches were recorded in 2016/ToLCVRES-2 (2.80). It was revealed from pooled mean of 2016-17 and 2017-18 that among all the entries evaluated the significant highest (5.00) number of secondary branches plant⁻¹ was found in Punjab Chhuhara followed by H-24 (4.90) and 2016/ToLCVRES-7 (3.70). The least number of branches were recorded in 2016/ToLCVRES-3 (3.10). However Punjab Chhuhara and H-24 were at par with each other.

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.59b. In 2016-17 there was non significant difference was observed among the nine entries evaluated however in 2017-18 the days to first flowering significantly ranged from 23.67 to 30.00 days. The minimum (23.67 days) days to first flowering were observed in 2016/ToLCVRES-6 and 2016/ToLCVRES-7 and maximum (30.00 days) were observed in 2016/ToLCVRES-1. It was also revealed from pooled mean of 2016-17 and 2017-18 that the days to first flowering of all the entries were non significant.

In 2016-17 the days to 50% flowering significantly ranged from 37.33 to 53.33 days (Table 4.59b). The minimum (37.33 days) days to 50% flowering were observed in 2016/ToLCVRES-4 followed by Punjab Chhuhara (38.00 days) and H-24 (40.67 days). The maximum (53.33 days) days to 50% flowering were observed in 2016/ToLCVRES-6. However 2016/ToLCVRES-7 (41.00 days), H-24, Punjab Chhuhara and 2016/ToLCVRES-4 were at par with each other.

In 2017-18 the days to 50% flowering significantly ranged from 34.33 to 41.33 days. The minimum (34.33 days) days to 50% flowering were recorded in 2016/ToLCVRES-4 followed by 2016/ToLCVRES-7 (35.00 days) and 2016/ToLCVRES-5 (35.33). The maximum (41.33 days) days to 50% flowering were observed in H-24. However Punjab Chhuhara (37.67 days), 2016/ToLCVRES-1 (37.33 days), 2016/ToLCVRES-3 (37.00 days), 2016/ToLCVRES-6 (36.67 days), 2016/ToLCVRES-5 (35.33 days) and 2016/ToLCVRES-7 (35.00 days) were at par with 2016/ToLCVRES-4 (34.33 days). It was revealed from the pooled mean of 2016-17 and 2017-18 that among all the 2016/ToLCVRES entries evaluated the significant least (35.83) days to 50% flowering were observed in 2016/ToLCVRES-4 followed by Punjab Chhuhara (37.83 days) and 2016/ToLCVRES-7 (38.00 days) whereas these three were at par with each other. The maximum (45.00 days) days to 50% flowering were observed in 2016/ToLCVRES-6 (Table 4.59b).

In 2016-17 the days to first fruiting significantly varied from 36.00 to 48.67 days. The minimum (36.00 days) days to first fruiting were observed in 2016/ToLCVRES-2 followed by 2016/ToLCVRES-4 (37.00 days) and 2016/ToLCVRES-7 (38.67 days). The maximum (48.67 days) days to first fruiting were observed in 2016/ToLCVRES-6. Whereas in 2017-18 the days to first fruiting were non significant and the pooled mean of the days to first fruiting also showed non significant variation among the entries (Table 4.59b).

4.4.3.7 Overall performance of 2016/ToLCVRES entries/ varieties

The overall performance of all the 2016/ToLCVRES entries were analyzed for both the years 2016-17 and 2017-18 and presented in Table 4.60 to 4.62.

Table 4.59b: Other parameters of 2016/ToLCVRES entries

Entry	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/ToLCVRES-1	25.33	30.00	27.67	40.33	37.33	38.83	39.33	40.00	39.67
2016/ToLCVRES-2	24.00	24.67	24.33	42.00	39.33	40.67	36.00	39.67	37.83
2016/ToLCVRES-3	25.67	25.00	25.33	41.33	37.00	39.17	40.00	39.67	39.83
2016/ToLCVRES-4	25.33	25.00	25.17	37.33	34.33	35.83	37.00	40.33	38.67
2016/ToLCVRES-5	27.33	25.67	26.50	46.00	35.33	40.67	41.00	38.00	39.50
2016/ToLCVRES-6	28.00	23.67	25.83	53.33	36.67	45.00	48.67	38.33	43.50
2016/ToLCVRES-7	27.00	23.67	25.33	41.00	35.00	38.00	38.67	36.33	37.50
Sem±	1.000	0.972	0.705	1.312	0.785	0.683	1.862	1.437	1.195
CD (p=0.05)	3.081 NS	2.994*	2.173 NS	4.044*	2.419*	2.106*	5.736*	4.429 NS	3.681 NS
CV	6.637	6.632	4.746	5.280	3.733	2.978	8.042	6.399	5.239

It was clearly visible from Table 4.60 that in 2016-17 2016/ToLCVRES-1 gave best overall performance followed by 2016/ToLCVRES-4. Though these entries attained commendable overall performance and showed moderately resistant and susceptible reaction with 2016/ToLCVRES-1 recorded maximum (647.91 q) per ha total yield but this was followed by 2016/ToLCVRES-3 (531.96 q) with susceptible reaction and. Moreover the performance of each entry was different for different parameter such as the maximum average fruit weight was obtained from 2016/ToLCVRES-1 with average fruit weight of 86.67 g followed by 2016/ToLCVRES-4 (83.90 g). However largest round fruits were recorded in 2016/ToLCVRES-4 with equatorial diameter of 55.96 mm followed by 2016/ToLCVRES-1 (55.28 mm). 2016/ToLCVRES-2 was recorded for the longest fruit with polar diameter of 65.92 mm followed by Punjab Chhuhara (58.15 mm). However 2016/ToLCVRES-1 had the maximum (5.61 mm) pericarp thickness followed by 2016/ToLCVRES-4 (5.21 mm). In case of TSS the maximum total soluble solids content (5.45 °Brix) was found in 2016/ToLCVRES-1 followed by 2016/ToLCVRES-6 (4.99 °Brix). However the minimum (36.00 days) days to first fruiting were observed in 2016/ToLCVRES-2 followed by 2016/ToLCVRES-4 (37.00 days).

It was clearly visible from Table 4.61 that in 2017-18 2016/ToLCVRES-1 attained best overall performance followed by 2016/ToLCVRES-5. Though these entries attained commendable overall performance and showed moderately resistant and susceptible reaction with 2016/ToLCVRES-1 recorded maximum (615.71 q) per ha total yield but this was followed by 2016/ToLCVRES-6 (460.03 q) with susceptible reaction and. Moreover the performance of each entry was different for different parameter such as the maximum average fruit weight was obtained from 2016/ToLCVRES-4 with average fruit weight of 84.17 g followed by 2016/ToLCVRES-1 (75.89 g). However largest round fruits were recorded in 2016/ToLCVRES-4 with equatorial diameter of 54.28 mm followed by 2016/ToLCVRES-5 (52.84 mm). 2016/ToLCVRES-2 was recorded for the longest fruit with polar diameter of 55.40 mm followed by Punjab Chhuhara (54.90 mm). However 2016/ToLCVRES-5 had the maximum (6.31 mm) pericarp thickness followed by 2016/ToLCVRES-1 (5.49 mm). In case of TSS the maximum total

soluble solids content (4.56 °Brix) was found in 2016/ToLCVRES-2 followed by H-24 (4.19 °Brix). However the minimum (36.33 days) days to first fruiting were observed in 2016/ToLCVRES-7 followed by 2016/ToLCVRES-5 (38.00 days).

It was revealed from the average data of both the years (2016-17 and 2016-17) 2016/ToLCVRES-1 attained best overall performance followed by 2016/ToLCVRES-4 (Table 4.62). Though these entries attained commendable overall performance and showed moderately resistant and susceptible reaction with 2016/ToLCVRES-1 recorded maximum (631.81 q) per ha total yield but this was followed by 2016/ToLCVRES-4 (462.66 q) with susceptible reaction and. Moreover the performance of each entry was different for different parameter such as the maximum average fruit weight was obtained from 2016/ToLCVRES-4 with average fruit weight of 84.03 g followed by 2016/ToLCVRES-1 (81.28 g). However largest round fruits were recorded in 2016/ToLCVRES-4 with equatorial diameter of 55.12 mm followed by 2016/ToLCVRES-5 (53.24 mm). 2016/ToLCVRES-2 was recorded for the longest fruit with polar diameter of 60.66 mm followed by Punjab Chhuhara (56.53 mm). However 2016/ToLCVRES-5 had the maximum (5.74 mm) pericarp thickness followed by 2016/ToLCVRES-1 (5.55 mm). In case of TSS the maximum total soluble solids content (4.61 °Brix) was found in 2016/ToLCVRES-2 followed by 2016/ToLCVRES-6 (4.53 °Brix). However the minimum (37.50 days) days to first fruiting were observed in 2016/ToLCVRES-7 followed by 2016/ToLCVRES-2 (37.83 days).

4.4.3.8 Correlation of leaf curl disease with different parameters of 2016/ToLCVRES entries

The relationship of leaf curl disease was worked out with various parameters of 2015/ToLCVRES entries for the year 2016-17 and 2017-18 and presented in table 4.63. Percent disease index of leaf curl indicated significant negative correlation with fruit Marketable yield q ha⁻¹ ($r = -0.755$, $p = 0.005$), Total yield q ha⁻¹ ($r = -0.749$, 0.005) and first flowering ($r = -0.878$, $p = 0.001$). However rest other parameters showed either non significant positive or negative correlation with percent disease index.

Table 4.60: Overall performance of 2016/ToLCVRES entries in 2016-17

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/ToLCVRES-1	29.08	19.54	MR	86.67	647.91	55.28	56.27	5.61	5.45	39.33
2016/ToLCVRES-2	78.96	59.47	S	50.00	188.73	42.14	65.92	4.94	4.67	36.00
2016/ToLCVRES-3	78.69	55.17	S	43.33	531.96	45.19	43.00	4.38	4.38	40.00
2016/ToLCVRES-4	66.03	45.30	S	83.90	513.28	55.96	51.19	5.21	3.17	37.00
2016/ToLCVRES-5	58.08	39.76	S	65.61	342.86	53.63	54.95	5.17	4.37	41.00
2016/ToLCVRES-6	87.69	63.42	S	73.21	435.87	51.39	44.35	4.57	4.99	48.67
2016/ToLCVRES-7	78.85	54.67	S	75.83	487.83	53.23	47.72	4.87	3.95	38.67
Sem±				2.400	6.768	0.929	1.443	0.147	0.088	1.862
CD (p=0.05)				7.396*	20.854*	2.863*	4.447*	0.453*	0.272*	5.736*
CV				6.081	2.606	3.157	4.816	5.130	3.451	8.042

Table 4.61: Overall performance of 2016/ToLCVRES entries in 2017-18

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/ToLCVRES-1	33.08	24.90	MR	75.89	615.71	51.01	53.28	5.49	3.52	40.00
2016/ToLCVRES-2	96.45	76.38	S	38.15	107.94	39.25	55.40	5.25	4.56	39.67
2016/ToLCVRES-3	88.59	65.40	S	34.33	250.56	45.28	38.65	4.43	3.12	39.67
2016/ToLCVRES-4	83.38	60.97	S	84.17	412.04	54.28	48.93	4.94	2.79	40.33
2016/ToLCVRES-5	85.09	62.47	S	68.33	256.06	52.84	54.82	6.31	3.63	38.00
2016/ToLCVRES-6	89.09	65.72	S	73.33	460.03	51.26	46.34	4.79	4.06	38.33
2016/ToLCVRES-7	86.23	63.22	S	61.18	306.59	51.11	43.25	4.38	3.14	36.33
Sem±				3.323	6.314	1.515	1.735	0.074	0.124	1.437
CD (p=0.05)				10.238*	19.454*	4.669*	5.345*	0.228*	0.381*	4.429 NS
CV				9.253	3.178	5.324	6.173	2.520	6.041	6.399

Table 4.62: Overall performance of 2016/ToLCVRES entries in both the years (2016-17 and 2017-18)

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/ToLCVRES-1	31.08	22.22	MR	81.28	631.81	53.14	54.77	5.55	4.49	39.67
2016/ToLCVRES-2	87.71	67.93	S	44.08	148.34	40.70	60.66	5.09	4.61	37.83
2016/ToLCVRES-3	83.64	60.28	S	38.83	391.26	45.23	40.83	4.41	3.75	39.83
2016/ToLCVRES-4	74.71	53.14	S	84.03	462.66	55.12	50.06	5.07	2.98	38.67
2016/ToLCVRES-5	71.59	51.12	S	66.97	299.46	53.24	54.88	5.74	4.00	39.50
2016/ToLCVRES-6	88.39	64.57	S	73.27	447.95	51.33	45.34	4.68	4.53	43.50
2016/ToLCVRES-7	82.54	58.95	S	68.51	397.21	52.17	45.49	4.62	3.54	37.50
Sem±				2.151	5.378	0.778	1.080	0.074	0.063	1.195
CD (p=0.05)				6.626*	16.572*	2.396*	3.328*	0.228*	0.195*	3.681 NS
CV				5.706	2.347	2.687	3.720	2.546	2.744	5.239

Table 4.63: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2016/ToLCVRES entries

Parameters	Mean	
	Disease incidence	PDI
PDI	0.993 ^{**}	-
No of fruits plant⁻¹	0.174 ^{NS}	0.132 ^{NS}
Fruit yield plant⁻¹ (kg)	-0.275 ^{NS}	-0.353 ^{NS}
Average fruit weight (g)	-0.514 ^{NS}	-0.558 ^{NS}
Marketable yield q ha⁻¹	-0.705 [*]	-0.755 [*]
Unmarketable yield q ha⁻¹	0.216 ^{NS}	0.199 ^{NS}
Total yield (q ha⁻¹)	-0.699 [*]	-0.749 [*]
Equatorial diameter of fruit (mm)	-0.440 ^{NS}	-0.523 ^{NS}
Polar diameter of fruit (mm)	-0.319 ^{NS}	-0.232 ^{NS}
Number of locules fruit⁻¹	-0.047 ^{NS}	-0.134 ^{NS}
Thickness of pericarp (mm)	-0.637 ^{NS}	-0.609 ^{NS}
TSS (% Brix)	-0.166 ^{NS}	-0.080 ^{NS}
Plant height (cm)	-0.344 ^{NS}	-0.429 ^{NS}
No. of primary branches plant⁻¹	0.595 ^{NS}	0.636 ^{NS}
No. of secondary branches plant⁻¹	-0.375 ^{NS}	-0.419 ^{NS}
First flowering (DAT)	-0.854 ^{**}	-0.878 ^{**}
50 per cent flowering (DAT)	0.298 ^{NS}	0.330 ^{NS}
First fruiting (DAT)	0.054 ^{NS}	0.036 ^{NS}

4.4.4 Popular commercial varieties/ hybrids

A sum of twenty three commercial varieties/ hybrids with a susceptible check variety viz. Punjab Chhuhara were evaluated against tomato leaf curl disease (ToLCD) during *Rabi* 2015-16 and 2016-17 and results were presented in Table 4.64a to 4.74 (Fig 4.34).

4.4.4.1 Disease incidence and percent disease index (PDI)

Substantial variability was found in incidence and percent disease index (PDI) of all commercial varieties/ hybrids evaluated under the study. During 2015-16 disease incidence was varied from 0 to 4.56, 0 to 12.69, 3.37 to 34.51, 4.72 to 61.07, 9.19 to 80.86 and 10.34 to 92.02 percent for first (15 DAT), second (30 DAT), third (45 DAT), fourth (60 DAT), fifth (75 DAT) and sixth (90 DAT) observation respectively. However, the calculated percent disease index (PDI) was also varied from 0 to 3.26, 0 to 8.60, 1.49 to 21.66, 3.05 to 42.98, 5.58 to 59.20 and 6.73 to 70.77 percent for first, second, third, fourth, fifth and sixth observation respectively. The hybrids Bharani, Karan, Saksham and NS 962 were free from the disease up to 30 days after transplanting but in the rest other, symptoms of tomato leaf curl was appeared either 15 or 30 DAT (Table 4.64a - 4.65b).

While during 2016-17 disease incidence was varied from 0 to 4.94, 1.19 to 13.91, 3.70 to 28.99, 6.27 to 43.57, 10.78 to 64.37 and 12.70 to 86.89 percent for first (15 DAT), second (30 DAT), third (45 DAT), fourth (60 DAT), fifth (75 DAT) and sixth (90 DAT) observation respectively. However, the calculated percent disease index (PDI) was also varied from 0 to 3.53, 0.18 to 8.16, 1.24 to 18.43, 2.64 to 30.11, 5.41 to 48.54 and 8.80 to 68.81 percent for first, second, third, fourth, fifth and sixth observation respectively. The varieties Arundhatti 809, Abhilash, Kohinoor, Karan, Priya-6636, Karishma, VNR- 3357 and Saksham were free from the disease up to 15 days after transplanting but others showed first symptoms of tomato leaf curl disease at 15 days after transplanting (Table 4.64a - 4.65b).

The average incidence and PDI of both years (2015-16 and 2016-17) depicted that disease incidence was varied from 0 to 4.29, 0.60 to 12.98, 3.90 to 31.58, 5.50 to 61.07, 10.34 to 72.62 and 11.61 to 88.75 percent for first (15 DAT),

second (30 DAT), third (45 DAT), fourth (60 DAT), fifth (75 DAT) and sixth (90 DAT) observation respectively. However, the calculated percent disease index (PDI) was varied from 0 to 3.07, 0.27 to 8.38, 1.47 to 20.05, 3.22 to 36.55, 5.79 to 53.87 and 7.77 to 69.79 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The hybrids/ varieties Abhilash, Kohinoor, Karan, Priya-6636, Karishma, VNR- 3357 and Saksham were free from the disease up to 15 days after transplanting whereas others were found infected with the leaf curl at 15 days after transplanting (Table 4.64a - 4.65b).

During 2015-16 at 90 DAT the lowest percent incidence and PDI was recorded in Abhilash (10.34, 6.73 %) followed by Karan (13.19, 9.07 %), Lakshmi (15.49, 11.06 %) and Karishma (16.72, 11.26 %) and highest in Punjab Chhuhara (92.02, 70.77 %) followed by Pusa ruby (90.60, 68.47 %) and S-22 (68.80, 48.78 %) (Table 4.64a - 4.65b).

Whereas during 2016-17 at 90 DAT the lowest percent incidence was noted in Karishma (12.70%) followed by Abhilash (12.87%), Arundhati 809 (13.68%) and Karan (14.58%) and highest was recorded in Pusa ruby (86.89%) followed by Punjab Chhuhara (84.33%) and Red Ruby (53.70%). However lowest PDI of leaf curl was recorded in Abhilash (8.80%) followed by Bhagyawan (9.06%), Karishma (9.07%) and NS 962 (9.10%) however the highest percent disease index was observed in Punjab Chhuhara (68.81%) followed by Pusa ruby (65.81%) and Red Ruby (35.48%) (Table 4.64a - 4.65b).

The average incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) showed that at 90 DAT the lowest per cent incidence and PDI of leaf curl was observed in Abhilash (11.61, 7.77 %) followed by Karan (13.89, 9.56 %), Karishma (14.71, 10.17 %) and Bhagyawan (17.38, 11.20 %). The highest mean percent incidence was recorded in Pusa ruby (88.75%) followed by Punjab Chhuhara (88.18%) and S-22 (57.60%). However the highest mean PDI was noted in Punjab Chhuhara (69.79%) followed by Pusa ruby (67.14%) and S-22 (39.98%) (Table 4.64a - 4.65b).

4.4.4.2 Reaction and level of resistance of commercial varieties of tomato against ToLCD

Among the twenty three varieties evaluated during 2015-16, eleven varieties viz. Bharani, Bhagyan, Abhilash, Karan, Kareena, Priya-6636, Karishma, VNR-3357, Lakshmi, Saksham and NS 962 were regarded as resistant and fall under the grade 1. Of them eight varieties viz. MHTM 256, Arundhati 809, Anvitha, Kohinoor, VNR-3348, Nun 7610, Kundan and Arka Rakshak were categorized as moderately resistant with rating 3. However one variety i.e. Red Ruby was kept in moderately susceptible category with rating 5. Three varieties viz. S-22, Pusa Ruby and Punjab Chhuhara were classified under the susceptible reaction with rating 7 (Table 4.66).

Out of twenty three varieties evaluated during 2016-17 thirteen varieties viz. Bharani, Arundhati 809, Bhagyan, Abhilash, Kohinoor, Karan, Kareena, Karishma, VNR-3348, VNR-3357, Lakshmi, Saksham and NS 962 were resistant against ToLCD and fall under the grade 1. Five varieties viz. MHTM 256, Anvitha, Priya-6636, Nun 7610 and Kundan were regarded as moderately resistant with rating 3. Three varieties viz. S-22, Red Ruby and Arka Rakshak were categorized as moderately susceptible and assigned with rating 5. Two varieties viz. Pusa Ruby and Punjab Chhuhara were shown as susceptible with rating 7 (Table 4.66).

The result of evaluation for both years (2015-16 and 2016-17) displayed that the performance of seventeen varieties were constant. Of them ten varieties viz. Bharani, Bhagyan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham and NS 962 were found resistant against ToLCD with rating 1. Four varieties viz. MHTM 256, Anvitha, Nun 7610 and Kundan were moderately resistant and rated 3. Only one variety i.e. Red Ruby was denoted as moderately susceptible with rating 5. Two varieties viz. Pusa Ruby and Punjab Chhuhara were put in reaction category susceptible and fall under rating 7 (Table 4.66).

4.4.4.3 Yield parameters of commercial varieties/ hybrids

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out for both the years (2015-16 and 2016-17) and presented in Table 4.67.

Table 4.64a: Percent incidence of tomato leaf curl disease in popular commercial varieties/ hybrids

Variety	Percent disease incidence at 15-day intervals (DAT)									
	15			30			45			Mean
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	
MHTM 256	2.26	1.19	1.73	5.83	7.23	6.53	13.07	9.85	11.46	
S-22	3.45	3.57	3.51	12.03	4.76	8.40	32.13	12.19	22.16	
Bharani	0.00	1.19	0.60	0.00	3.70	1.85	8.61	8.65	8.63	
Arundhati 809	1.11	0.00	0.56	7.43	1.19	4.31	14.67	5.33	10.00	
Bhagyawan	0.00	1.19	0.60	3.53	3.57	3.55	9.32	7.50	8.41	
Abhilash	0.00	0.00	0.00	3.37	1.23	2.30	3.37	6.55	4.96	
Anvitha	2.30	1.28	1.79	8.47	2.52	5.50	17.11	7.79	12.45	
Red Ruby	3.53	3.61	3.57	8.78	8.42	8.60	22.70	17.60	20.15	
Kohinoor	0.00	0.00	0.00	2.38	1.19	1.79	11.79	3.70	7.75	
Karan	0.00	0.00	0.00	0.00	1.23	0.62	3.53	5.03	4.28	
Kareena	0.00	1.19	0.60	2.39	1.19	1.79	9.31	3.91	6.61	
Priya-6636	0.00	0.00	0.00	3.41	3.61	3.51	12.64	7.77	10.21	
Karishma	0.00	0.00	0.00	1.15	1.28	1.22	3.57	4.23	3.90	
VNR-3348	2.47	1.23	1.85	4.94	2.42	3.68	13.40	7.27	10.34	
Nun 7610	3.33	1.19	2.26	7.93	2.47	5.20	15.21	7.57	11.39	
VNR- 3357	0.00	0.00	0.00	1.15	2.47	1.81	5.01	7.22	6.12	
Kundan	0.00	1.19	0.60	4.95	6.08	5.52	16.32	11.75	14.04	
Lakshmi	0.00	1.23	0.62	2.42	2.47	2.45	7.19	7.02	7.11	
Saksham	0.00	0.00	0.00	0.00	1.23	0.62	8.77	6.31	7.54	
NS 962	0.00	1.19	0.60	0.00	1.19	0.60	11.74	4.01	7.88	
Arka Rakshak	2.42	1.28	1.85	8.10	7.78	7.94	17.84	17.74	17.79	
Pusa Ruby	4.56	3.61	4.09	12.69	9.61	11.15	34.51	23.02	28.77	
Punjab Chuhara	3.63	4.94	4.29	12.04	13.91	12.98	34.17	28.99	31.58	

Table 4.64b: Percent incidence of tomato leaf curl disease in popular commercial varieties/ hybrids

Variety	Percent disease incidence at 15-day intervals (DAT)											
	60			75			90					
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean			
MHTM 256	21.29	16.32	18.81	26.05	23.21	24.63	28.44	32.35	30.40			
S-22	55.08	21.76	38.42	66.34	32.74	49.54	68.80	46.40	57.60			
Bharani	18.31	11.08	14.70	20.70	16.84	18.77	23.17	16.84	20.01			
Arundhati 809	20.77	9.23	15.00	23.24	10.78	17.01	24.39	13.68	19.04			
Bhagyawan	15.03	9.98	12.51	18.41	15.16	16.79	19.60	15.16	17.38			
Abhilash	6.89	8.93	7.91	9.19	11.48	10.34	10.34	12.87	11.61			
Anvitha	28.33	15.64	21.99	32.03	24.03	28.03	33.32	28.09	30.71			
Red Ruby	30.30	27.12	28.71	39.17	39.09	39.13	46.77	53.70	50.24			
Kohinoor	17.75	8.60	13.18	21.23	11.49	16.36	23.66	15.24	19.45			
Karan	4.72	6.27	5.50	9.57	11.85	10.71	13.19	14.58	13.89			
Kareena	13.65	9.20	11.43	17.31	12.93	15.12	19.70	16.73	18.22			
Priya-6636	21.84	11.68	16.76	22.99	18.76	20.88	22.99	25.42	24.21			
Karishma	7.19	7.13	7.16	14.34	12.70	13.52	16.72	12.70	14.71			
VNR-3348	20.68	8.61	14.65	23.06	13.87	18.47	24.25	16.44	20.35			
Nun 7610	27.18	16.52	21.85	30.71	20.57	25.64	33.14	26.38	29.76			
VNR- 3357	6.15	10.42	8.29	13.08	15.46	14.27	18.41	20.39	19.40			
Kundan	18.89	16.53	17.71	22.78	24.02	23.40	25.31	26.75	26.03			
Lakshmi	14.34	11.20	12.77	15.49	20.29	17.89	15.49	23.19	19.34			
Saksham	17.44	11.25	14.35	20.97	15.31	18.14	23.45	19.11	21.28			
NS 962	15.31	6.58	10.95	19.99	12.22	16.11	22.33	14.94	18.64			
Arka Rakshak	24.91	24.81	24.86	31.73	36.87	34.30	36.24	46.99	41.62			
Pusa Ruby	58.17	43.57	50.87	80.86	64.37	72.62	90.60	86.89	88.75			
Punjab Chhuhara	61.07	42.19	61.07	78.84	60.69	69.77	92.02	84.33	88.18			

Table 4.65b: Evaluation of popular commercial varieties/ hybrids against tomato leaf curl disease

Variety	Percent disease index at 15-day intervals (DAT)										Reaction					
	60					75					90				(at final observation)	
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Constant	
MHTM 256	12.48	9.14	10.81	16.54	13.67	15.11	18.95	21.64	20.30	MR	MR	MR	MR	MR	MR	
S-22	32.19	11.62	21.91	42.02	20.64	31.33	48.78	31.17	39.98	S	MS	S	MS			
Bharani	10.62	6.19	8.41	13.74	9.06	11.40	15.84	11.65	13.75	R	R	R	R	R	R	
Arundhati 809	10.97	3.22	7.10	13.76	5.42	9.59	16.73	9.77	13.25	MR	R	MR	R			
Bhagyawan	8.76	3.21	5.99	11.50	5.41	8.46	13.33	9.06	11.20	R	R	R	R	R	R	
Abhilash	4.27	4.17	4.22	5.58	6.00	5.79	6.73	8.80	7.77	R	R	R	R	R	R	
Anvitha	15.67	6.72	11.20	19.36	11.93	15.65	22.37	17.84	20.11	MR	MR	MR	MR	MR	MR	
Red Ruby	19.49	13.61	16.55	25.47	22.17	23.82	31.98	35.48	33.73	MS	MS	MS	MS	MS	MS	
Kohinoor	11.00	3.68	7.34	13.84	5.64	9.74	16.23	9.44	12.84	MR	R	MR	R			
Karan	3.05	3.39	3.22	6.16	7.33	6.75	9.07	10.05	9.56	R	R	R	R	R	R	
Kareena	8.66	3.20	5.93	10.95	5.92	8.44	13.39	10.12	11.76	R	R	R	R	R	R	
Priya-6636	11.99	5.78	8.89	14.12	10.41	12.27	15.77	16.65	16.21	R	MR	R	MR			
Karishma	4.79	2.64	3.72	9.22	6.62	7.92	11.26	9.07	10.17	R	R	R	R	R	R	
VNR-3348	12.66	4.39	8.53	14.73	8.06	11.40	16.63	10.98	13.81	MR	R	MR	R			
Nun 7610	16.70	7.33	12.02	18.87	10.86	14.87	21.99	18.07	20.03	MR	MR	MR	MR	MR	MR	
VNR- 3357	4.40	6.16	5.28	8.48	8.81	8.65	11.95	13.15	12.55	R	R	R	R	R	R	
Kundan	12.41	8.23	10.32	15.19	11.71	13.45	16.99	17.19	17.09	MR	MR	MR	MR	MR	MR	
Lakshmi	9.22	5.58	7.40	9.71	9.98	9.85	11.06	14.47	12.77	R	R	R	R	R	R	
Saksham	10.31	5.91	8.11	13.21	8.74	10.98	15.69	12.92	14.31	R	R	R	R	R	R	
NS 962	9.57	3.57	6.57	12.26	6.40	9.33	15.29	9.10	12.20	R	R	R	R	R	R	
Arka Rakshak	15.83	12.76	14.30	20.70	20.76	20.73	25.05	30.97	28.01	MR	MS	MR	MS			
Pusa Ruby	38.86	26.97	32.92	58.11	46.23	52.17	68.47	65.81	67.14	S	S	S	S	S	S	
PC	42.98	30.11	36.55	59.20	48.54	53.87	70.77	68.81	69.79	S	S	S	S	S	S	

Table 4.66: Classification of popular commercial varieties/ hybrids in different reaction categories

Year	Reaction category	No. of variety	Name of variety
Varieties with constant reaction in both the years	Resistant	10	Bharani, Bhagyawan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham, NS 962
	Moderately resistant	4	MHTM 256, Anvitha, Nun 7610, Kundan
	Moderately susceptible	1	Red Ruby
	Susceptible	2	Pusa Ruby, Punjab Chhuhara
	Resistant	11	Bharani, Bhagyawan, Abhilash, Karan, Kareena, Priya-6636, Karishma, VNR-3357, Lakshmi, Saksham, NS 962
	Moderately resistant	8	MHTM 256, Arundhati 809, Anvitha, Kohinoor, VNR-3348, Nun 7610, Kundan, Arka Rakshak
	Moderately susceptible	1	Red Ruby
	Susceptible	3	S-22, Pusa Ruby, Punjab Chhuhara
	Resistant	13	Bharani, Arundhati 809, Bhagyawan, Abhilash, Kohinoor, Karan, Kareena, Karishma, VNR-3348, VNR-3357, Lakshmi, Saksham, NS 962
	Moderately resistant	5	MHTM 256, Anvitha, Priya-6636, Nun 7610, Kundan
2016-17	Moderately susceptible	3	S-22, Red Ruby, Arka Rakshak
	Susceptible	2	Pusa Ruby, Punjab Chhuhara

The number of fruits plant⁻¹ is an important attribute that contributes to the final productivity of tomato plant (Table 4.67). During 2015-16 the number of fruits plant⁻¹ significantly ranged from 11.20 (Punjab Chhuhara) to 54.60 (Arka Rakshak). The significant maximum number of fruits plant⁻¹ was recorded in Arka Rakshak (54.60) followed by Bhagyan (43.60), Bharani (39.93), Kundan (39.47) and Priya-6636 (37.20). However, Bharani and Kundan were at par with Bhagyan. The lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (11.20) followed by NS 962 (16.87) and Pusa Ruby (19.27). During 2016-17 the number of fruits plant⁻¹ significantly ranged from 11.00 (Punjab Chhuhara) to 53.78 (Arka Rakshak). The significant maximum number of fruits plant⁻¹ was recorded in Arka Rakshak (53.78) followed by Bhagyan (45.00), Kundan (38.63), Priya-6636 (38.60) and Bharani (36.53). However Bharani and Priya-6636 were at par with Kundan. The lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (11.00) followed by NS 962 (16.60) and Pusa Ruby (18.13). The mean number of fruits plant⁻¹ of both years (2015-16 and 2016-17) exhibited that the number of fruits plant⁻¹ significantly ranged from 11.10 (Punjab Chhuhara) to 54.19 (Arka Rakshak). The significant maximum number of fruits plant⁻¹ was observed in Arka Rakshak (54.19) followed by Bhagyan (44.30), Kundan (39.05), Bharani (38.23) and Priya-6636 (37.90). However, Priya-6636 and Bharani were at par with Kundan. The lowest number of fruits plant⁻¹ was recorded in Punjab Chhuhara (11.10) followed by NS 962 (16.73) and Pusa Ruby (18.70).

Fruit yield plant⁻¹ is an important character that contributes the yield potential of tomato plant. The significant difference was observed among commercial varieties for fruit yield plant⁻¹ (Table 4.67). During 2015-16, it ranged from 0.38 (Punjab Chhuhara) to 4.03 kg (Arka Rakshak). The maximum fruit yield plant⁻¹ was observed in Arka Rakshak (4.03 kg) followed by Bharani (2.11 kg), Priya-6636 (2.03 kg), Bhagyan (1.91 kg) and Kundan (1.83 kg) and the minimum was in Punjab Chhuhara (0.38 kg) followed by Pusa Ruby (0.86 kg) and NS 962 (0.94 kg). During 2016-17, the fruit yield plant⁻¹ ranged from 0.37 (Punjab Chhuhara) to 3.91 kg (Arka Rakshak). The maximum fruit yield plant⁻¹ was recorded in Arka Rakshak (3.91 kg) followed by Priya-6636 (2.08 kg), Bharani (2.02 kg), Bhagyan (2.01 kg), and Kundan (1.97 kg) and minimum were

observed in Punjab Chhuhara (0.37 kg). The mean fruit yield plant⁻¹ of both years (2015-16 and 2016-17) displayed that the fruit yield plant⁻¹ significantly ranged from 0.37 kg (Punjab Chhuhara) to 3.97 kg (Arka Rakshak). The maximum fruit yield plant⁻¹ was noted in Arka Rakshak (3.97 kg) followed by Bharani (2.06 kg), Priya-6636 (2.06 kg), Bhagyawan (1.96 kg) and Kundan (1.90 kg) and the minimum was observed in Punjab Chhuhara (0.37 kg) followed by Pusa Ruby (0.83 kg).

Average fruit weight is an important yield contributing parameter that contributes the yield of tomato. The significant variation was observed in average fruit weight of commercial varieties evaluated during 2015-16 and 2016-17 (Table 4.67). During 2015-16, the average fruit weight ranged from 34.15 (Punjab Chhuhara) to 75.30 g (Anvitha). The maximum average fruit weight was recorded in Anvitha (75.30 g) followed by Arka Rakshak (73.96 g), VNR-3357 (71.37 g), Lakshmi (67.46 g) and Karan (66.42 g). However Arka Rakshak and VNR-3357 were at par with Anvitha. The minimum was observed in Punjab Chhuhara (34.15 g). During 2016-17, average fruit weight range was observed from 33.22 (Punjab Chhuhara) to 76.38 g (Anvitha). The maximum average fruit weight was recorded in Anvitha (76.38 g) followed by Arka Rakshak (72.70 g), VNR-3357 (70.78 g), Karan (65.66 g) and VNR-3348 (64.96 g). However Arka Rakshak and Karan were at par with Anvitha and VNR-3357 respectively. The minimum was observed in Punjab Chhuhara (33.22 g) followed by S-22 (40.94 g). The mean average fruit weight for both the years expressed that average fruit weight ranged from 33.68 (Punjab Chhuhara) to 75.84 g (Anvitha). The maximum average fruit weight was observed in Anvitha (75.84 g) followed by Arka Rakshak (73.33 g), VNR-3357 (71.07 g), Karan (66.04 g) and VNR-3348 (65.50 g). However Arka Rakshak and VNR-3348 were at par with Anvitha and Karan respectively. The minimum was recorded in Punjab Chhuhara (33.68 g) followed by S-22 (41.94 g).

4.4.4.4 Yield of commercial varieties/ hybrids

Yield is one of the most important parameters for selection of any crop and/or variety. Marketable yield ha⁻¹, Unmarketable yield ha⁻¹ and Total yield ha⁻¹

were computed for all the commercial varieties evaluated in both the years (2015-16 and 2016-17) and depicted in Table 4.68.

Marketable yield ha^{-1} directly influences the economic yield of tomato. The significant difference was observed in marketable yield ha^{-1} of varieties evaluated during 2015-16 and 2016-17 (Table 4.68). During 2015-16, the marketable yield ha^{-1} ranged from 35.23 q (Punjab Chhuhara) to 472.82 q (Arka Rakshak). The highest marketable yield ha^{-1} was noted in Arka Rakshak (472.82 q) followed by Abhilash (399.26 q), Bharani (368.52 q), Bhagyan (361.11 q) and Priya-6636 (305.56 q). The minimum marketable yield ha^{-1} was observed in Punjab Chhuhara (35.23 q) followed NS 962 (83.52 q). During 2016-17, the marketable yield ha^{-1} ranged between 34.82 q (Punjab Chhuhara) to 452.41 q (Arka Rakshak). The maximum marketable yield ha^{-1} was recorded in Arka Rakshak (452.41 q) followed by Bharani (407.96 q), Abhilash (383.56 q), Bhagyan (382.59 q) and Saksham (303.70 q). The minimum marketable yield ha^{-1} was registered in Punjab Chhuhara (34.82 q) followed Pusa Ruby (69.00 q). It reveals from the mean marketable yield ha^{-1} of both years (2015-16 and 2016-17) that the average fruit weight ranged from 35.02 q (Punjab Chhuhara) to 462.61 q (Arka Rakshak). The significant maximum marketable yield ha^{-1} was observed in Arka Rakshak (462.61 q) followed by Abhilash (391.41 q), Bharani (388.24 q), Bhagyan (371.85 q) and Saksham (301.48 q). The minimum was noted in Punjab Chhuhara (35.02 q) followed by Pusa Ruby (79.32 q) and NS 962 (98.11 q).

Unmarketable yield ha^{-1} directly influences the yield of tomato. The significant variation was observed in unmarketable yield ha^{-1} among the varieties evaluated in both the years, 2015-16 and 2016-17 (Table 4.68). There is no unmarketable yield was recorded in varieties like Lakshmi, NS 962, Arka Rakshak and Pusa Ruby. However, the rest were produced unmarketable yield ha^{-1} during 2015-16, ranged from 0 to 46.85 q. The minimum was registered by Kundan (1.48 q). The maximum was observed by Nun 7610 (46.85 q) followed Priya-6636 (46.30 q) and VNR-3357 (42.96 q). During 2016-17 it ranged from 2.11 to 29.07 q and the minimum was recorded in Saksham (2.11 q) followed by Kundan (3.96 q), Karan (5.96 q), Bhagyan (7.22 q) and VNR-3348 (8.70 q). The maximum unmarketable yield ha^{-1} was observed in Bharani (29.07 q) followed Punjab

Chhuhara (21.63 q) and Pusa Ruby (19.37 q). Whereas, for both the years (i.e. 2015-16 and 2016-17) it showed that the range from 1.98 to 31.25 q with the significant minimum unmarketable yield ha^{-1} was recorded in Saksham (1.98 q) followed by Kundan (2.72 q), NS 962 (4.72 q), Lakshmi (7.59 q) and Arka Rakshak (8.61 q). The maximum unmarketable yield ha^{-1} was observed in Bharani (31.25 q) followed by Nun 7610 (31.06 q) and Priya-6636 (27.94 q).

Total yield ha^{-1} directly contributes the final yield of the crop. In both the years (2015-16 and 2016-17) significant difference was observed in total yield ha^{-1} among the varieties evaluated under the study (Table 4.68). During 2015-16, the total yield ha^{-1} ranged from 41.26 q (Punjab Chhuhara) to 472.82 q (Arka Rakshak). The maximum total yield ha^{-1} was noted in Arka Rakshak (472.82 q) followed by Abhilash (425.92 q), Bharani (401.94 q), Bhagyan (382.41 q) and Priya-6636 (351.85 q). However Bharani and Priya-6636 were at par with Abhilash and Bhagyan respectively. The minimum marketable yield ha^{-1} was observed in Punjab Chhuhara (41.26 q) followed by NS 962 (83.52 q) and Pusa Ruby (89.63 q). During 2016-17, the total yield ha^{-1} ranged between 56.44 q (Punjab Chhuhara) to 469.63 q (Arka Rakshak). The highest total yield ha^{-1} was recorded in Arka Rakshak (469.63 q) followed by Bharani (437.03 q), Abhilash (398.93 q), Bhagyan (389.82 q) and Arundhati 809 (308.34 q). However Abhilash and Bhagyan were at par with each other. The minimum total yield ha^{-1} was observed in Punjab Chhuhara (56.44 q) followed by Pusa Ruby (88.37 q) and NS 962 (122.15 q). Whereas, mean total yield ha^{-1} for both years (2015-16 and 2016-17) exhibited that total yield ha^{-1} ranged from 48.85 q (Punjab Chhuhara) to 471.22 q (Arka Rakshak). The maximum total yield ha^{-1} was observed in Arka Rakshak (471.22 q) followed by Bharani (419.49 q), Abhilash (412.43 q), Bhagyan (386.11 q) and Priya-6636 (327.35 q). However, Abhilash and Bharani were at par with each other. The minimum total yield ha^{-1} was noted in Punjab Chhuhara (48.85 q) followed by Pusa Ruby (89.00 q) and NS 962 (102.83 q).

4.4.4.5 Quality parameters of commercial varieties/ hybrids

The selection of any variety/ entry depends on yield and yield depends on various parameters of yield contributing factors along with resistance. The

Table 4.67: Yield parameters of popular commercial varieties/ hybrids

Variety	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
MHTM 256	25.93	25.30	25.62	1.58	1.56	1.57	60.26	62.54	61.40
S-22	24.60	24.93	24.77	1.02	1.01	1.02	42.93	40.94	41.94
Bharani	39.93	36.53	38.23	2.11	2.02	2.06	52.94	55.61	54.27
Arundhati 809	27.00	26.33	26.67	1.33	1.31	1.32	49.61	49.63	49.62
Bhagyawan	43.60	45.00	44.30	1.91	2.01	1.96	44.71	44.69	44.70
Abhilash	27.33	27.53	27.43	1.69	1.61	1.65	61.92	58.63	60.28
Anvitha	22.00	22.73	22.37	1.68	1.71	1.69	75.30	76.38	75.84
Red Ruby	25.40	26.00	25.70	1.59	1.65	1.62	63.89	63.52	63.70
Kohinoor	22.20	22.93	22.57	1.16	1.39	1.28	50.94	60.74	55.84
Karan	25.20	27.00	26.10	1.67	1.77	1.72	66.42	65.66	66.04
Kareena	29.53	28.20	28.87	1.55	1.50	1.52	54.56	53.32	53.94
Priya-6636	37.20	38.60	37.90	2.03	2.08	2.06	55.90	53.99	54.95
Karishma	24.13	25.93	25.03	1.14	1.20	1.17	49.14	47.18	48.16
VNR-3348	26.07	27.60	26.83	1.79	1.79	1.79	66.03	64.96	65.50
Nun 7610	22.87	25.53	24.20	1.38	1.44	1.41	62.51	56.92	59.72
VNR- 3357	24.67	25.60	25.13	1.78	1.80	1.79	71.37	70.78	71.07
Kundan	39.47	38.63	39.05	1.83	1.97	1.90	46.03	50.88	48.45
Lakshmi	22.93	26.40	24.67	1.54	1.61	1.58	67.46	61.47	64.47
Saksham	31.87	29.67	30.77	1.58	1.68	1.63	48.86	58.16	53.51
NS 962	16.87	16.60	16.73	0.94	1.02	0.98	54.02	61.78	57.90
Arka Rakshak	54.60	53.78	54.19	4.03	3.91	3.97	73.96	72.70	73.33
Pusa Ruby	19.27	18.13	18.70	0.86	0.80	0.83	46.57	44.35	45.46
Punjab Chhuhara	11.20	11.00	11.10	0.38	0.37	0.37	34.15	33.22	33.68
Sem±	1.569	1.071	1.033	0.082	0.053	0.049	1.997	1.964	1.238
CD (p=0.05)	4.471*	3.051*	2.944*	0.235*	0.152*	0.140*	5.691*	5.597*	3.529*
CV	9.705	6.562	6.360	8.977	5.724	5.308	6.121	5.981	3.783

Table 4.68: Yield performance of popular commercial varieties/ hybrids

Variety	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
MHTM 256	232.59	227.78	230.18	27.04	15.71	21.37	259.63	243.48	251.56
S-22	158.96	188.33	173.65	17.96	16.48	17.22	176.93	204.81	190.87
Bharani	368.52	407.96	388.24	33.43	29.07	31.25	401.94	437.03	419.49
Arundhati 809	266.48	292.22	279.35	19.07	16.11	17.59	285.56	308.34	296.95
Bhagyanwan	361.11	382.59	371.85	21.30	7.22	14.26	382.41	389.82	386.11
Abhilash	399.26	383.56	391.41	26.67	15.37	21.02	425.92	398.93	412.43
Anvitha	253.15	263.89	258.52	27.96	11.11	19.54	281.11	275.00	278.06
Red Ruby	234.26	241.67	237.96	26.67	9.52	18.09	260.93	251.19	256.06
Kohinoor	153.70	170.00	161.85	38.15	15.18	26.67	191.85	185.18	188.52
Karan	278.52	288.15	283.33	32.04	5.96	19.00	310.56	294.11	302.33
Kareena	207.22	228.89	218.06	21.11	12.41	16.76	228.33	241.30	234.82
Priya-6636	305.56	293.26	299.41	46.30	9.59	27.94	351.85	302.85	327.35
Karishma	172.78	177.22	175.00	30.19	14.07	22.13	202.96	191.30	197.13
VNR-3348	170.37	207.22	188.80	41.48	8.70	25.09	211.85	215.93	213.89
Nun 7610	177.22	203.63	190.43	46.85	15.26	31.06	224.07	218.89	221.48
VNR- 3357	217.22	191.11	204.17	42.96	12.59	27.78	260.19	203.70	231.95
Kundan	251.85	279.26	265.56	1.48	3.96	2.72	253.33	283.22	268.28
Lakshmi	161.48	153.70	157.59	0.00	15.19	7.59	161.48	168.89	165.18
Saksham	299.26	303.70	301.48	1.85	2.11	1.98	301.11	305.81	303.46
NS 962	83.52	112.70	98.11	0.00	9.45	4.72	83.52	122.15	102.83
Arka Rakshak	472.82	452.41	462.61	0.00	17.22	8.61	472.82	469.63	471.22
Pusa Ruby	89.63	69.00	79.32	0.00	19.37	9.69	89.63	88.37	89.00
Punjab Chuhhara	35.23	34.82	35.02	6.04	21.63	13.83	41.26	56.44	48.85
Sem±	9.594	7.303	6.080	0.809	0.693	0.543	9.133	9.464	6.372
CD (p=0.05)	27.343*	20.816*	17.328*	2.305*	1.975*	1.547*	26.030*	26.975*	18.160*
CV	7.143	5.239	4.442	6.335	9.099	5.326	6.209	6.438	4.333

resistance of variety/ entry to the disease and its yield parameters, quality parameters of fruit may also influence the selection of variety/ entry by affecting the market value of produce (fruits). Therefore quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each variety were also evaluated during 2015-16 and 2016-17 and mentioned in (Table 4.69a and 4.69b).

The equatorial diameter indicates the globosity of fruit that directly affects the value of produce. During 2015-16 the significant difference was noticed in equatorial diameter which ranged from 36.42 to 62.29 mm. The largest fruit was observed for MHTM 256 with equatorial diameter of 62.29 mm. This was followed by Kareena (60.21 mm), Anvitha (59.70 mm), Abhilash (58.88 mm) and Red Ruby (56.95 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (36.42 mm) followed by Pusa Ruby (37.48 mm) and Kundan (48.27 mm). While during 2016-17 the equatorial diameter was ranged from 38.36 to 63.49 mm. The largest fruit was observed for Anvitha with equatorial diameter of 63.49 mm followed by Kareena (63.02 mm), Kohinoor (61.60 mm), Arundhati 809 (61.25 mm) and MHTM 256 (60.23 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (38.36 mm) followed by Pusa Ruby (43.33 mm) and Kundan (47.48 mm). Kareena, Kohinoor, Arundhati 809 and MHTM 256 were at par with Anvitha and each other. The mean equatorial diameter in both the years (2015-16 and 2016-17) ranged from 37.39 to 61.62 mm. The largest fruit was observed in Kareena with equatorial diameter of 61.62 mm. This was followed by Anvitha (61.60 mm), MHTM 256 (61.26 mm), Arundhati 809 (58.90 mm) and Abhilash (58.38 mm). The minimum equatorial diameter was recorded in Punjab Chhuhara (37.39 mm) followed by Pusa Ruby (40.41 mm) and Arka Rakshak (48.40 mm) (Table 4.69a).

The polar diameter represents the length/ height of fruit that determines the fruit shape and size. The significant variation was observed in polar diameter of varieties evaluated. During 2015-16 polar diameter ranged between 32.51 to 56.16 mm. The longest fruit was obtained from Karan with polar circumference of 56.19 mm. This was followed by Kundan (53.65 mm), Punjab Chhohara (53.07), Arka Rakshak (52.69 mm) and Kohinoor (50.05 mm). The fruit height of Pusa Ruby was

found lowest (32.51 mm) followed by S-22 (39.50 mm). In 2016-17 the polar diameter ranged from 34.12 to 57.02 mm among the evaluated varieties. The longest fruit was recorded from Karan with polar diameter of 57.02 mm followed by Kohinoor (55.34 mm), Punjab Chhohara (53.15), Kundan (52.90 mm) and Arka Rakshak (50.51 mm). The fruit height of Pusa Ruby was measured lowest (34.12 mm) followed by Kareena (41.47 mm) and Lakshmi (42.32 mm). The pooled mean of both the years (2015-16 and 2016-17) displayed significant variation in polar diameter with range of 33.32 to 56.59 mm (Table 4.69a). The longest fruit was received from Karan with polar diameter of 56.59 mm. This was followed by Kundan (53.28 mm), Punjab Chhohara (53.11), Kohinoor (52.70 mm) and Arka Rakshak (51.60 mm). The fruit height of Pusa Ruby was lowest (33.32 mm) followed by S-22 (40.93 mm).

A significant variation was observed in the number of locules among evaluated varieties in both the years (2015-16 and 2016-17). In 2015-16 the number of locules ranged from 2.13 to 5.40. The maximum number of locules (5.40) was observed in Kareena followed by MHTM 256 (5.13), Bharani, Arundhati 809, Karishma, Lakshmi, and Saksham (4.53). The minimum number of locules (2.13) was recorded in Kundan followed by Arka Rakshak (2.47) and Punjab Chhuhara (2.60). In 2016-17 the number of locules ranged from 2.47 to 5.20. The maximum number of locules (5.20) was observed in Bharani followed by Red Ruby (5.07), Kareena (5.07), Karishma (4.93) and MHTM 256 (4.73). The minimum number of locules (2.47) was recorded in Kundan followed by Punjab Chhuhara (2.53) and Arka Rakshak (2.60). The pooled mean obtained from both the years (2015-16 and 2016-17) data exhibited significant variation in number of locules among varieties and ranged between 2.30 to 5.23 mm (Table 4.69a). The maximum number of locules (5.23) was observed in Kareena followed by MHTM 256 (4.93), Bharani (4.87), Karishma (4.73) and Red Ruby (4.60). The minimum number of locules (2.30) was recorded in Kundan followed by Arka Rakshak (2.53) and Punjab Chhuhara (2.57).

The significant variation was observed on pericarp thickness among evaluated varieties in both the years 2015-16 and 2016-17 (Table 4.69b). In 2015-16 among the commercial varieties evaluated, Abhilash had the maximum (6.12

mm) pericarp thickness followed by Karan (6.04 mm), Kareena (5.81 mm), Nun 7610 (5.74 mm) and MHTM 256 (5.70). Pusa ruby had the minimum (3.23 mm) pericarp thickness followed by S-22 (4.58 mm) and Arka Rakshak (4.80 mm). In 2016-17 the pericarp thickness ranged from 3.52 to 6.29 mm. The fruits of Abhilash had the maximum (6.29 mm) pericarp thickness which was followed by Kareena (6.15 mm), Bhagyawan (6.11 mm), Karan (5.84 mm) and Red Ruby (5.73). However, Pusa ruby had the minimum (3.52 mm) pericarp thickness followed by S-22 (4.41 mm) and Saksham (4.47 mm). The mean data of 2015-16 and 2016-17 also showed that the maximum (6.21 mm) pericarp thickness was recorded in Abhilash followed by Kareena (5.98 mm), Karan (5.94 mm), Bhagyawan (5.86 mm) and Nun 7610 (5.66 mm). The thinnest pericarp was measured in Pusa ruby (3.38 mm) followed by S-22 (4.50 mm) and Saksham (4.69 mm).

The significant difference was noticed on TSS among evaluated varieties in both the years 2015-16 and 2016-17 (Table 4.69b). In 2015-16 the TSS ranged from 3.47 to 4.93 °Brix. Among the twenty three commercial varieties evaluated, the maximum total soluble solids content (4.93 °Brix) was found in Kundan followed by Red Ruby (4.60 °Brix), Karan (4.56 °Brix), Arundhati 809 (4.33 °Brix) and Bharani (4.29 °Brix). However Red Ruby was at par with Kundan and Arundhati 809 and Bharani were at par with Karan. The minimum total soluble solids content was recorded in Nun 7610 (3.47 °Brix) followed by Karishma (3.64 °Brix) and Kareena (3.75 °Brix). In 2016-17 the the maximum total soluble solids content (5.02 °Brix) was found in Kundan followed by Red Ruby (4.74 °Brix), S-22 (4.45 °Brix), Bhagyawan (4.33 °Brix) and Karan (4.31 °Brix). However Red Ruby was at par with Kundan and Bhagyawan and Karan were at par with S-22 and each other. The minimum total soluble solids content (3.62 °Brix) was recorded in Nun 7610 followed by Kohinoor (3.64 °Brix) and VNR-3357 (3.68 °Brix). The mean data of 2015-16 and 2016-17 also showed significant variation in total soluble solids (TSS) among the varieties and ranged between 3.55 to 4.98 °Brix. The maximum total soluble solids content (4.98 °Brix) was obtained in Kundan followed by Red Ruby (4.67 °Brix), Karan (4.44 °Brix), S-22 (4.34 °Brix) and Arundhati 809 (4.30 °Brix). However Red Ruby was at par with Kundan and

S-22 and Arundhati 809 were at par with Karan and each other. The minimum total soluble solids content (3.55 °Brix) was recorded in Nun 7610 followed by Karishma (3.74 °Brix) and Kohinoor (3.75 °Brix).

Out of twenty three varieties three were oval shaped, one was pear shaped and another one was round to oval and rest of the commercial varieties was either round or flattish round in shape (Table 4.69b). Among the twenty three varieties evaluated five varieties (Karan, Kareena, Priya-6636, Karishma and VNR-3357) were light red to red, three (VNR-3348, Lakshmi and NS 962) were light red to deep red, five (MHTM 256, Anvitha, Nun 7610, Kundan and Saksham) were red, nine (S-22, Bharani, Bhagyawan, Abhilash, Red Ruby, Kohinoor, Arka Rakshak, Pusa Ruby and Punjab Chhuhara) were red to deep red and one (Arundhati 809) was deep red (Table 4.69b).

4.4.4.6 Other parameters of commercial varieties/ hybrids

Some other parameters such as plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering, days to 50% flowering and days to first fruiting were recorded for all the varieties during 2015-16 and 2016-17 and presented in Table 4.70a and 4.70b.

In 2015-16 plant height was ranged from 51.27 to 85.03 cm. The significantly highest (85.03 cm) plant height was recorded in Saksham followed by Kundan (85.01 cm), Karan (84.99 cm), Lakshmi (84.15) and Kareena (79.11 cm). However Kundan, Karan, Lakshmi and Kareena were at par with Saksham. The lowest plant height (51.27 cm) was measured in VNR-3357 followed by S-22 (54.36 cm) and Punjab Chhuhara (55.28 cm). Data presented in Table 4.70a showed that plant height was significantly ranged from 42.01 to 68.43 cm during 2016-17. The highest (68.43 cm) plant height was recorded in Abhilash followed by Kundan (60.55 cm), Punjab Chhuhara (56.30), Saksham (54.86 cm) and VNR-3357 (54.39 cm). However Punjab Chhuhara and VNR-3357 were at par with Kundan and Saksham respectively. The lowest (42.01 cm) plant height was observed in Nun 7610 followed by MHTM 256 (43.25 cm) and Lakshmi (44.32 cm). The pooled mean data of 2015-16 and 2016-17 exhibited significant variation in plant height among the varieties with ranged of 50.11 to 73.44 cm. The highest

Table 4.69a: Quality parameters of popular commercial varieties/ hybrids

Variety	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
MHTM 256	62.29	60.23	61.26	43.68	44.07	43.87	5.13	4.73	4.93
S-22	51.38	53.33	52.35	39.50	42.35	40.93	4.27	4.60	4.43
Bharani	53.40	57.67	55.54	42.68	46.21	44.44	4.53	5.20	4.87
Arundhati 809	56.55	61.25	58.90	45.33	45.28	45.30	4.53	4.07	4.30
Bhagyawan	54.22	60.09	57.16	42.94	43.29	43.12	3.73	4.27	4.00
Abhilash	58.88	57.87	58.38	47.42	47.38	47.40	4.00	3.87	3.93
Anvitha	59.70	63.49	61.60	44.58	47.15	45.86	4.13	4.33	4.23
Red Ruby	56.95	55.82	56.39	45.07	46.13	45.60	4.13	5.07	4.60
Kohinoor	54.81	61.60	58.20	50.05	55.34	52.70	3.40	3.60	3.50
Karan	51.75	53.45	52.60	56.16	57.02	56.59	2.80	3.20	3.00
Kareena	60.21	63.02	61.62	43.09	41.47	42.28	5.40	5.07	5.23
Priya-6636	53.89	55.41	54.65	42.03	45.04	43.54	4.40	4.27	4.33
Karishma	56.69	59.39	58.04	45.54	45.17	45.36	4.53	4.93	4.73
VNR-3348	53.70	56.50	55.10	44.76	46.21	45.48	3.73	4.07	3.90
Nun 7610	55.52	56.35	55.94	47.99	48.20	48.09	3.00	3.27	3.13
VNR- 3357	55.99	56.03	56.01	47.57	47.31	47.44	3.60	3.40	3.50
Kundan	48.27	50.14	49.21	53.65	52.90	53.28	2.13	2.47	2.30
Lakshmi	52.10	50.85	51.47	41.63	42.32	41.98	4.53	4.33	4.43
Saksham	52.79	53.09	52.94	40.47	42.46	41.47	4.53	4.47	4.50
NS 962	50.04	54.38	52.21	41.09	43.95	42.52	2.80	3.00	2.90
Arka Rakshak	49.32	47.48	48.40	52.69	50.51	51.60	2.47	2.60	2.53
Pusa Ruby	37.48	43.33	40.41	32.51	34.12	33.32	2.80	3.07	2.93
Punjab Chhuhara	36.42	38.36	37.39	53.07	53.15	53.11	2.60	2.53	2.57
Sem±	2.029	1.606	1.429	1.601	1.378	1.053	0.123	0.191	0.119
CD (p=0.05)	5.784*	4.577*	4.073*	4.563*	3.926*	3.001*	0.352*	0.545*	0.338*
CV	6.613	5.040	4.570	6.112	5.143	3.975	5.641	8.421	5.324

Table 4.69b: Quality parameters of popular commercial varieties/ hybrids

Variety	Pericarp thickness (mm)			TSS (Brix %)			Fruit shape	Fruit colour
	2015-16	2016-17	Mean	2015-16	2016-17	Mean		
MHTM 256	5.70	5.52	5.61	3.92	3.80	3.86	Round	Red
S-22	4.58	4.41	4.50	4.23	4.45	4.34	Round	Red - Deep red
Bharani	5.36	5.57	5.47	4.29	4.15	4.22	Round	Red - Deep red
Arundhati 809	5.35	5.24	5.29	4.33	4.27	4.30	Round	Deep red
Bhagyanwan	5.61	6.11	5.86	4.15	4.33	4.24	Round	Red - Deep red
Abhilash	6.12	6.29	6.21	3.97	4.10	4.04	Round	Red - Deep red
Anvitha	5.03	4.87	4.95	4.25	4.16	4.21	Round	Red
Red Ruby	5.28	5.73	5.50	4.60	4.74	4.67	Round	Red - Deep red
Kohinoor	5.45	5.18	5.32	3.85	3.64	3.75	Round to oval	Red - Deep red
Karan	6.04	5.84	5.94	4.56	4.31	4.44	Oval	Light red - Red
Kareena	5.81	6.15	5.98	3.75	3.81	3.78	Round	Light red - Red
Priya-6636	5.31	5.24	5.28	4.07	3.93	4.00	Round	Light red - Red
Karishma	5.51	5.62	5.57	3.64	3.84	3.74	Round	Light red - Red
VNR-3348	4.82	4.60	4.71	3.99	4.12	4.06	Round	Light red - Deep red
Nun 7610	5.74	5.58	5.66	3.47	3.62	3.55	Round	Red
VNR- 3357	5.33	5.10	5.22	3.84	3.68	3.76	Round	Light red - Red
Kundan	5.48	5.69	5.59	4.93	5.02	4.98	Oval	Red
Lakshmi	5.15	5.38	5.26	4.09	4.25	4.17	Round	Light red - Deep red
Saksham	4.91	4.47	4.69	3.87	3.78	3.82	Round	Red
NS 962	5.26	5.09	5.18	4.11	3.92	4.01	Round	Light red - Deep red
Arka Rakshak	4.80	4.63	4.71	3.92	4.04	3.98	Oval	Red - Deep red
Pusa Ruby	3.23	3.52	3.38	4.17	4.25	4.21	Round	Red - Deep red
Punjab Chhuhara	4.89	4.94	4.91	4.27	4.29	4.28	Pear	Red - Deep red
Sem±	0.227	0.225	0.159	0.102	0.133	0.084		
CD (p=0.05)	0.648*	0.641*	0.454*	0.291*	0.379*	0.240*		
CV	7.504	7.419	5.256	4.313	5.612	3.552		

(73.44 cm) plant height was recorded in Abhilash followed by Kundan (72.78 cm), Saksham (69.94 cm), Karan (69.65 cm) and Lakshmi (64.23 cm). However Kundan, Saksham and Karan were at par with Abhilash. The lowest (50.11 cm) plant height was noted in Red Ruby followed by Pusa Ruby (51.20 cm) and S-22 (52.22 cm).

In 2015-16 the number of primary branches plant⁻¹ varied significantly (Table 4.70a). The highest (7.53) number of branches was observed in Punjab Chhuhara followed by Pusa Ruby (7.40), Nun 7610 (7.00), Arundhati 809 and Red Ruby (6.80). However Pusa Ruby and Nun 7610 were at par with Punjab Chhuhara. The least number of branches were recorded in Anvitha (3.93) followed by MHTM 256 (4.20) and Karishma (4.27). In 2016-17 the highest number of branches was observed in Punjab Chhuhara (7.53) followed by Pusa Ruby (7.27), Red Ruby (7.20), Nun 7610 (7.00) and Saksham (6.60). However, the least number of branches were noticed in Anvitha (3.40) followed by Abhilash (4.20) and MHTM 256 (4.40). The pooled mean of 2015-16 and 2016-17 shows that among all the commercial varieties evaluated the significant highest (7.53) number of primary branches plant⁻¹ was found in Punjab Chhuhara followed by Pusa Ruby (7.33), Red Ruby and Nun 7610 (7.00), Arundhati 809 (6.40) and Saksham (6.37). The least number of branches were recorded from Anvitha (3.67) followed by MHTM 256 and Abhilash (4.30).

In 2015-16 the number of secondary branches plant⁻¹ varied significantly (Table 4.70a) with highest number of secondary branches observed in Red Ruby (5.73) followed by Punjab Chhuhara (5.13), Pusa Ruby (4.47), S-22 (4.40) and Bhagyawan (4.13). However S-22 and Bhagyawan were at par with Pusa Ruby. The lowest number of branches were recorded in MHTM 256 (2.00) followed by Karishma (2.20) and Anvitha (2.33). In 2016-17 the highest number of branches was also observed in Red Ruby (5.60) followed by Punjab Chhuhara (4.93), S-22 and Pusa Ruby (4.20), Bhagyawan (4.00) and Lakshmi (3.80). However Bhagyawan and Lakshmi were at par with S-22 and Pusa Ruby. The least number of branches were recorded in MHTM 256 (1.80) followed by Anvitha, Karishma and VNR-3348 (2.20). It was revealed from pooled mean of 2015-16 and 2016-17 that among all the commercial varieties evaluated the significant highest number

of secondary branches plant⁻¹ was found in Red Ruby (5.67) followed by Punjab Chhuhara (5.03), Pusa Ruby (4.33), S-22 (4.30) and Bhagyawan (4.07). The minimum number of branches were recorded in MHTM 256 (1.90) followed by Karishma (2.20) and Anvitha (2.27).

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.70b. In 2015-16 the days to first flowering significantly varied from 25 to 30.67 days. The minimum (25.00 days) days to first flowering were observed in NS 962 followed by Priya-6636 (25.33 days), Karishma (25.67 days), MHTM 256 and Bharani (26.00 days). The maximum (30.67 days) days to first flowering were observed in Kundan followed by Punjab Chhuhara (30.33 days) and Nun 7610 and VNR-3357 (30.00 days). In 2016-17 the days to first flowering significantly ranged with minimum (14.00 days) days to first flowering NS 962 followed by Priya-6636 (18.00 days), MHTM 256, Bharani and Karishma (18.67 days) and maximum (30.67 days) days to first flowering in Punjab Chhuhara. In 2016-17 the days to first flowering significantly varied from 14 to 30.67 days. The minimum (14.00 days) days to first flowering were observed in NS 962 followed by Priya-6636 (18.00 days), MHTM 256, Bharani and Karishma (18.67 days). However Priya-6636, MHTM 256, Bharani and Karishma were at par with Priya-6636. The maximum (30.67 days) days to first flowering were observed in Punjab Chhuhara followed by Kundan (26.33 days) and Nun 7610 (24.67 days). It was revealed from pooled mean of 2015-16 and 2016-17 that among all the commercial varieties evaluated the significant lowest (19.50) days to first flowering were observed in NS 962 followed by Priya-6636 (21.67 days), Karishma (22.17 days), MHTM 256 and Bharani (22.33 days). The maximum (30.50 days) days to first flowering were observed in Punjab Chhuhara followed by Kundan (28.50 days) and Nun 7610 (27.33 days).

In 2015-16 the days to 50% flowering significantly ranged from 29.33 to 35.67 days (Table 4.70b). The minimum (29.33 days) days to 50% flowering were observed in NS 962 followed by Priya-6636 (29.67 days), S-22, Bharani, Arundhati 809 and Arka Rakshak (31.00 days). The maximum (35.67 days) days to 50% flowering were observed in Kundan followed by Punjab Chhuhara (35.33 days) and Nun 7610 and VNR-3357 (34.00 days). However S-22, Bharani,

Arundhati 809 and Arka Rakshak were at par with Priya-6636. In 2016-17 the minimum (21.67 days) days to 50% flowering were recorded in NS 962 followed by MHTM 256 (24.33 days), Arundhati 809 (27.67 days), Bhagyawan and Karishma (28.00). The maximum (36.00 days) days to first flowering were observed in Punjab Chhuhara followed by Kundan (35.00 days) and Pusa Ruby-3357 (33.00 days). It was revealed from pooled mean of 2015-16 and 2016-17 that among all the commercial varieties evaluated the significant least (25.50) days to 50% flowering were observed in NS 962 followed by MHTM 256 (27.83 days), Arundhati 809, Priya-6636 and Karishma (29.33 days). However Arundhati 809, Priya-6636 and Karishma were at par with MHTM 256. The maximum (35.67 days) days to 50% flowering were observed in Punjab Chhuhara followed by Kundan (35.33 days) and Abhilash and Nun 7610 (33.00 days).

In 2015-16 the days to first fruiting significantly varied from 32.33 to 40.33 days (Table 4.70b). The minimum (32.33 days) days to first fruiting were observed in NS 962 followed by Priya-6636 (33.00 days), MHTM 256 and Karishma (33.67 days) and Bharani (34.33 days). However MHTM 256, Karishma and Bharani were at par with Priya-6636. The maximum (40.33 days) days to first fruiting were observed in Kundan followed by Punjab Chhuhara (39.33 days) Abhilash and Nun 7610 (38.67 days). In 2016-17 the significant least (25.00 days) number of days required for first fruiting were recorded in NS 962 followed by MHTM 256 and Priya-6636 (27.33 days), Karishma (27.67 days) and Bharani (28.33 days). The maximum (39.67 days) days to first fruiting were observed in Punjab Chhuhara followed by Kundan (35.00 days), Abhilash and Pusa Ruby (32.67 days). The pooled mean data showed that the least (28.67 days) number of days required for first fruiting were noted in NS 962 followed by Priya-6636 (30.17 days), MHTM 256 (30.50 days), Karishma (30.67 days) and Bharani (31.33 days). However, Priya-6636, MHTM 256 and Karishma were at par with NS 962 and each other. The maximum (39.50 days) days to first fruiting were observed in Punjab Chhuhara followed by Kundan (37.67 days) and Abhilash (35.67 days).

Table 4.70a: Other parameters of popular commercial varieties/ hybrids

Variety	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
MHTM 256	74.97	43.25	59.11	4.20	4.40	4.30	2.00	1.80	1.90
S-22	54.36	50.07	52.22	6.00	5.60	5.80	4.40	4.20	4.30
Bharani	66.67	52.17	59.42	4.80	4.60	4.70	3.13	3.00	3.07
Arundhati 809	69.61	49.11	59.36	6.80	6.00	6.40	3.33	2.80	3.07
Bhagyawan	70.35	52.37	61.36	6.00	5.80	5.90	4.13	4.00	4.07
Abhilash	78.45	68.43	73.44	4.40	4.20	4.30	3.20	3.00	3.10
Anvitha	68.04	48.22	58.13	3.93	3.40	3.67	2.33	2.20	2.27
Red Ruby	49.73	50.48	50.11	6.80	7.20	7.00	5.73	5.60	5.67
Kohinoor	67.41	52.52	59.97	6.00	4.80	5.40	3.20	3.20	3.20
Karan	84.99	54.30	69.65	4.40	4.60	4.50	3.07	3.40	3.23
Kareena	79.11	48.77	63.94	6.40	6.00	6.20	3.00	2.80	2.90
Priya-6636	68.75	46.17	57.46	5.27	5.60	5.43	3.20	3.40	3.30
Karishma	68.77	45.52	57.14	4.27	4.40	4.33	2.20	2.20	2.20
VNR-3348	77.70	49.10	63.40	5.07	4.80	4.93	2.47	2.20	2.33
Nun 7610	65.77	42.01	53.89	7.00	7.00	7.00	2.80	2.80	2.80
VNR- 3357	51.27	54.39	52.83	4.53	4.80	4.67	2.73	3.00	2.87
Kundan	85.01	60.55	72.78	4.60	4.60	4.60	3.13	3.00	3.07
Lakshmi	84.15	44.32	64.23	4.40	6.00	5.20	2.87	3.80	3.33
Saksham	85.03	54.86	69.94	6.13	6.60	6.37	3.33	3.20	3.27
NS 962	76.49	50.99	63.74	5.33	5.00	5.17	3.00	2.80	2.90
Arka Rakshak	72.73	46.17	59.45	6.00	6.20	6.10	3.27	3.40	3.33
Pusa Ruby	56.89	45.51	51.20	7.40	7.27	7.33	4.47	4.20	4.33
Punjab Chhuhara	55.28	56.30	55.79	7.53	7.53	7.53	5.13	4.93	5.03
Sem±	3.011	1.903	1.886	0.195	0.341	0.251	0.183	0.244	0.193
CD (p=0.05)	8.581*	5.425*	5.376*	0.554*	0.973*	0.714*	0.521*	0.695*	0.550*
CV	7.442	6.505	5.412	6.089	10.756	7.873	9.557	12.957	10.173

Table 4.70b: Other parameters of popular commercial varieties/ hybrids

Variety	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
MHTM 256	26.00	18.67	22.33	31.33	24.33	27.83	33.67	27.33	30.50
S-22	27.00	19.00	23.00	31.00	31.00	31.00	34.67	28.67	31.67
Bharani	26.00	18.67	22.33	31.00	28.67	29.83	34.33	28.33	31.33
Arundhati 809	26.67	19.00	22.83	31.00	27.67	29.33	34.67	28.67	31.67
Bhagyanwan	27.00	20.00	23.50	31.33	28.00	29.67	35.00	30.00	32.50
Abhilash	29.00	24.00	26.50	33.33	32.67	33.00	38.67	32.67	35.67
Anvitha	27.00	19.00	23.00	31.33	28.33	29.83	34.67	28.67	31.67
Red Ruby	28.00	22.67	25.33	31.67	29.00	30.33	37.00	31.33	34.17
Kohinoor	27.67	22.00	24.83	33.00	30.00	31.50	35.67	30.00	32.83
Karan	27.00	22.00	24.50	32.00	32.33	32.17	35.00	30.00	32.50
Kareena	28.33	23.00	25.67	32.33	30.33	31.33	36.33	31.00	33.67
Priya-6636	25.33	18.00	21.67	29.67	29.00	29.33	33.00	27.33	30.17
Karishma	25.67	18.67	22.17	30.67	28.00	29.33	33.67	27.67	30.67
VNR-3348	28.00	23.00	25.50	32.00	32.67	32.33	37.00	31.33	34.17
Nun 7610	30.00	24.67	27.33	34.00	32.00	33.00	38.67	31.33	35.00
VNR- 3357	30.00	24.33	27.17	34.00	31.33	32.67	38.00	30.67	34.33
Kundan	30.67	26.33	28.50	35.67	35.00	35.33	40.33	35.00	37.67
Lakshmi	27.00	19.33	23.17	32.33	30.00	31.17	35.67	30.00	32.83
Saksham	27.00	19.33	23.17	31.33	30.33	30.83	35.00	29.67	32.33
NS 962	25.00	14.00	19.50	29.33	21.67	25.50	32.33	25.00	28.67
Arka Rakshak	27.00	21.00	24.00	31.00	30.67	30.83	35.67	30.33	33.00
Pusa Ruby	28.00	22.33	25.17	32.33	33.00	32.67	36.33	32.67	34.50
Punjab Chhuhara	30.33	30.67	30.50	35.33	36.00	35.67	39.33	39.67	39.50
Sem±	0.649	1.190	0.673	0.662	1.430	0.677	0.808	1.384	0.778
CD (p=0.05)	1.850*	3.390*	1.918*	1.885*	4.075*	1.931*	2.302*	3.944*	2.218*
CV	4.080	9.678	4.772	3.576	8.231	3.777	3.902	7.906	4.073

4.4.4.7 Overall performance of popular commercial varieties/ hybrids

The overall performance of all the commercial varieties were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.71 to 4.73.

It was clearly visible from Table 4.71 that in 2015-16 Karan gave best overall rank followed by Abhilash, VNR-3357, Bhagyanwan and Bharani. Though these five varieties showed commendable overall rank with resistant reaction but Arka Rakshak recorded maximum per ha total yield (472.82 q) and exhibited moderately resistant reaction followed by Abhilash (425.92 q), Bharani (401.94 q), Bhagyanwan (382.41 q) and Priya-6636 (351.85 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from Anvitha with average fruit weight of 75.30 g followed by Arka Rakshak (73.96 g), VNR-3357 (71.37 g), Lakshmi (67.46 g) and Karan (66.42 g). However largest round fruits were recorded in MHTM 256 with equatorial diameter of 62.29 mm followed by Kareena (60.21 mm), Anvitha (59.70 mm), Abhilash (58.88 mm) and Red Ruby (56.95 mm). Karan was recorded for the longest fruit with polar diameter of 56.19 mm followed by Kundan (53.65 mm), Punjab Chhohara (53.07), Arka Rakshak (52.69 mm) and Kohinoor (50.05 mm). However Abhilash had the maximum (6.12 mm) pericarp thickness followed by Karan (6.04 mm), Kareena (5.81 mm), Nun 7610 (5.74 mm) and MHTM 256 (5.70 mm). In case of TSS the maximum total soluble solids content (4.93 °Brix) was found in Kundan followed by Red Ruby (4.60 °Brix), Karan (4.56 °Brix), Arundhati 809 (4.33 °Brix) and Bharani (4.29 °Brix). Whereas the minimum (32.33 days) days to first fruiting were observed in NS 962 followed by Priya-6636 (33.00 days), MHTM 256 and Karishma (33.67 days) and Bharani (34.33 days).

It was revealed from the experimental data presented in Table 4.72 that in 2016-17 Karan performed outstanding followed by Abhilash, Bhagyanwan, Arundhati 809 and Bharani. Though these varieties were superfine in overall performance with resistant reaction but maximum (469.63 q) per ha total yield was recorded in Arka Rakshak that showed moderately susceptible reaction. This was followed by Bharani (437.03 q), Abhilash (398.93 q), Bhagyanwan (389.82 q) and Arundhati 809 (308.34 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from Anvitha with

average fruit weight of 76.38 g followed by Arka Rakshak (72.70 g), VNR-3357 (70.78 g), Karan (65.66 g) and VNR-3348 (64.96 g). While largest round fruits were recorded in Anvitha with equatorial diameter of 63.49 mm followed by Kareena (63.02 mm), Kohinoor (61.60 mm), Arundhati 809 (61.25 mm) and MHTM 256 (60.23 mm). Karan was recorded for the longest fruit with polar diameter of 57.02 mm followed by Kohinoor (55.34 mm), Punjab Chhuhara (53.15 mm), Kundan (52.90 mm) and Arka Rakshak (50.51 mm). However Abhilash had the maximum (6.29 mm) pericarp thickness followed by Kareena (6.15 mm), Bhagyanwan (6.11 mm), Karan (5.84 mm) and Red Ruby (5.73 mm). In case of TSS the maximum total soluble solids content (5.02 °Brix) was found in Kundan followed by Red Ruby (4.74 °Brix), S-22 (4.45 °Brix) Bhagyanwan (4.33 °Brix), and Karan (4.31 °Brix). While the least (25.00 days) number of days required for first fruiting were recorded in NS 962 followed by MHTM 256 and Priya-6636 (27.33 days), Karishma (27.67 days) and Bharani (28.33 days).

It was revealed from the average data of both the years (2015-16 and 2016-17) that the overall performance of Karan was best which was followed by Abhilash, Bhagyanwan, Arundhati 809 and Bharani (Table 4.73). Though these varieties were superfine in overall performance with resistant reaction but maximum (471.22 q) per ha total yield was recorded in Arka Rakshak that showed moderately susceptible reaction. This was followed by Bharani (419.49 q), Abhilash (412.43 q), Bhagyanwan (386.11 q) and Priya-6636 (327.35 q). Moreover the performance of each variety was different for different parameter such as the heaviest fruit was obtained from Anvitha with average fruit weight of 75.84 g followed by Arka Rakshak (73.33 g), VNR-3357 (71.07 g), Karan (66.04 g) and VNR-3348 (65.50 g). While largest round fruits were recorded in Kareena with equatorial diameter of 61.62 mm followed by Anvitha (61.60 mm), MHTM 256 (61.26 mm), Arundhati 809 (58.90 mm) and Abhilash (58.38 mm). Karan was recorded for the longest fruit with polar diameter of 56.59 mm followed by Kundan (53.28 mm), Punjab Chhuhara (53.11 mm), Kohinoor (52.70 mm) and Arka Rakshak (51.60 mm). However Abhilash had the maximum (6.21 mm) pericarp thickness followed by Kareena (5.98 mm), Karan (5.94 mm), Bhagyanwan (5.86 mm) and Nun 7610 (5.66 mm). In case of TSS the maximum total soluble

Table 4.71: Overall performance of popular commercial varieties/ hybrids in 2015-16

Variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
MHTM 256	28.44	18.95	MR	60.26	259.63	62.29	43.68	5.70	3.92	33.67
S-22	68.80	48.78	S	42.93	176.93	51.38	39.50	4.58	4.23	34.67
Bharani	23.17	15.84	R	52.94	401.94	53.40	42.68	5.36	4.29	34.33
Arundhati 809	24.39	16.73	MR	49.61	285.56	56.55	45.33	5.35	4.33	34.67
Bhagyawan	19.60	13.33	R	44.71	382.41	54.22	42.94	5.61	4.15	35.00
Abhilash	10.34	6.73	R	61.92	425.92	58.88	47.42	6.12	3.97	38.67
Anvitha	33.32	22.37	MR	75.30	281.11	59.70	44.58	5.03	4.25	34.67
Red Ruby	46.77	31.98	MS	63.89	260.93	56.95	45.07	5.28	4.60	37.00
Kohinoor	23.66	16.23	MR	50.94	191.85	54.81	50.05	5.45	3.85	35.67
Karan	13.19	9.07	R	66.42	310.56	51.75	56.16	6.04	4.56	35.00
Kareena	19.70	13.39	R	54.56	228.33	60.21	43.09	5.81	3.75	36.33
Priya-6636	22.99	15.77	R	55.90	351.85	53.89	42.03	5.31	4.07	33.00
Karishma	16.72	11.26	R	49.14	202.96	56.69	45.54	5.51	3.64	33.67
VNR-3348	24.25	16.63	MR	66.03	211.85	53.70	44.76	4.82	3.99	37.00
Nun 7610	33.14	21.99	MR	62.51	224.07	55.52	47.99	5.74	3.47	38.67
VNR- 3357	18.41	11.95	R	71.37	260.19	55.99	47.57	5.33	3.84	38.00
Kundan	25.31	16.99	MR	46.03	253.33	48.27	53.65	5.48	4.93	40.33
Lakshmi	15.49	11.06	R	67.46	161.48	52.10	41.63	5.15	4.09	35.67
Saksham	23.45	15.69	R	48.86	301.11	52.79	40.47	4.91	3.87	35.00
NS 962	22.33	15.29	R	54.02	83.52	50.04	41.09	5.26	4.11	32.33
Arka Rakshak	36.24	25.05	MR	73.96	472.82	49.32	52.69	4.80	3.92	35.67
Pusa Ruby	90.60	68.47	S	46.57	89.63	37.48	32.51	3.23	4.17	36.33
Punjab Chuhara	92.02	70.77	S	34.15	41.26	36.42	53.07	4.89	4.27	39.33
Sem±				1.997	9.133	2.03	1.61	0.23	0.10	0.81
CD (p=0.05)				5.691*	26.030*	5.779*	4.582*	0.648*	0.291*	2.302*
CV				6.121	6.209	6.627	6.158	7.504	4.313	3.902

Table 4.72: Overall performance of popular commercial varieties/ hybrids in 2016-17

Variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
MHTM 256	32.35	21.64	MR	62.54	243.48	60.23	44.07	5.52	3.80	27.33
S-22	46.40	31.17	MS	40.94	204.81	53.33	42.35	4.41	4.45	28.67
Bharani	16.84	11.65	R	55.61	437.03	57.67	46.21	5.57	4.15	28.33
Arundhati 809	13.68	9.77	R	49.63	308.34	61.25	45.28	5.24	4.27	28.67
Bhagyanwan	15.16	9.06	R	44.69	389.82	60.09	43.29	6.11	4.33	30.00
Abhilash	12.87	8.8	R	58.63	398.93	57.87	47.38	6.29	4.10	32.67
Anvitha	28.09	17.84	MR	76.38	275.00	63.49	47.15	4.87	4.16	28.67
Red Ruby	53.70	35.48	MS	63.52	251.19	55.82	46.13	5.73	4.74	31.33
Kohinoor	15.24	9.44	R	60.74	185.18	61.60	55.34	5.18	3.64	30.00
Karan	14.58	10.05	R	65.66	294.11	53.45	57.02	5.84	4.31	30.00
Kareena	16.73	10.12	R	53.32	241.30	63.02	41.47	6.15	3.81	31.00
Priya-6636	25.42	16.65	MR	53.99	302.85	55.41	45.04	5.24	3.93	27.33
Karishma	12.70	9.07	R	47.18	191.30	59.39	45.17	5.62	3.84	27.67
VNR-3348	16.44	10.98	R	64.96	215.93	56.50	46.21	4.60	4.12	31.33
Nun 7610	26.38	18.07	MR	56.92	218.89	56.35	48.20	5.58	3.62	31.33
VNR- 3357	20.39	13.15	R	70.78	203.70	56.03	47.31	5.10	3.68	30.67
Kundan	26.75	17.19	MR	50.88	283.22	50.14	52.90	5.69	5.02	35.00
Lakshmi	23.19	14.47	R	61.47	168.89	50.85	42.32	5.38	4.25	30.00
Saksham	19.11	12.92	R	58.16	305.81	53.09	42.46	4.47	3.78	29.67
NS 962	14.94	9.1	R	61.78	122.15	54.38	43.95	5.09	3.92	25.00
Arka Rakshak	46.99	30.97	MS	72.70	469.63	47.48	50.51	4.63	4.04	30.33
Pusa Ruby	86.89	65.81	S	44.35	88.37	43.33	34.12	3.52	4.25	32.67
Punjab Chuhara	84.33	68.81	S	33.22	56.44	38.36	53.15	4.94	4.29	39.67
Sem±				2.083	9.464	1.649	1.378	0.225	0.133	1.384
CD (p=0.05)				5.936*	26.975*	4.700*	3.926*	0.641*	0.379*	3.944*
CV				6.461	6.438	5.193	5.143	7.419	5.612	7.906

Table 4.73: Overall performance of popular commercial varieties/ hybrids in both the years (2015-16 and 2016-17)

Variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
MHTM 256	30.40	20.30	MR	61.40	251.56	61.26	43.87	5.61	3.86	30.50
S-22	57.60	39.98	S	41.94	190.87	52.35	40.93	4.50	4.34	31.67
Bharani	20.01	13.75	R	54.27	419.49	55.54	44.44	5.47	4.22	31.33
Arundhati 809	19.04	13.25	R	49.62	296.95	58.90	45.30	5.29	4.30	31.67
Bhagyawan	17.38	11.20	R	44.70	386.11	57.16	43.12	5.86	4.24	32.50
Abhilash	11.61	7.77	R	60.28	412.43	58.38	47.40	6.21	4.04	35.67
Anvitha	30.71	20.11	MR	75.84	278.06	61.60	45.86	4.95	4.21	31.67
Red Ruby	50.24	33.73	MS	63.70	256.06	56.39	45.60	5.50	4.67	34.17
Kohinoor	19.45	12.84	R	55.84	188.52	58.20	52.70	5.32	3.75	32.83
Karan	13.89	9.56	R	66.04	302.33	52.60	56.59	5.94	4.44	32.50
Kareena	18.22	11.76	R	53.94	234.82	61.62	42.28	5.98	3.78	33.67
Priya-6636	24.21	16.21	MR	54.95	327.35	54.65	43.54	5.28	4.00	30.17
Karishma	14.71	10.17	R	48.16	197.13	58.04	45.36	5.57	3.74	30.67
VNR-3348	20.35	13.81	R	65.50	213.89	55.10	45.48	4.71	4.06	34.17
Nun 7610	29.76	20.03	MR	59.72	221.48	55.94	48.09	5.66	3.55	35.00
VNR- 3357	19.40	12.55	R	71.07	231.95	56.01	47.44	5.22	3.76	34.33
Kundan	26.03	17.09	MR	48.45	268.28	49.21	53.28	5.59	4.98	37.67
Lakshmi	19.34	12.77	R	64.47	165.18	51.47	41.98	5.26	4.17	32.83
Saksham	21.28	14.31	R	53.51	303.46	52.94	41.47	4.69	3.82	32.33
NS 962	18.64	12.20	R	57.90	102.83	52.21	42.52	5.18	4.01	28.67
Arka Rakshak	41.62	28.01	MS	73.33	471.22	48.40	51.60	4.71	3.98	33.00
Pusa Ruby	88.75	67.14	S	45.46	89.00	40.41	33.32	3.38	4.21	34.50
Punjab Chhuhara	88.18	69.79	S	33.68	48.85	37.39	53.11	4.91	4.28	39.50
Sem±				1.238	6.372	1.414	1.053	0.159	0.084	0.778
CD (p=0.05)				3.529*	18.160*	4.029*	3.000*	0.454*	0.240*	2.218*
CV				3.783	4.333	4.535	3.981	5.256	3.552	4.073

Table 4.74: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of popular commercial varieties/hybrids

Parameters	Mean	
	Disease incidence	PDI
PDI	0.997 ^{**}	-
No of fruits plant⁻¹	-0.328 ^{NS}	-0.355 ^{NS}
Fruit yield plant⁻¹ (kg)	-0.331 ^{NS}	-0.365 ^{NS}
Average fruit weight (g)	-0.427 [*]	-0.459 [*]
Marketable yield q ha⁻¹	-0.470 [*]	-0.490 [*]
Unmarketable yield q ha⁻¹	-0.222 ^{NS}	-0.219 ^{NS}
Total yield (q ha⁻¹)	-0.483 [*]	-0.503 [*]
Equatorial diameter of fruit (mm)	-0.750 ^{**}	-0.774 ^{**}
Polar diameter of fruit (mm)	-0.195 ^{NS}	-0.180 ^{NS}
Number of locules fruit⁻¹	-0.338 ^{NS}	-0.352 ^{NS}
Thickness of pericarp (mm)	-0.681 ^{**}	-0.670 ^{**}
TSS (% Brix)	0.265 ^{NS}	0.252 ^{NS}
Plant height (cm)	-0.566 ^{**}	-0.540 ^{**}
No. of primary branches plant⁻¹	0.640 ^{**}	0.641 ^{**}
No. of secondary branches plant⁻¹	0.660 ^{**}	0.652 ^{**}
First flowering (DAT)	0.372 ^{NS}	0.392 ^{NS}
50 per cent flowering (DAT)	0.360 ^{NS}	0.381 ^{NS}
First fruiting (DAT)	0.440 [*]	0.461 [*]



Fig 4.33: Experimental plots of 2016/ToLCVRES entries



Fig 4.34: Experimental plots of commercial varieties

solids content (4.98 °Brix) was found in Kundan followed by Red Ruby (4.67 °Brix), Karan (4.44 °Brix), S-22 (4.34 °Brix) and Arundhati 809 (4.30 °Brix). Whereas the least (28.67 days) number of days required for first fruiting were noted in NS 962 followed by Priya-6636 (30.17 days), MHTM 256 (30.50 days), Karishma (30.67 days) and Bharani (31.33 days).

4.4.4.8 Correlation of leaf curl disease with different parameters of popular commercial varieties/ hybrids

The relationship of leaf curl disease was worked out with various parameters of popular commercial varieties/ hybrids for the year 2015-16 and 2016-17 and presented in table 4.74. Percent disease index of leaf curl indicated significant negative correlation with average fruit weight ($r = -0.427$, $p = 0.005$), marketable yield $q\ ha^{-1}$ ($r = -0.490$, $p = 0.005$), total yield ($r = -0.503$, $p = 0.005$), equatorial diameter of fruit ($r = -0.774$, $p = 0.001$), thickness of pericarp ($r = -0.670$, $p = 0.001$) and plant height ($r = -0.540$, $p = 0.001$). It was revealed from the data that no. of primary branches $plant^{-1}$ ($r = 0.641$, $p = 0.001$), no. of secondary branches $plant^{-1}$ ($r = 0.652$, $p = 0.001$) and First fruiting ($r = 0.461$, $p = 0.005$) expressed significant positive correlation with percent disease index of leaf curl. However rest other parameters showed either non significant positive or negative correlation with percent disease index.

4.4.5 2014/ToDVAR entries/ varieties

Seven 2014/ToDVAR entries/ varieties were evaluated against tomato leaf curl disease (ToLCD) during *rabi* 2015-16 and 2016-17 and results were presented in Table 4.75a to 4.85 (Fig 4.35).

4.4.5.1 Disease incidence and percent disease index (PDI)

Substantial variability was found in incidence and percent disease index (PDI) of all 2014/ToDVAR entries/ varieties evaluated. During 2015-16 disease incidence was varied from 0 to 4.11, 2.22 to 8.66, 6.07 to 18.94, 11.45 to 32.54, 20.55 to 58.36 and 30.46 to 82.51 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. However, the calculated percent disease index (PDI) was varied from 0 to 2.53, 0.95 to 5.08, 3.90 to 11.89, 7.08 to 23.24, 13.59

to 42.18 and 21.53 to 64.43 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. It was observed that two entries viz. 2014/TODVAR-2 and 2014/TODVAR-5 were free from the disease at 15 days after transplanting whereas in the rest others, symptoms of tomato leaf curl was appeared at 15 DAT (Table 4.75a – 4.76b).

While during 2016-17 disease incidence and percent disease index (PDI) was varied from 0 to 4.85, 1.01 to 11.60, 7.14 to 26.05, 14.35 to 54.51, 18.46 to 74.32 and 21.56 to 89.17 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Whereas the percent disease index was varied from 0 to 2.90, 0.14 to 5.23, 3.09 to 12.15, 9.34 to 34.00, 13.45 to 56.24 and 16.53 to 69.36 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The entries/ varieties 2014/TODVAR-3, 2014/TODVAR-5 and H-86 were free from the disease up to 15 days after transplanting but others showed first symptoms of tomato leaf curl disease at 15 days after transplanting (Table 4.75a – 4.76b).

However the average incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) exhibited that the incidence of leaf curl was varied from 0 to 3.04, 1.62 to 8.32, 6.61 to 19.23, 12.90 to 43.53, 19.51 to 66.34 and 26.01 to 85.84 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The calculated percent disease index (PDI) was varied from 0 to 1.93, 0.55 to 3.80, 3.50 to 12.02, 8.21 to 27.77, 13.52 to 49.21 and 19.03 to 66.90 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Only one entry i.e. 2014/TODVAR-5 was free from the disease at 15 days after transplanting and rest others showed first symptoms of tomato leaf curl disease at 15 days after transplanting (Table 4.75a – 4.76b).

During 2015-16 at 90 DAT the lowest incidence and percent disease index was recorded in 2014/TODVAR-5 (30.46, 21.53%) followed by 2014/TODVAR-4 (41.43, 30.61 %) and 2014/TODVAR-2 (50.61, 38.68 %) and highest in 2014/TODVAR-6 (82.51, 64.43 %) (Table 4.75a – 4.76b).

During 2016-17 at 90 DAT the lowest incidence and percent disease index (PDI) was also observed lowest in 2014/TODVAR-5 (21.56, 16.53%) followed by

H-86 (28.70, 21.33%) and 2014/TODVAR-2 (45.21, 37.51%) with highest in 2014/TODVAR-6 (89.17, 69.36%) (Table 4.75a – 4.76b).

The average percent incidence and percent disease index (PDI) for both years (2015-16 and 2016-17) also showed that lowest percent incidence and PDI of leaf curl was observed in 2014/TODVAR-5 (26.01, 19.03%) followed by H-86 (43.73, 32.78%) and 2014/ToLCVRES-2 (47.91, 38.10 %). However, the highest mean percent incidence and PDI was recorded in 2014/TODVAR-6 (85.84 and 66.90 %) (Table 4.75a – 4.76b).

4.4.5.2 Reaction and level of resistance of 2014/ToDVAR entries/ varieties of tomato against ToLCD

Among the seven entries evaluated during 2015-16 and 2016-17 none of the any entry found resistant against tomato leaf curl disease in both the years. However in 2015-16 one entry (2014/TODVAR-5) showed moderately resistant reaction and fall under the grade 3. Of them one entry (2014/TODVAR-4) exhibited moderately susceptible reaction with rating 5. The remaining five entries viz. 2014/TODVAR-1, 2014/TODVAR-2, 2014/TODVAR-3, 2014/TODVAR-6, H-86 were regarded as susceptible reaction with rating 7 (Table 4.77).

However in 2016-17 two entries viz. 2014/TODVAR-5 and H-86 showed moderately resistant reaction and one entry (2014/TODVAR-1) displayed moderately susceptible reaction. The rest other entries viz. 2014/TODVAR-2, 2014/TODVAR-3, 2014/TODVAR-4 and 2014/TODVAR-6 were found susceptible against tomato leaf curl disease (Table 4.77).

Among the seven entries evaluated during 2015-16 and 2016-17 the performance of four entries was constant with one (2014/TODVAR-5) moderately resistant and three (2014/TODVAR-2, 2014/TODVAR-3 and 2014/TODVAR-6) susceptible reaction in both the years and rest other showed variation in their reaction (Table 4.77).

4.4.5.3 Yield parameters of 2014/ToDVAR entries/ varieties

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out during 2015-16 and 2016-17 and presented in Table 4.78.

Table 4.75a: Percent incidence of tomato leaf curl disease in 2014/ToDVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)								
	15			30			45		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	3.84	0.95	2.40	8.66	5.83	7.25	16.37	11.84	14.11
2014/TODVAR-2	0.00	0.95	0.48	3.86	6.75	5.31	10.17	15.41	12.79
2014/TODVAR-3	1.48	0.00	0.74	5.19	2.86	4.03	11.85	11.43	11.64
2014/TODVAR-4	0.72	4.85	2.79	5.03	11.60	8.32	9.37	26.05	17.71
2014/TODVAR-5	0.00	0.00	0.00	2.22	1.01	1.62	6.07	7.14	6.61
2014/TODVAR-6	4.11	1.96	3.04	8.22	6.98	7.60	18.94	19.52	19.23
H-86 (Kashi Vishesh)	1.48	0.00	0.74	5.53	1.90	3.72	13.61	6.87	10.24

Table 4.75b: Percent incidence of tomato leaf curl disease in 2014/ToDVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)								
	60			75			90		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	30.72	23.47	27.10	52.93	37.39	45.16	79.34	45.36	62.35
2014/TODVAR-2	20.44	28.91	24.68	35.13	38.52	36.83	50.61	45.21	47.91
2014/TODVAR-3	23.70	27.62	25.66	40.00	43.81	41.91	51.85	49.52	50.69
2014/TODVAR-4	16.22	47.20	31.71	29.94	71.23	50.59	41.43	84.68	63.06
2014/TODVAR-5	11.45	14.35	12.90	20.55	18.46	19.51	30.46	21.56	26.01
2014/TODVAR-6	32.54	54.51	43.53	58.36	74.32	66.34	82.51	89.17	85.84
H-86	24.58	19.65	22.12	41.67	25.76	33.72	58.75	28.70	43.73

Table 4.76a: Evaluation of 2014/ToDVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)											
	15						30					
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	2.53	0.14	1.34	5.08	2.50	3.79	10.74	7.04	8.89			
2014/TODVAR-2	0.00	0.14	0.07	2.33	3.44	2.89	6.62	12.11	9.37			
2014/TODVAR-3	0.85	0.00	0.43	3.28	1.77	2.53	7.19	5.99	6.59			
2014/TODVAR-4	0.31	2.90	1.61	2.37	5.23	3.80	5.44	13.07	9.26			
2014/TODVAR-5	0.00	0.00	0.00	0.95	0.14	0.55	3.90	3.09	3.50			
2014/TODVAR-6	2.46	1.40	1.93	4.70	4.14	4.42	11.89	12.15	12.02			
H-86	0.40	0.00	0.20	3.24	0.54	1.89	7.90	3.24	5.57			

Table 4.76b: Evaluation of 2014/ToDVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)									Reaction		
	60			75			90			(at final observation)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Constant
2014/TODVAR-1	22.13	17.63	19.88	40.85	28.97	34.91	61.83	36.32	49.08	S	MS	
2014/TODVAR-2	13.02	23.37	18.20	26.02	31.91	28.97	38.68	37.51	38.10	S	S	S
2014/TODVAR-3	15.87	15.37	15.62	28.15	29.12	28.64	38.94	38.91	38.93	S	S	S
2014/TODVAR-4	10.37	34.00	22.19	20.35	55.00	37.68	30.61	66.81	48.71	MS	S	
2014/TODVAR-5	7.08	9.34	8.21	13.59	13.45	13.52	21.53	16.53	19.03	MR	MR	MR
2014/TODVAR-6	23.24	32.29	27.77	42.18	56.24	49.21	64.43	69.36	66.90	S	S	S
H-86	15.89	12.07	13.98	30.60	16.43	23.52	44.22	21.33	32.78	S	MR	

Table 4.77: Classification of 2014/TODVAR entries in different reaction category

Year	Reaction class	No. of Entry/ variety	Name of Entry/ variety
Entries/ varieties with constant reaction in both the years 2015-16	Resistant	0	
	Moderately resistant	1	2014/TODVAR-5
	Moderately susceptible	0	
	Susceptible	3	2014/TODVAR-2, 2014/TODVAR-3, 2014/TODVAR-6
	Resistant	0	
	Moderately resistant	1	2014/TODVAR-5
	Moderately susceptible	1	2014/TODVAR-4
	Susceptible	5	2014/TODVAR-1, 2014/TODVAR-2, 2014/TODVAR-6, H-86
	Resistant	0	
	Moderately resistant	2	2014/TODVAR-5, H-86
2016-17	Moderately susceptible	1	2014/TODVAR-1
	Susceptible	4	2014/TODVAR-2, 2014/TODVAR-3, 2014/TODVAR-6
			2014/TODVAR-4,

During 2015-16 the number of fruits plant⁻¹ significantly ranged from 19.68 to 55.77. The significant maximum number of fruits plant⁻¹ (55.77) was recorded in 2014/TODVAR-3 followed by 2014/TODVAR-4 (52.74) and lowest number of fruits plant⁻¹ (19.68) was recorded in 2014/TODVAR-2. However 2014/TODVAR-3 and 2014/TODVAR-4 were at par with each other. During 2016-17 the number of fruits plant⁻¹ significantly ranged from 21.00 to 56.45. The significant maximum number of fruits plant⁻¹ (56.45) was recorded in H-86 followed by 2014/TODVAR-3 (54.97) and lowest number of fruits plant⁻¹ (21.00) was recorded in 2014/TODVAR-2. However 2014/TODVAR-3 and H-86 were at par with each other. The mean number of fruits plant⁻¹ of both years (2015-16 and 2016-17) exhibited that the significant maximum number of fruits plant⁻¹ (55.37) was observed in 2014/TODVAR-3 followed by H-86 (52.32) and lowest number of fruits plant⁻¹ (20.34) was recorded in 2014/TODVAR-2. However 2014/TODVAR-3 and H-86 were at par with each other (Table 4.78).

There was significant variation was observed among 2014/ToDVAR entries/ varieties for Fruit yield plant⁻¹ (Table 4.78). The fruit yield plant⁻¹ significantly ranged from 1.10 to 3.98 kg and 1.25 to 4.75 kg in 2015-6 and 2016-17 respectively. In both the years the significant maximum fruit yield plant⁻¹ was obtained from H-86 with 3.98 and 4.75 kg fruit plant⁻¹ in 2015-16 and 2016-17 respectively. This was followed by 2014/TODVAR-4 (3.50 kg) and 2014/TODVAR-3 (3.37 kg) in 2015-16 and 2016-17 respectively. 2014/TODVAR-2 gave the lowest (1.10 and 1.25 kg) fruit yield plant⁻¹ in both of the years. 2014/TODVAR-3 (3.48 kg) and 2014/TODVAR-4 (3.50 kg) were at par with each other while in 2016-17 2014/TODVAR-3 (3.37 kg) and 2014/TODVAR-1 (3.34 kg) were at par with each other. The pooled mean of both years (2015-16 and 2016-17) expressed that the fruit yield plant⁻¹ significantly ranged from 1.18 kg to 4.36 kg. The significant maximum fruit yield plant⁻¹ (4.36 kg) was noted in H-86 followed by 2014/TODVAR-3 (3.42 kg) and minimum (1.18 kg) was observed in 2014/TODVAR-2. Whereas 2014/TODVAR-3 (3.42 kg) and 2014/TODVAR-4 (3.22 kg) were at par with each other.

The significant variation was observed in average fruit weight of 2014/ToDVAR entries/ varieties evaluated during 2015-16 and 2016-17 (Table

4.78). The average fruit weight significantly ranged from 47.52 to 82.67 g in 2015-16 and 49.05 to 84.10 g in 2016-17. In both the years significant maximum (82.67 and 84.10 g) average fruit weight was recorded in H-86 followed by 2014/ToDVAR-1 (73.66 and 75.99 g) and minimum (47.52 and 49.05 g) was observed in 2014/ToDVAR-6. However 2014/ToDVAR-3 (62.35 and 61.24 g) and 2014/ToDVAR-4 (66.43 and 61.81 g) were at par with each other. The pooled mean of both years (2015-16 and 2016-17) displayed that the average fruit weight significantly ranged from 48.29 to 83.39 g. The significant maximum average fruit weight (83.39 g) was observed in H-86. This was followed by 2014/ToDVAR-1 (74.83 g) and minimum (48.29 g) was recorded in 2014/ToDVAR-6. However 2014/ToDVAR-3 (61.79 g) and 2014/ToDVAR-4 (64.12 g) were at par with each other.

4.4.5.4 Yield of 2014/ToDVAR entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or entry. Marketable yield ha^{-1} , Unmarketable yield ha^{-1} and Total yield ha^{-1} were computed for all the 2014/ToDVAR entries/ varieties evaluated in both the years (2015-16 and 2016-17) and depicted in Table 4.79.

The significant difference was observed in marketable yield ha^{-1} of entries evaluated during 2015-16 and 2016-17 (Table 4.79). Marketable yield ha^{-1} significantly ranged from 106.59 to 292.56 q in 2015-16 and 172.72 to 343.35 q in 2016-17. In both years the significant maximum marketable yield ha^{-1} (292.56 and 343.35 q) was noted in H-86 followed by 2014/TODVAR-4 (263.63 q) and 2014/TODVAR-3 (243.45 q) in 2015-16 and 2016-17 respectively. The minimum marketable yield ha^{-1} was observed in 2014/TODVAR-1 (106.59 q) and 2014/TODVAR-4 (172.72 q) in 2015-16 and 2016-17 respectively. 2014/TODVAR-3 (250.44 q) and 2014/TODVAR-4 (263.63 q) were at par with each other in 2015-16 while 2014/TODVAR-2 (233.73 q) and 2014/TODVAR-3 (243.45 q) were at par with each other in 2016-17. Whereas the pooled mean marketable yield ha^{-1} of both years (2015-16 and 2016-17) displayed that the marketable yield ha^{-1} significantly ranged from 143.82 to 317.96 q. The significant maximum marketable yield ha^{-1} (317.96 q) was obtained from H-86 followed by

2014/TODVAR-3 (246.95 q). The minimum marketable yield ha^{-1} (143.82 q) was noted in 2014/TODVAR-1.

The significant deviation was noticed among entries for unmarketable yield ha^{-1} in both year 2015-16 and 2016-17 (Table 4.79). During 2015-16, the unmarketable yield ha^{-1} significantly ranged from 15.14 to 33.57 q. The minimum unmarketable yield ha^{-1} (15.14 q) was recorded in 2014/TODVAR-2 followed by 2014/TODVAR-6 (18.38 q). However the maximum unmarketable yield ha^{-1} (33.57 q) was noted in 2014/TODVAR-3. Whereas during 2016-17, the unmarketable yield ha^{-1} ranged from 4.56 to 11.51 q. The minimum unmarketable yield ha^{-1} (4.56 q) was noticed in 2014/TODVAR-4 followed by 2014/TODVAR-1 (6.31 q). The maximum unmarketable yield ha^{-1} (11.51 q) was recorded in H-86. However 2014/TODVAR-5 (6.55 q) and 2014/TODVAR-1 (6.31 q) were at par with each other. The pooled mean of unmarketable yield ha^{-1} from both years (2015-16 and 2016-17) showed that unmarketable yield ha^{-1} significantly ranged from 12.33 to 22.37 q. The minimum unmarketable yield ha^{-1} (12.33 q) was found in 2014/TODVAR-2 followed by 2014/TODVAR-1 (12.38 q). The maximum unmarketable yield ha^{-1} (22.37 q) was registered in 2014/TODVAR-3. However 2014/TODVAR-6 (13.65 q), 2014/TODVAR-1 (12.38 q) and 2014/TODVAR-3 (12.33 q) were at par with each other.

The significant difference was observed in total yield ha^{-1} of entries evaluated during 2015-16 and 2016-17 (Table 4.79). Total yield ha^{-1} significantly ranged from 125.04 to 319.82 q in 2015-16 and 177.28 to 354.86 q in 2016-17. In both years the significant maximum total yield ha^{-1} (319.82 and 354.86 q) was noted in H-86 followed by 2014/TODVAR-4 (286.81 q) and 2014/TODVAR-3 (254.62 q) in 2015-16 and 2016-17 respectively. The minimum total yield ha^{-1} was observed in 2014/TODVAR-1 (125.04 q) and 2014/TODVAR-4 (177.28 q) in 2015-16 and 2016-17 respectively. 2014/TODVAR-3 (284.01 q) and 2014/TODVAR-4 (286.81 q) were at par with each other in 2015-16 while 2014/TODVAR-2 (243.25 q) and 2014/TODVAR-3 (254.62 q) were at par with each other in 2016-17. Whereas the pooled mean of total yield ha^{-1} of both years (2015-16 and 2016-17) displayed that the total yield ha^{-1} significantly ranged from 156.20 to 337.34 q. The significant maximum total yield ha^{-1} (337.34 q) was

Table 4.78: Yield parameters of 2014/TODVAR entries

Entry/ variety	No of fruits plant ⁻¹				Fruit yield plant ⁻¹ (kg)				Average fruits weight (g)			
	2015-16	2016-17	Mean		2015-16	2016-17	Mean		2015-16	2016-17	Mean	
2014/TODVAR-1	28.24	43.97	36.10		2.08	3.34	2.71		73.66	75.99	74.83	
2014/TODVAR-2	19.68	21.00	20.34		1.10	1.25	1.18		56.07	59.72	57.90	
2014/TODVAR-3	55.77	54.97	55.37		3.48	3.37	3.42		62.35	61.24	61.79	
2014/TODVAR-4	52.74	47.51	50.13		3.50	2.94	3.22		66.43	61.81	64.12	
2014/TODVAR-5	37.94	40.17	39.06		1.81	2.01	1.91		47.71	50.03	48.87	
2014/TODVAR-6	28.27	30.80	29.53		1.34	1.51	1.43		47.52	49.05	48.29	
H-86	48.19	56.45	52.32		3.98	4.75	4.36		82.67	84.10	83.39	
Sem±	1.376	1.660	1.242		0.076	0.084	0.062		1.511	1.413	1.230	
CD (p=0.05)	4.240*	5.116*	3.828*		0.234*	0.258*	0.191*		4.654*	4.355*	3.791*	
CV	6.160	6.827	5.325		5.317	5.298	4.115		4.197	3.878	3.397	

Table 4.79: Yield performance of 2014/TODVAR entries

Entry/ variety	Marketable yield q ha ⁻¹				Unmarketable yield q ha ⁻¹				Total yield q ha ⁻¹			
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	106.59	181.05	143.82	18.45	6.31	12.38	125.04	187.36	156.20			
2014/TODVAR-2	213.31	233.73	223.52	15.14	9.52	12.33	228.45	243.25	235.85			
2014/TODVAR-3	250.44	243.45	246.95	33.57	11.17	22.37	284.01	254.62	269.32			
2014/TODVAR-4	263.63	172.72	218.18	23.17	4.56	13.87	286.81	177.28	232.04			
2014/TODVAR-5	183.13	218.15	200.64	22.30	6.55	14.43	205.43	224.70	215.07			
2014/TODVAR-6	191.11	218.15	204.63	18.38	8.93	13.65	209.49	227.08	218.29			
H-86	292.56	343.35	317.96	27.26	11.51	19.39	319.82	354.86	337.34			
Sem±	7.924	8.060	4.964	1.072	0.562	0.555	8.578	8.295	5.667			
CD (p=0.05)	24.417*	24.836*	15.297*	3.303*	1.731*	1.710*	26.432*	25.558*	17.461*			
CV	6.402	6.068	3.869	8.210	11.635	6.208	6.269	6.025	4.129			

obtained from H-86 followed by 2014/TODVAR-3 (269.32 q). The minimum total yield ha^{-1} (156.20 q) was noted in 2014/TODVAR-1.

4.4.5.5 Quality parameters of 2014/ToDVAR entries/ varieties

Quality parameters of fruit are one of the important factors that directly or indirectly influence the market value of yield. Quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each entry were studied during 2015-16 and 2016-17 and mentioned in Table 4.80a and 4.80b.

The significant difference was noticed in equatorial diameter of fruits. The equatorial diameter of fruits significantly ranged from 41.28 to 51.37 mm in 2015-16 and 41.43 to 56.41 mm in 2016-17 (Table 4.80a). In both years the largest fruit (51.37 and 56.41 mm) was gained from H-86 followed by 2014/TODVAR-3 (51.24 mm) and 2014/TODVAR-1 (51.66 mm) in 2015-16 and 2016-17 respectively. The minimum equatorial diameter was recorded in 2014/TODVAR-5 (41.28 mm) and 2014/TODVAR-4 (41.43 mm) in 2015-16 and 2016-17 respectively. 2014/TODVAR-2 (50.04 mm), 2014/TODVAR-3 (51.24 mm) and H-86 (51.37 mm) were at par with each other in 2015-16 whereas in 2016-17 2014/TODVAR-6 (49.18 mm), 2014/TODVAR-3 (50.53 mm) and 2014/TODVAR-2 (51.45 mm) were at par with 2014/TODVAR-1 (51.66 mm). The pooled mean of equatorial diameter from both years (2015-16 and 2016-17) significantly ranged from 43.32 to 53.89 mm. The largest fruit was observed in H-86 with equatorial diameter of 53.89 mm followed by 2014/TODVAR-3 (50.88 mm) and minimum was recorded in 2014/TODVAR-5 (43.32 mm). Whereas 2014/TODVAR-6 (48.31 mm), 2014/TODVAR-2 (50.75 mm) and 2014/TODVAR-3 (50.88 mm) were at par with each other.

The significant variation was observed in polar diameter of entries evaluated. During 2015-16 polar diameter ranged from 42.55 to 50.39 mm (Table 4.80a). The longest fruit was obtained from 2014/TODVAR-5 with polar diameter of 50.39 mm followed by H-86 (47.86 mm). Whereas 2014/TODVAR-6 (47.47 mm) and H-86 (47.86 mm) were at par with 2014/TODVAR-5 (50.39 mm). The lowest fruit height (42.55 mm) was obtained from 2014/TODVAR-1. The

significant variation was noticed in polar diameter among the evaluated entries in 2016-17 and polar diameter ranged from 39.51 to 53.57 mm. The longest fruit (53.57) mm was recorded from H-86 followed by 2014/TODVAR-5 (51.05 mm). However 2014/TODVAR-5 (51.05 mm) and H-86 (53.57 mm) were at par with each other. The lowest fruit height (39.51 mm) was obtained from 2014/TODVAR-4. The pooled mean of both the years (2015-16 and 2016-17) displayed significant variation in polar diameter among entries which ranged from 41.71 to 50.72 mm (Table 4.80a). The longest fruit was received from 2014/TODVAR-5 and H-86 (50.72 mm) followed by 2014/TODVAR-6 (47.88 mm). The lowest fruit height (41.71 mm) was obtained from 2014/TODVAR-4.

A significant variation was observed in the number of locules among evaluated entries in both the years 2015-16 and 2016-17 (Table 4.80a). The number of locules ranged from 2.40 to 4.80 and 2.53 to 5.00 in 2015-16 and 2016-17 respectively. The maximum number of locules (4.80 and 5.00) was observed from 2014/TODVAR-1 in both years followed by 2014/TODVAR-3 (4.40) and H-86 (4.40). 2014/TODVAR-1 (4.80) and 2014/TODVAR-3 (4.40) were at par with each other in 2015-16 and 2014/TODVAR-3 (4.20) and H-86 (4.40) were at par with each other in 2016-17. In both years the minimum number of locules (2.40 and 2.53) was recorded in 2014/TODVAR-6. The pooled mean obtained from both years (2015-16 and 2016-17) data exhibited significant variation in number of locules among entries and ranged from 2.47 to 4.90 (Table 4.80a). The maximum number of locules (4.90) was observed in 2014/TODVAR-1 followed by 2014/TODVAR-3 (4.30) and minimum number of locules (2.47) was found in 2014/TODVAR-6. However 2014/TODVAR-2 (3.97) and H-86 (4.20) were at par with 2014/TODVAR-3 (4.30).

A significant variation was observed on pericarp thickness among evaluated entries in both the years 2015-16 and 2016-17 (Table 4.80b). The pericarp thickness ranged from 4.01 to 5.79 and 3.94 to 5.95 mm in 2015-16 and 2016-17. Among the entries the maximum (5.79 and 5.95 mm) pericarp thickness was observed in 2014/TODVAR-6 in both years followed by 2014/TODVAR-4 (4.53 mm) and 2014/TODVAR-5 (4.66 mm) in 2015-16 and 2016-17 respectively. 2014/TODVAR-3 had the minimum (4.01 and 3.94 mm) pericarp thickness in both

the years. 2014/TODVAR-5 (4.39 mm) and 2014/TODVAR-4 (4.53 mm) were at par with each other in 2015-16 whereas H-86 and 2014/TODVAR-5 (4.66 mm) were at par with each other in 2016-17. The mean data of 2015-16 and 2016-17 also showed significant variation in pericarp thickness among the entries and ranged from 3.98 to 5.87 mm. The maximum (5.87 mm) pericarp thickness was recorded in 2014/TODVAR-6 followed by 2014/TODVAR-5 (4.53 mm) and minimum pericarp thickness (3.98 mm) was recorded in 2014/TODVAR-3. However 2014/TODVAR-4 (4.35 mm) and 2014/TODVAR-5 (4.53 mm) were at par with each other.

In 2015-16 the TSS ranged from 3.73 to 4.75 °Brix and among the seven 2014/ToDVAR entries/ varieties evaluated, the maximum total soluble solids content (4.75 °Brix) was found in 2014/TODVAR-2 followed by 2014/TODVAR-5 (4.31 °Brix). The minimum total soluble solids content (3.73 °Brix) was recorded in 2014/TODVAR-1. However 2014/TODVAR-5 (4.31) and 2014/TODVAR-6 (4.09) were at par with each other. In 2016-17 the TSS ranged from 3.67 to 4.81 °Brix and out of seven entries 2014/TODVAR-2 had maximum total soluble solids content (4.81 °Brix) followed by 2014/TODVAR-5 (4.58 °Brix). The minimum total soluble solids content (3.67 °Brix) was recorded in 2014/TODVAR-4. However 2014/TODVAR-1 and H-86 (4.10 °Brix) were at par with 2014/TODVAR-6 (4.21 °Brix). The pooled mean data of 2015-16 and 2016-17 also showed significant variation in total soluble solids (TSS) among the entries and ranged from 3.77 to 4.78 °Brix. The maximum total soluble solids content (4.78 °Brix) was obtained in 2014/TODVAR-2 followed by 2014/TODVAR-5 (4.44 °Brix). The minimum total soluble solids content (3.77 °Brix) was recorded in 2014/TODVAR-3. However 2014/TODVAR-1 (3.92 °Brix) and H-86 (3.97 °Brix) were at par with each other (Table 4.80b).

One (2014/ToDVAR-5) out of seven entries was oval shaped, and rest of the 2014/ToDVAR entries/ varieties was either round or flattish round in shape. Among the seven entries evaluated two (2014/ToDVAR-2 and 2014/ToDVAR-3) were pinkish red other two (2014/ToDVAR-5 and H-86) were red and three (2014/ToDVAR-1, 2014/ToDVAR-4 and 2014/ToDVAR-6) were red to deep red colour (Table 4.80b).

Table 4.80a: Quality parameters of 2014/ToDVAR entries

Entry/ variety	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	46.17	51.66	48.91	42.55	49.17	45.86	4.80	5.00	4.90
2014/TODVAR-2	50.04	51.45	50.75	44.91	45.04	44.98	4.07	3.87	3.97
2014/TODVAR-3	51.24	50.53	50.88	43.96	43.74	43.85	4.40	4.20	4.30
2014/TODVAR-4	45.51	41.43	43.47	43.91	39.51	41.71	3.47	3.20	3.33
2014/TODVAR-5	41.28	45.36	43.32	50.39	51.05	50.72	3.13	3.60	3.37
2014/TODVAR-6	47.44	49.18	48.31	47.47	48.28	47.88	2.40	2.53	2.47
H-86	51.37	56.41	53.89	47.86	53.57	50.72	4.00	4.40	4.20
Sem±	1.116	1.133	0.850	1.084	1.245	0.692	0.181	0.154	0.113
CD (p=0.05)	3.438*	3.492*	2.620*	3.340*	3.835*	2.131*	0.556*	0.474*	0.348*
CV	4.062	3.971	3.036	4.094	4.567	2.574	8.333	6.965	5.165

Table 4.80b: Quality parameters of 2014/TODVAR entries

Entry/ variety	Pericarp thickness (mm)			TSS (Brix %)			Fruit shape	Fruit colour
	2015-16	2016-17	Mean	2015-16	2016-17	Mean		
2014/TODVAR-1	4.18	4.40	4.29	3.73	4.10	3.92	Round	Red – Deep red
2014/TODVAR-2	4.13	4.16	4.14	4.75	4.81	4.78	Round	Pinkish red
2014/TODVAR-3	4.01	3.94	3.98	3.84	3.70	3.77	Round	Pinkish red
2014/TODVAR-4	4.53	4.18	4.35	3.89	3.67	3.78	Round	Red – Deep red
2014/TODVAR-5	4.39	4.66	4.53	4.31	4.58	4.44	Oval	Red
2014/TODVAR-6	5.79	5.95	5.87	4.09	4.21	4.15	Round	Red – Deep red
H-86	4.11	4.53	4.32	3.84	4.10	3.97	Round	Red
Sem±	0.102	0.091	0.057	0.078	0.054	0.033		
CD (p=0.05)	0.314*	0.282*	0.177*	0.241*	0.166*	0.100*		
CV	3.970	3.481	2.213	3.331	2.233	1.367		

4.4.5.6 Other parameters of 2014/ToDVAR entries/ varieties

Some other parameters such as Plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF) were recorded for each and every entry during 2015-16 and 2016-17 and presented in Table 4.81a and 4.81b.

In 2015-16 plant height was ranged from 47.01 to 70.01 cm and significantly highest (70.01 cm) plant height was recorded in 2014/ToDVAR-3 followed by 2014/ToDVAR-4 (66.25 cm). The lowest plant height (47.01 cm) was registered in 2014/ToDVAR-1. However 2014/ToDVAR-2 (63.11 cm) and 2014/ToDVAR-4 (66.25 cm) were at par with 2014/ToDVAR-3 (70.01 cm). Data presented in Table 4.81a showed that plant height was significantly ranged from 56.05 to 69.39 cm during 2016-17. The highest (69.39 cm) plant height was recorded in 2014/ToDVAR-3 followed by H-86 (68.82 cm). The lowest (56.05 cm) plant height was noted in 2014/ToDVAR-1. However 2014/ToDVAR-4 (61.77 cm), 2014/ToDVAR-6 (62.52 cm) and H-86 (68.82 cm) were at par with 2014/ToDVAR-3 (69.39 cm). The pooled mean of plant height in 2015-16 and 2016-17 exhibited that significant highest (69.70 cm) plant height was recorded in 2014/ToDVAR-3 followed by 2014/ToDVAR-2 (64.37 cm). The lowest (51.53 cm) plant height was noted in 2014/ToDVAR-1. However 2014/ToDVAR-4 (64.01 cm), H-86 (64.05 cm) and 2014/ToDVAR-2 (64.37 cm) were at par with 2014/ToDVAR-3 (69.70 cm).

In 2015-16 the number of primary branches plant⁻¹ varied significantly (Table 4.81a). The highest (10.73) number of branches was observed in 2014/ToDVAR-4 followed by 2014/ToDVAR-3 (9.73). The least number of branches (5.80) were observed in 2014/ToDVAR-1. However 2014/ToDVAR-2 (8.80), H-86 (8.80) and 2014/ToDVAR-5 (9.07) were at par with 2014/ToDVAR-6 (9.20). In 2016-17 there was significant difference was observed in number of primary branches plant⁻¹ among entries and varied from 7.20 to 10.53. The highest (10.53) number of branches was observed in 2014/ToDVAR-4 which was followed by H-86 (10.20). The least (7.20) number of branches were noticed in 2014/ToDVAR-1. However H-86 and 2014/ToDVAR-4 were at par with each

other. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2014/ToDVAR entries/ varieties evaluated the significant highest (10.63) number of primary branches plant⁻¹ was found in 2014/ToDVAR-4 followed by 2014/ToDVAR-3 (9.60) and least number of branches were recorded from 2014/ToDVAR-1 (6.50). However 2014/ToDVAR-2 (8.97) and 2014/ToDVAR-6 (8.97) were at par with 2014/ToDVAR-3 (9.60).

In 2015-16 the number of secondary branches plant⁻¹ varied significantly from 4.33 to 11.40 (Table 4.81a). The highest (11.40) number of secondary branches was observed in 2014/ToDVAR-4 followed by 2014/ToDVAR-3 (11.20). The least number of branches were recorded in 2014/ToDVAR-1 (4.33). However 2014/ToDVAR-3 and 2014/ToDVAR-4 were at par with each other. In 2016-17 there was significant difference was observed in number of secondary branches plant⁻¹ among the entries. The highest (11.27) number of branches was observed in 2014/ToDVAR-2 followed by 2014/ToDVAR-3 and 2014/ToDVAR-4 (11.07). The least number of branches were recorded in 2014/ToDVAR-1 (5.13). However 2014/ToDVAR-3 and 2014/ToDVAR-4 were at par with 2014/ToDVAR-2. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2014/ToDVAR entries/ varieties evaluated the significant highest (11.23) number of secondary branches plant⁻¹ was found in 2014/ToDVAR-4 followed by 2014/ToDVAR-3 (11.13). The least number of branches were recorded in 2014/ToDVAR-1 (4.73). However 2014/ToDVAR-2 (10.80) and 2014/ToDVAR-3 (11.13) were at par with 2014/ToDVAR-4 (11.23).

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.81b. In both years days to first flowering significantly varied from 23.00 to 29.33 days and 24.33 to 31.00 days in 2015-16 and 2016-17 respectively. In both years the minimum (23.00 and 24.33 days) days to first flowering were observed in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (26.67 and 26.33 days). The maximum (29.33 and 31.00 days) days to first flowering were observed in 2014/ToDVAR-5. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2014/ToDVAR entries/ varieties evaluated the significant lowest (23.67 days) days to first flowering were observed

in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (26.50) and maximum (30.17 days) days to first flowering were observed in 2014/ToDVAR-5.

The days to 50% flowering significantly ranged from 31.00 to 36.33 days and 31.67 to 38.67 days in 2015-16 and 2016-17 respectively (Table 4.81b). In both years the minimum (31.00 and 31.67 days) days to 50% flowering were observed in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (34.33 and 33.67 days) and maximum (36.33 and 38.67 days) days to 50% flowering were observed in 2014/ToDVAR-5. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2014/ToDVAR entries/ varieties evaluated the significant least (31.33 days) days to 50% flowering were observed in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (34.00 days) and maximum (37.50 days) days to 50% flowering were observed in 2014/ToDVAR-5.

The days to first fruiting significantly ranged from 29.33 to 37.67 days and 31.00 to 39.00 days in 2015-16 and 2016-17 respectively (Table 4.81b). In both years the minimum (29.33 and 31.00 days) days to first fruiting were observed in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (33.33 and 33.33 days) and maximum (37.67 and 39.00 days) days to first fruiting were observed in 2014/ToDVAR-5. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2014/ToDVAR entries/ varieties evaluated the significant least (30.17 days) days to first fruiting were observed in 2014/ToDVAR-1 followed by 2014/ToDVAR-6 (33.33 days) and maximum (38.33 days) days to first fruiting were observed in 2014/ToDVAR-5.

4.4.5.7 Overall performance of 2014/ToDVAR entries/ varieties

The overall performance of all the 2014/ToDVAR entries/ varieties were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.82 to 4.84.

It was seen from the experimental data presented in Table 4.82 that in 2015-16 2014/TODVAR-4 and 2014/TODVAR-5 attained best overall performance followed by H-86. Though these three entries attained commendable overall performance and showed moderately susceptible, moderately resistant and susceptible reaction with H-86 recorded maximum (319.82 q) per ha total yield but

Table 4.81a: Other parameters of 2014/TODVAR entries

Entry/ variety	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	47.01	56.05	51.53	5.80	7.20	6.50	4.33	5.13	4.73
2014/TODVAR-2	63.11	65.63	64.37	8.80	9.13	8.97	10.33	11.27	10.80
2014/TODVAR-3	70.01	69.39	69.70	9.73	9.47	9.60	11.20	11.07	11.13
2014/TODVAR-4	66.25	61.77	64.01	10.73	10.53	10.63	11.40	11.07	11.23
2014/TODVAR-5	52.15	57.11	54.63	9.07	8.73	8.90	7.53	8.33	7.93
2014/TODVAR-6	58.09	62.52	60.31	9.20	8.73	8.97	8.40	9.27	8.83
H-86	59.29	68.82	64.05	8.80	10.20	9.50	7.87	9.33	8.60
Sem±	3.335	3.179	2.715	0.311	0.328	0.208	0.283	0.295	0.139
CD (p=0.05)	10.276*	9.796*	8.366*	0.958*	1.010*	0.640*	0.872*	0.910*	0.429*
CV	9.722	8.735	7.681	6.069	6.212	3.993	5.616	5.472	2.669

Table 4.81b: Other parameters of 2014/TODVAR entries

Entry/ variety	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2014/TODVAR-1	23.00	24.33	23.67	31.00	31.67	31.33	29.33	31.00	30.17
2014/TODVAR-2	28.67	27.67	28.17	35.67	34.33	35.00	36.00	35.33	35.67
2014/TODVAR-3	27.33	28.67	28.00	35.00	35.33	35.17	34.33	35.00	34.67
2014/TODVAR-4	27.67	28.67	28.17	35.00	34.67	34.83	35.67	36.00	35.83
2014/TODVAR-5	29.33	31.00	30.17	36.33	38.67	37.50	37.67	39.00	38.33
2014/TODVAR-6	26.67	26.33	26.50	34.33	33.67	34.00	33.33	33.33	33.33
H-86	28.00	27.33	27.67	34.67	34.00	34.33	37.67	36.67	37.17
Sem±	0.514	0.463	0.313	0.901	0.810	0.512	0.684	0.653	0.535
CD (p=0.05)	1.585*	1.426*	0.964*	2.777*	2.496*	1.577*	2.109*	2.011*	1.647*
CV	3.271	2.893	1.972	4.515	4.053	2.562	3.400	3.212	2.643

this was followed by 2014/TODVAR-4 (286.81 q) with moderately susceptible reaction. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from H-86 with average fruit weight of 82.67 g followed by 2014/TODVAR-1 (73.66 g). The largest round fruits were recorded in H-86 with equatorial diameter of 51.37 mm followed by 2014/TODVAR-3 (51.24 mm). However 2014/TODVAR-5 was recorded for the longest fruit with polar diameter of 50.39 mm followed by H-86 (47.86 mm). 2014/TODVAR-6 had the maximum (5.79 mm) pericarp thickness followed by 2014/TODVAR-4 (4.53 mm). In case of TSS the maximum total soluble solids content (4.75 °Brix) was found in 2014/TODVAR-2 followed by 2014/TODVAR-5 (4.31 °Brix). Whereas the minimum (29.33 days) days to first fruiting were observed in 2014/TODVAR-1 followed by 2014/TODVAR-6 (33.33 days).

It was revealed from the Table 4.83 that in 2016-17 H-86 attained best overall performance followed by 2014/TODVAR-1 and 2014/TODVAR-5. Though these entries were superfine in overall performance and showed moderately resistant, moderately susceptible and moderately resistant reaction respectively with maximum (354.86 q) per ha total yield was recorded in H-86. But this was followed by 2014/TODVAR-3 (254.62 q) with susceptible reaction. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from H-86 with average fruit weight of 84.10 g followed by 2014/TODVAR-1 (75.99 g). The largest round fruits were recorded in H-86 with equatorial diameter of 56.41 mm followed by 2014/TODVAR-1 (51.66 mm) and longest fruit (53.57) was also recorded from H-86 followed by 2014/TODVAR-5 (51.05 mm). However 2014/TODVAR-6 had the maximum (5.95 mm) pericarp thickness followed by 2014/TODVAR-5 (4.66 mm). In case of TSS the maximum total soluble solids content (4.81 °Brix) was found in 2014/TODVAR-2 followed by 2014/TODVAR-5 (4.58 °Brix) whereas the minimum (31.00 days) days to first fruiting were observed in 2014/TODVAR-1 followed by 2014/TODVAR-6 (33.33 days).

It was revealed from the pooled mean of both the years (2015-16 and 2016-17) H-86 attained best overall performance followed by 2014/TODVAR-5 (Table 4.84). Though these entries were superfine in overall performance and exhibited

Table 4.82: Overall performance of 2014/TODVAR in 2015-16 entries

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/TODVAR-1	79.34	61.83	S	73.66	125.04	46.17	42.55	4.18	3.73	29.33
2014/TODVAR-2	50.61	38.68	S	56.07	228.45	50.04	44.91	4.13	4.75	36.00
2014/TODVAR-3	51.85	38.94	S	62.35	284.01	51.24	43.96	4.01	3.84	34.33
2014/TODVAR-4	41.43	30.61	MS	66.43	286.81	45.51	43.91	4.53	3.89	35.67
2014/TODVAR-5	30.46	21.53	MR	47.71	205.43	41.28	50.39	4.39	4.31	37.67
2014/TODVAR-6	82.51	64.43	S	47.52	209.49	47.44	47.47	5.79	4.09	33.33
H-86	58.75	44.22	S	82.67	319.82	51.37	47.86	4.11	3.84	37.67
Sem±				1.511	8.578	1.116	1.084	0.102	0.078	0.684
CD (p=0.05)				4.654*	26.432*	3.438*	3.340*	0.314*	0.241*	2.109*
CV				4.197	6.269	4.062	4.094	3.970	3.331	3.400

Table 4.83: Overall performance of 2014/TODVAR in 2016-17 entries

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/TODVAR-1	45.36	36.32	MS	75.99	187.36	51.66	49.17	4.40	4.10	31.00
2014/TODVAR-2	45.21	37.51	S	59.72	243.25	51.45	45.04	4.16	4.81	35.33
2014/TODVAR-3	49.52	38.91	S	61.24	254.62	50.53	43.74	3.94	3.70	35.00
2014/TODVAR-4	84.68	66.81	S	61.81	177.28	41.43	39.51	4.18	3.67	36.00
2014/TODVAR-5	21.56	16.53	MR	50.03	224.70	45.36	51.05	4.66	4.58	39.00
2014/TODVAR-6	89.17	69.36	S	49.05	227.08	49.18	48.28	5.95	4.21	33.33
H-86	28.70	21.33	MR	84.10	354.86	56.41	53.57	4.53	4.10	36.67
Sem±				1.413	8.295	1.133	1.245	0.091	0.054	0.653
CD (p=0.05)				4.355*	25.558*	3.492*	3.835*	0.282*	0.166*	2.011*
CV				3.878	6.025	3.971	4.567	3.481	2.233	3.212

Table 4.84: Overall performance of 2014/TODVAR entries in both the years (2015-16 and 2016-17)

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2014/TODVAR-1	62.35	49.08		74.83	156.20	48.91	45.86	4.29	3.92	30.17
2014/TODVAR-2	47.91	38.10	S	57.90	235.85	50.75	44.98	4.14	4.78	35.67
2014/TODVAR-3	50.69	38.93	S	61.79	269.32	50.88	43.85	3.98	3.77	34.67
2014/TODVAR-4	63.06	48.71		64.12	232.04	43.47	41.71	4.35	3.78	35.83
2014/TODVAR-5	26.01	19.03	MR	48.87	215.07	43.32	50.72	4.53	4.44	38.33
2014/TODVAR-6	85.84	66.90	S	48.29	218.29	48.31	47.88	5.87	4.15	33.33
H-86	43.73	32.78		83.39	337.34	53.89	50.72	4.32	3.97	37.17
Sem±				1.230	5.667	0.850	0.692	0.057	0.033	0.535
CD (p=0.05)				3.791*	17.461*	2.620*	2.131*	0.177*	0.100*	1.647*
CV				3.397	4.129	3.036	2.574	2.213	1.367	2.643

Table 4.85: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2014/ToDVAR entries

Parameters	Mean	
	Disease incidence	PDI
PDI	0.999 ^{**}	-
No of fruits plant⁻¹	-0.211 ^{NS}	-0.243 ^{NS}
Fruit yield plant⁻¹ (kg)	-0.181 ^{NS}	-0.207 ^{NS}
Average fruit weight (g)	-0.095 ^{NS}	-0.099 ^{NS}
Marketable yield q ha⁻¹	-0.290 ^{NS}	-0.313 ^{NS}
Unmarketable yield q ha⁻¹	-0.261 ^{NS}	-0.285 ^{NS}
Total yield (q ha⁻¹)	-0.294 ^{NS}	-0.317 ^{NS}
Equatorial diameter of fruit (mm)	0.045 ^{NS}	0.050 ^{NS}
Polar diameter of fruit (mm)	-0.386 ^{NS}	-0.403 ^{NS}
Number of locules fruit⁻¹	-0.359 ^{NS}	-0.341 ^{NS}
Thickness of pericarp (mm)	0.643 ^{NS}	0.628 ^{NS}
TSS (% Brix)	-0.335 ^{NS}	-0.309 ^{NS}
Plant height (cm)	0.033 ^{NS}	0.026 ^{NS}
No. of primary branches plant⁻¹	-0.079 ^{NS}	-0.102 ^{NS}
No. of secondary branches plant⁻¹	-0.019 ^{NS}	-0.023 ^{NS}
First flowering (DAT)	-0.623 ^{NS}	-0.636 ^{NS}
50 per cent flowering (DAT)	-0.618 ^{NS}	-0.631 ^{NS}
First fruiting (DAT)	-0.679 [*]	-0.697 [*]

moderately susceptible and moderately resistant reaction with maximum (337.34 q) per ha total yield in H-86. But this was followed by 2014/TODVAR-3 (269.32 q) with susceptible reaction. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from H-86 with average fruit weight of 83.39 g followed by 2014/TODVAR-1 (74.83 g). The largest round fruits were also recorded in H-86 with equatorial diameter of 53.89 mm followed by 2014/TODVAR-3 (50.88 mm) and longest fruit (50.72 mm) was recorded from 2014/TODVAR-5 and H-86 followed by 2014/TODVAR-6 (47.88 mm). However 2014/TODVAR-6 had the maximum (5.87 mm) pericarp thickness followed by 2014/TODVAR-5 (4.53 mm). In case of TSS the maximum total soluble solids content (4.78 °Brix) was found in 2014/TODVAR-2 followed by 2014/TODVAR-5 (4.44 °Brix). However the minimum (30.17 days) days to first fruiting were observed in 2014/TODVAR-1 followed by 2014/TODVAR-6 (33.33 days).

4.4.5.8 Correlation of leaf curl disease with different parameters of 2014/TODVAR entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2014/ TODVAR entries/ varieties for the year 2015-16 and 2016-17 and presented in table 4.85. The significant negative correlation was observed between percent disease index of leaf curl and first fruiting ($r = -0.697$, $p = 0.005$). However rest other parameters showed either non significant positive or negative correlation with the disease.

4.4.6 2016/ToDVAR entries/ varieties

Eleven 2016/ToDVAR entries/ varieties were evaluated against tomato leaf curl disease (ToLCD) during *Rabi* 2016-17 and 2017-18 and results were presented in Table 4.86a to 4.96 (Fig 4.36).

4.4.6.1 Disease incidence and percent disease index (PDI)

Substantial variability was found in incidence and percent disease index (PDI) of all 2016/ToDVAR entries/ varieties evaluated. During 2016-17 disease incidence was varied from 0.0 to 2.31, 0.0 to 7.78, 7.22 to 34.35, 10.19 to 68.33,

14.45 to 85.11 and 17.03 to 90.78 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The calculated percent disease index (PDI) was varied from 0.0 to 0.42, 0.0 to 5.24, 3.80 to 20.79, 6.44 to 47.44, 8.62 to 63.59 and 10.63 to 69.66 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Only one entry (*i.e.* 2016/ToDVAR-12) was free from leaf curl disease at 30 days after transplanting but rest all of the entries showed disease symptoms at 15 DAT (Table 4.86a – 4.87b).

During 2017-18 disease incidence was varied from 0.0 to 1.33, 0 to 6.36, 0.74 to 18.17, 4.26 to 43.43, 8.40 to 76.74 and 10.56 to 92.41 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The percent disease index was varied from 0.0 to 0.90, 0.0 to 3.58, 0.11 to 11.93, 1.66 to 21.84, 4.56 to 53.51 and 6.49 to 68.26 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. Three entries *viz.* 2016/TODVAR-5, 2016/TODVAR-10 and 2016/TODVAR-12 were free from the disease at 30 days after transplanting but in the rest other, symptoms of tomato leaf curl was appeared either 15 or 30 DAT (Table 4.86a – 4.87b).

However the average incidence and percent disease index of both years (2016-17 and 2017-18) showed that disease incidence was varied from 0.0 to 1.79, 0.0 to 7.07 and 3.98 to 26.26, 7.23 to 53.72, 11.43 to 79.13 and 13.80 to 91.67 at 15, 30, 45, 60, 75 and 90 DAT respectively. The calculated percent disease index was varied from 0.0 to 0.66, 0.0 to 4.38, 2.17 to 16.36, 4.09 to 34.03, 7.01 to 56.71 and 8.68 to 68.81 percent at 15, 30, 45, 60, 75 and 90 DAT respectively. Only one entry (*i.e.* 2016/ToDVAR-12) was free from leaf curl disease at 30 days after transplanting whereas others were found infected with the leaf curl at 15 days after transplanting (Table 4.86a – 4.87b).

During 2016-17 at 90 DAT the lowest incidence and percent disease index was recorded in 2016/ToDVAR-5 (17.03, 10.63 %) followed by 2016/ToDVAR-12 (19.06, 12.93 %) and 2016/ToDVAR-10 (25.59, 16.79 %) and highest in 2016/ToDVAR-1 (90.78, 69.66 %) (Table 4.86a – 4.87b).

During 2017-18 at final observation (90 DAT) the lowest incidence was recorded in 2016/ToDVAR-5 (10.56 %) this was followed by 2016/ToDVAR-12 (12.22 %) and 2016/ToDVAR-10 (20.59 %). However, the lowest percent disease

index of leaf curl was observed in 2016/ToDVAR-12 (6.49 %) followed by 2016/ToDVAR-5 (6.72 %) and 2016/ToDVAR-10 (13.82 %). The highest incidence and percent disease index was registered in 2016/ToDVAR-4 (92.41, 68.26 %) (Table 4.86a – 4.87b).

The average incidence and percent disease index of both years (2016-17 and 2017-18) indicated that at 90 DAT the lowest incidence and percent disease index of leaf curl was observed in 2016/ToDVAR-5 (13.80, 8.68 %) followed by 2016/ToDVAR-12 (15.64, 9.71 %) and 2016/ToDVAR-10 (23.09, 15.31 %). However, the highest mean percent incidence and percent disease index was recorded in 2016/ToDVAR-4 (91.67, 68.81 %) (Table 4.86a – 4.87b).

4.4.6.2 Reaction and level of resistance of 2016/ToDVAR entries/ varieties of tomato against ToLCD

Among the eleven entries/ varieties evaluated during 2016-17 two entries viz. 2016/ToDVAR-5 and 2016/ToDVAR-12 were regarded as resistant and fall under the grade 1. Of them only one entry (2016/ToDVAR-10) was categorized as moderately resistant with rating 3 and none of the entry was found moderately resistant. However remaining eight entries viz. 2016/ToDVAR-1, 2016/ToDVAR-2, 2016/ToDVAR-3, 2016/ToDVAR-4, 2016/ToDVAR-6, 2016/ToDVAR-7, 2016/ToDVAR-8 and 2016/ToDVAR-11 exhibited susceptible reaction against tomato leaf curl disease (Table 4.88).

Out of eleven entries evaluated during 2017-18 three entries viz. 2016/ToDVAR-5, 2016/ToDVAR-10 and 2016/ToDVAR-12 expressed resistant reaction. None of the any entry was found moderately resistant however three (2016/ToDVAR-3, 2016/ToDVAR-7 and 2016/ToDVAR-11) were moderately susceptible. Five entries viz. 2016/ToDVAR-1, 2016/ToDVAR-2, 2016/ToDVAR-4, 2016/ToDVAR-6 and 2016/ToDVAR-8 were shown susceptible reaction with rating 7 (Table 4.88).

The result of evaluation for both years (2015-16 and 2016-17) displayed that the performance of seventeen varieties were constant. Of them two entries viz. 2016/ToDVAR-5 and 2016/ToDVAR-12 were found resistant against ToLCD with rating 1 and none of the entry was moderately resistant or moderately susceptible. However, five entries viz. 2016/ToDVAR-1, 2016/ToDVAR-2, 2016/ToDVAR-4,

Table 4.86a: Percent incidence of tomato leaf curl disease in 2016/TODVAR entries

Entry	Percent disease incidence at 15-day intervals (DAT)									
	15					30				
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17
2016/TODVAR-1	1.90	0.74	1.32	7.78	6.36	7.07	34.35	18.17	26.26	18.17
2016/TODVAR-2	0.83	0.00	0.42	3.33	4.72	4.03	17.65	13.76	15.70	13.76
2016/TODVAR-3	0.00	0.00	0.00	2.44	3.63	3.04	12.95	10.86	11.90	10.86
2016/TODVAR-4	0.00	1.33	0.67	2.08	5.57	3.83	11.19	17.84	14.52	17.84
2016/TODVAR-5	0.00	0.00	0.00	0.76	0.00	0.38	7.22	0.74	3.98	0.74
2016/TODVAR-6	2.31	1.26	1.79	6.94	6.34	6.64	27.39	16.48	21.94	16.48
2016/TODVAR-7	0.00	0.00	0.00	0.78	1.39	1.08	9.56	5.55	7.56	5.55
2016/TODVAR-8	0.00	0.78	0.39	1.71	2.97	2.34	11.51	13.74	12.62	13.74
2016/TODVAR-10	0.00	0.00	0.00	0.81	0.00	0.41	9.28	2.84	6.06	2.84
2016/TODVAR-11	0.00	0.72	0.36	1.77	2.17	1.97	10.14	7.42	8.78	7.42
2016/TODVAR-12	0.00	0.00	0.00	0.00	0.00	0.00	9.20	0.79	5.00	0.79

Table 4.86b: Percent incidence of tomato leaf curl disease in 2016/TODVAR entries

Entry	Percent disease incidence at 15-day intervals (DAT)									
	60			75			90			Mean
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	
2016/TODVAR-1	68.33	39.11	53.72	85.11	67.79	76.45	90.78	87.64	89.21	
2016/TODVAR-2	47.07	32.20	39.64	75.89	56.96	66.43	85.94	73.10	79.52	
2016/TODVAR-3	34.73	25.31	30.02	63.72	42.11	52.92	84.69	51.64	68.16	
2016/TODVAR-4	52.85	43.43	48.14	81.52	76.74	79.13	90.93	92.41	91.67	
2016/TODVAR-5	10.19	4.26	7.23	14.45	8.40	11.43	17.03	10.56	13.80	
2016/TODVAR-6	49.48	35.61	42.55	72.54	59.08	65.81	84.89	74.43	79.66	
2016/TODVAR-7	41.43	17.91	29.67	69.33	38.28	53.81	85.70	52.41	69.06	
2016/TODVAR-8	47.33	35.34	41.34	74.50	64.54	69.52	87.07	81.19	84.13	
2016/TODVAR-10	12.67	7.35	10.01	21.00	15.45	18.23	25.59	20.59	23.09	
2016/TODVAR-11	26.28	19.16	22.72	56.72	37.04	46.88	65.96	50.10	58.03	
2016/TODVAR-12	15.79	3.88	9.84	16.57	8.47	12.52	19.06	12.22	15.64	

Table 4.87b: Evaluation of 2016/TODVAR entries against tomato leaf curl disease

Entry	Percent disease index at 15-day intervals (DAT)									Reaction (at final observation)				
	60			75			90			2016-17	2016-17	2017-18	2017-18	Constant
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean					
2016/TODVAR-1	47.44	20.61	34.03	63.59	48.42	56.00	69.66	65.94	67.80	S	S	S	S	S
2016/TODVAR-2	30.46	15.18	22.82	53.91	39.51	46.71	63.48	50.84	57.16	S	S	S	S	S
2016/TODVAR-3	22.96	13.95	18.46	46.21	27.93	37.07	63.26	34.18	48.72	S	MS			
2016/TODVAR-4	37.95	21.84	29.90	59.90	53.51	56.71	69.36	68.26	68.81	S	S	S	S	S
2016/TODVAR-5	6.44	1.75	4.09	8.62	5.40	7.01	10.63	6.72	8.68	R	R	R	R	R
2016/TODVAR-6	34.64	13.59	24.12	52.46	41.58	47.02	63.61	52.48	58.05	S	S	S	S	S
2016/TODVAR-7	27.92	7.83	17.88	49.30	25.79	37.55	63.35	35.76	49.56	S	MS			
2016/TODVAR-8	33.51	17.99	25.75	53.88	45.91	49.89	65.50	60.65	63.08	S	S	S	S	S
2016/TODVAR-10	7.22	2.76	4.99	12.42	9.31	10.86	16.79	13.82	15.31	MR	R			
2016/TODVAR-11	15.81	10.24	13.03	38.70	24.72	31.71	46.46	34.99	40.73	S	MS			
2016/TODVAR-12	10.07	1.66	5.87	9.88	4.56	7.22	12.93	6.49	9.71	R	R	R	R	R

Table 4.88: Classification of 2016/TODVAR entries in different reaction categories

Year	Reaction category	No. of entry	Name of entry
Entries with constant reaction in both the years	Resistant	2	2016/TODVAR-5, 2016/TODVAR-12
	Moderately resistant	0	
	Moderately susceptible	0	
	Susceptible	5	2016/TODVAR-1, 2016/TODVAR-2, 2016/TODVAR-4, 2016/TODVAR-6, 2016/TODVAR-8
2016-17	Resistant	2	2016/TODVAR-5, 2016/TODVAR-12
	Moderately resistant	1	2016/TODVAR-10
		0	Moderately susceptible
	Susceptible	8	2016/TODVAR-1, 2016/TODVAR-2, 2016/TODVAR-3, 2016/TODVAR-4, 2016/TODVAR-6, 2016/TODVAR-7, 2016/TODVAR-8, 2016/TODVAR-11
2017-18	Resistant	3	2016/TODVAR-5, 2016/TODVAR-10, 2016/TODVAR-12
	Moderately resistant	0	
	Moderately susceptible	3	2016/TODVAR-3, 2016/TODVAR-7, 2016/TODVAR-11
	Susceptible	5	2016/TODVAR-1, 2016/TODVAR-2, 2016/TODVAR-4, 2016/TODVAR-6, 2016/TODVAR-8

2016/ToDVAR-6 and 2016/ToDVAR-8 were put in reaction category susceptible and fall under rating 7 (Table 4.88).

4.4.6.3 Yield parameters of 2016/ToDVAR entries/ varieties

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out during 2016-17 and 2017-18 and presented in Table 4.89.

The significant variation was observed in number of fruits plant⁻¹ of 2016/ToDVAR entries evaluated during 2016-17 and 2017-18 (Table 4.89). The number of fruits plant⁻¹ significantly ranged from 23.99 to 54.55 in 2016-17 and 24.47 to 55.03 in 2017-18. In both the years significant maximum (54.55 and 55.03) number of fruits was recorded in 2016/ToDVAR-5 followed by 2016/ToDVAR-12 (45.79 and 50.07) and 2016/ToDVAR-10 (41.27 and 43.23) and minimum (23.99 and 24.47) was observed in 2016/ToDVAR-1. 2016/ToDVAR-10 and 2016/ToDVAR-12 were at par with each other in 2016-17. However 2016/ToDVAR-8 (39.33), 2016/ToDVAR-3 (40.03), 2016/ToDVAR-7 (40.33) and 2016/ToDVAR-6 (40.77) were at par with 2016/ToDVAR-10 (43.23) in 2017-18. The pooled mean of both years (2016-17 and 2017-18) displayed that the number of fruits plant⁻¹ significantly ranged from 24.23 to 54.79. The significant maximum number of fruits (54.79) was observed in 2016/ToDVAR-5. This was followed by 2016/ToDVAR-12 (47.93) and 2016/ToDVAR-10 (42.25) and minimum (24.23) was recorded in 2016/ToDVAR-1. However 2016/ToDVAR-11 (36.64) and 2016/ToDVAR-8 (38.59) were at par with 2016/ToDVAR-6 (38.70).

There was significant variation was observed among 2016/ToDVAR entries for Fruit yield plant⁻¹ (Table 4.89). The fruit yield plant⁻¹ significantly ranged from 1.86 to 3.94 kg and 1.90 to 4.16 kg in 2016-17 and 2017-18 respectively. During 2016-17 the significant maximum (3.94 kg) fruit yield plant⁻¹ was obtained from 2016/TODVAR-5 followed by 2016/TODVAR-12 (3.80 kg) and 2016/TODVAR-10 (3.21 kg). The lowest (1.86 kg) fruit yield was recorded in 2016/TODVAR-1. However 2016/TODVAR-12 and 2016/TODVAR-5 were at par with each other. In 2017-18 the significant maximum (4.16 kg) fruit yield plant⁻¹

was recorded from 2016/TODVAR-12 which was followed by 2016/TODVAR-5 (3.99 kg) and 2016/TODVAR-10 (3.29 kg). However 2016/TODVAR-5 and 2016/TODVAR-12 were at par with each other. The lowest (1.90 kg) fruit yield was recorded in 2016/TODVAR-1. The pooled mean of both years (2016-17 and 2017-18) expressed that the fruit yield plant⁻¹ significantly ranged from 1.88 kg to 3.98 kg. The significant maximum fruit yield plant⁻¹ (3.98 kg) was noted in 2016/TODVAR-12 followed by 2016/TODVAR-5 (3.97 kg) and 2016/TODVAR-10 (3.29 kg). The least (1.88 kg) fruit yield plant⁻¹ was noted in 2016/TODVAR-1 whereas 2016/TODVAR-5 and 2016/TODVAR-12 were at par with each other.

The significant variation was observed in average fruit weight of 2016/ToDVAR entries evaluated during 2016-17 and 2017-18 (Table 4.89). The average fruit weight significantly ranged from 55.13 to 83.08 g in 2016-17 and 55.17 to 83.16 g in 2017-18. In both the years significant maximum (83.08 and 83.16 g) average fruit weight was recorded in 2016/TODVAR-12 followed by 2016/ToDVAR-3 (81.32 and 82.02 g) and 2016/TODVAR-7 (80.08 and 81.08) and minimum (55.13 and 55.17 g) was observed in 2016/ToDVAR-8. 2016/ToDVAR-1 (77.41 g), 2016/ToDVAR-10 (77.92 g), 2016/ToDVAR-4 (80.07 g), 2016/ToDVAR-7 (80.08 g) and 2016/ToDVAR-3 (81.32 g) were at par with 2016/ToDVAR-12 (83.08 g) in 2016-17. However 2016/ToDVAR-10 (77.95 g), 2016/ToDVAR-4 (80.01 g), 2016/ToDVAR-7 (81.08 g) and 2016/ToDVAR-3 (82.02 g) were at par with 2016/ToDVAR-12 (83.16 g) in 2017-18. The pooled mean of both years (2016-17 and 2017-18) displayed that the average fruit weight significantly ranged from 55.15 to 83.12 g. The significant maximum average fruit weight (83.12 g) was gained from 2016/ToDVAR-12. This was followed by 2016/ToDVAR-3 (81.67 g) and 2016/ToDVAR-7 (80.58 g) and minimum (55.15 g) was recorded in 2016/ToDVAR-8. However 2016/ToDVAR-4 (80.04 g), 2016/ToDVAR-7 (80.58 g) and 2016/ToDVAR-3 (81.67 g) were at par with 2016/ToDVAR-12 (83.12 g).

4.4.6.4 Yield of 2016/ToDVAR entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or entry. Marketable yield ha⁻¹, Unmarketable yield ha⁻¹ and Total yield ha⁻¹

were computed for all the 2016/TODVAR entries evaluated in both the years (2016-17 and 2017-18) and depicted in Table 4.90.

The significant difference was observed in marketable yield ha^{-1} of entries evaluated during 2016-17 and 2017-18 (Table 4.90). Marketable yield ha^{-1} significantly ranged from 105.44 to 322.11 q in 2016-17 and 109.26 to 326.62 q in 2017-18. In both years the significant maximum marketable yield ha^{-1} (322.11 and 326.62 q) was noted in 2016/TODVAR-12 followed by 2016/TODVAR-5 (305.79 and 313.89 q) and 2016/TODVAR-10 (271.23 and 278.70 q) and also these two entries were at par with each other. The minimum marketable yield ha^{-1} was obtained from 2016/TODVAR-4 (105.44 and 109.26 q). It is clearly visible from the pooled mean of marketable yield ha^{-1} that the marketable yield ha^{-1} significantly ranged from 107.35 to 324.36 q. The significant maximum marketable yield ha^{-1} (324.36 q) was recorded in 2016/TODVAR-12 followed by 2016/TODVAR-5 (309.84 q) and 2016/TODVAR-10 (274.97 q) and also these two entries were at par with each other. The minimum marketable yield ha^{-1} (107.35 q) was noted in 2016/TODVAR-4.

The significant deviation was noticed among entries for unmarketable yield ha^{-1} in both years 2016-17 and 2017-18 (Table 4.90). During 2016-17, the unmarketable yield ha^{-1} significantly ranged from 8.52 to 24.33 q. The minimum unmarketable yield ha^{-1} (8.52 q) was recorded in 2016/TODVAR-8 followed by 2016/TODVAR-3 (9.72 q) and 2016/TODVAR-7 (11.79 q) and maximum (24.33 q) was noted in 2016/TODVAR-5. However 2016/TODVAR-3 and 2016/TODVAR-8 were at par with each other. Whereas during 2017-18, the unmarketable yield ha^{-1} ranged from 9.03 to 22.92 q. The minimum unmarketable yield ha^{-1} (9.03 q) was noticed in 2016/TODVAR-7 followed by 2016/TODVAR-8 (11.57 q) and 2016/TODVAR-4 (13.36 q) and maximum (22.92 q) was recorded in 2016/TODVAR-10. However 2016/TODVAR-7 and 2016/TODVAR-8 were at par with each other. The pooled mean of unmarketable yield ha^{-1} showed that unmarketable yield ha^{-1} significantly ranged from 10.05 to 22.23 q. The minimum unmarketable yield ha^{-1} (10.05 q) was found in 2016/TODVAR-8 followed by 2016/TODVAR-7 (10.41 q) and 2016/TODVAR-3 (11.58 q). The maximum unmarketable yield ha^{-1} (22.23 q) was registered in 2016/TODVAR-5. However

Table 4.89: Yield parameters of 2016/TODVAR entries

Entry	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/TODVAR-1	23.99	24.47	24.23	1.86	1.90	1.88	77.41	77.52	77.47
2016/TODVAR-2	30.90	34.70	32.80	2.29	2.60	2.45	74.24	74.93	74.59
2016/TODVAR-3	28.74	40.03	34.39	2.34	3.28	2.81	81.32	82.02	81.67
2016/TODVAR-4	24.80	25.00	24.90	1.99	2.00	1.99	80.07	80.01	80.04
2016/TODVAR-5	54.55	55.03	54.79	3.94	3.99	3.97	72.31	72.44	72.37
2016/TODVAR-6	36.63	40.77	38.70	2.35	2.64	2.49	64.07	64.68	64.38
2016/TODVAR-7	30.31	40.33	35.32	2.43	3.27	2.85	80.08	81.08	80.58
2016/TODVAR-8	37.85	39.33	38.59	2.09	2.17	2.13	55.13	55.17	55.15
2016/TODVAR-10	41.27	43.23	42.25	3.21	3.37	3.29	77.92	77.95	77.94
2016/TODVAR-11	34.85	38.43	36.64	2.58	2.86	2.72	73.96	74.33	74.15
2016/TODVAR-12	45.79	50.07	47.93	3.80	4.16	3.98	83.08	83.16	83.12
Sem±	1.679	1.625	0.876	0.056	0.073	0.051	1.988	1.780	1.281
CD (p=0.05)	4.952*	4.793*	2.584*	0.166*	0.216*	0.151*	5.865*	5.250*	3.778*
CV	8.208	7.175	4.065	3.720	4.324	3.189	4.622	4.118	2.971

Table 4.90: Yield performance of 2016/TODVAR entries

Entry	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/TODVAR-1	123.27	125.23	124.25	13.68	15.97	14.83	136.95	141.20	139.08
2016/TODVAR-2	157.59	167.83	162.71	19.42	17.25	18.33	177.01	185.07	181.04
2016/TODVAR-3	197.80	222.22	210.01	9.72	13.43	11.58	207.52	235.65	221.59
2016/TODVAR-4	105.44	109.26	107.35	16.83	13.36	15.09	122.27	122.62	122.44
2016/TODVAR-5	305.79	313.89	309.84	24.33	20.14	22.23	330.11	334.03	332.07
2016/TODVAR-6	136.46	138.89	137.67	14.95	16.78	15.87	151.41	155.67	153.54
2016/TODVAR-7	167.09	201.62	184.35	11.79	9.03	10.41	178.87	210.65	194.76
2016/TODVAR-8	181.67	183.80	182.73	8.52	11.57	10.05	190.19	195.37	192.78
2016/TODVAR-10	271.23	278.70	274.97	17.89	22.92	20.41	289.12	301.62	295.37
2016/TODVAR-11	137.11	152.55	144.83	23.26	16.62	19.94	160.37	169.17	164.77
2016/TODVAR-12	322.11	326.62	324.36	21.02	18.41	19.71	343.13	345.03	344.08
Sem±	9.167	8.557	6.393	1.025	1.243	0.841	9.739	10.946	6.731
CD (p=0.05)	27.042*	25.242*	18.861*	3.023*	3.666*	2.480*	28.731*	32.289*	19.855*
CV	8.295	7.341	5.631	10.761	13.493	8.974	8.114	8.703	5.477

2016/TODVAR-3, 2016/TODVAR-7 and 2016/TODVAR-8 were at par with each other.

The significant difference was observed in total yield ha^{-1} of entries evaluated during 2016-17 and 2017-18 (Table 4.90). Total yield ha^{-1} significantly ranged from 122.27 to 343.13 q in 2016-17 and 122.62 to 345.03 q in 2017-18. In both years the significant maximum total yield ha^{-1} (343.13 and 345.03 q) was noted in 2016/TODVAR-12 followed by 2016/TODVAR-5 (330.11 and 334.03 q) and 2016/TODVAR-10 (289.12 and 301.62 q) and minimum was recorded in 2016/TODVAR-4 (122.27 and 122.62 q). However 2016/TODVAR-5 and 2016/TODVAR-12 were at par with each other in both the years. Whereas the pooled mean displayed that the total yield ha^{-1} significantly ranged from 122.27 to 344.08 q. The significant maximum total yield ha^{-1} (344.08 q) was obtained from 2016/TODVAR-12 followed by 2016/TODVAR-5 (332.07 q) and 2016/TODVAR-12 (295.37 q). However 2016/TODVAR-5 and 2016/TODVAR-12 were at par with each. The minimum total yield ha^{-1} (122.44 q) was noticed in 2016/TODVAR-4.

4.4.6.5 Quality parameters of 2016/ToDVAR entries/ varieties

Quality parameters of fruit are one of the important factors that directly or indirectly influence the market value of yield. Quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each entry were studied during 2016-17 and 2017-18 and mentioned in Table 4.91a and 4.91b.

The significant difference was noticed in equatorial diameter of fruits. The equatorial diameter of fruits significantly ranged from 47.98 to 64.35 mm in 2016-17 and 48.77 to 68.05 mm in 2017-18 (Table 4.91a). In both years the largest fruit (64.35 and 68.05 mm) was recorded in 2016/TODVAR-7. This was followed by 2016/TODVAR-12 (63.31 mm) and 2016/TODVAR-10 (60.97 mm) in 2016-17 and 2016/TODVAR-12 (65.41 mm) and 2016/TODVAR-3 (62.57 mm) in 2017-18. 2016-17 2016/TODVAR-10 and 2016/TODVAR-12 were at par with 2016/TODVAR-7 in 2016-17 whereas 2016/TODVAR-12 and 2016/TODVAR-7 were at par with each other in 2017-18 for equatorial diameter. In both years the

minimum (47.98 and 48.77 mm) equatorial diameter was recorded in 2016/TODVAR-8. It can be seen from the pooled mean of both years that entry 2016/TODVAR-7 produced significantly large fruits with equatorial diameter of 66.20 mm. This was followed by 2016/TODVAR-12 (64.36 mm) and 2016/TODVAR-10 (60.90 mm). The minimum was recorded in 2016/TODVAR-8 (48.38 mm). However 2016/TODVAR-7 and 2016/TODVAR-10 were at par with each other.

Substantial variation was observed in polar diameter of entries evaluated during 2016-17 and 2017-18 and ranged from 46.12 to 63.98 mm and 47.01 to 63.77 mm respectively (Table 4.91a). In both years the longest fruit was found in 2016/TODVAR-1 with polar diameter of 63.98 and 63.77 mm. This was followed by 2016/TODVAR-5 (56.05 mm) and 2016/TODVAR-12 (55.13 mm) in 2016-17 and 2016/TODVAR-3 (58.59 mm) and 2016/TODVAR-5 (57.98 mm) in 2017-18. In 2016-17 2016/TODVAR-4 (55.00 mm) and 2016/TODVAR-12 (55.13 mm) were at par with 2016/TODVAR-5 (56.05 mm) whereas 2016/TODVAR-12 (56.59 mm), 2016/TODVAR-4 (56.62 mm) and 2016/TODVAR-5 (57.98 mm) were at par with 2016/TODVAR-3 (58.59 mm) in 2017-18. However in both the years the lowest fruit height (46.12 and 47.01 mm) was obtained from 2016/TODVAR-6. The pooled mean of both the years (2016-17 and 2017-18) displayed significant variation in polar diameter among entries which ranged from 46.56 to 63.87 mm. The longest fruit (63.87 mm) was received from 2016/TODVAR-1 followed by 2016/TODVAR-5 (57.02 mm) and 2016/TODVAR-12 (55.86 mm). However 2016/TODVAR-4 (55.81 mm), 2016/TODVAR-3 (55.83 mm) and 2016/TODVAR-12 (55.86 mm) were at par with 2016/TODVAR-5 (57.02 mm). The lowest fruit height (46.56 mm) was obtained from 2016/TODVAR-6.

A significant variation was observed in the number of locules among evaluated entries in both the years 2016-17 and 2017-18 (Table 4.91a). The number of locules ranged from 2.53 to 6.20 and 2.47 to 6.07 in 2016-17 and 2017-18 respectively. In both years the maximum number of locules (6.20 and 6.07) was observed from 2016/TODVAR-7. This was followed by 2016/TODVAR-11 (4.93 and 5.07) and 2016/TODVAR-12 (4.67 and 4.70) and also both of these were at par with each other. In both years the minimum number of locules (2.53 and 2.44)

was recorded in 2016/TODVAR-5. The pooled mean data of both years exhibited significant variation in number of locules among entries and ranged from 2.50 to 6.13. The maximum number of locules (6.13) was observed in 2016/TODVAR-7 followed by 2016/TODVAR-11 (5.00) and 2016/TODVAR-12 (4.70) and minimum was found in 2016/TODVAR- (2.50). However 2016/TODVAR-10 (4.20) and 2016/TODVAR-6 (4.37) were at par with each other.

A significant variation was observed on pericarp thickness among evaluated entries in both the years 2016-17 and 2017-18 (Table 4.91b). The pericarp thickness ranged from 4.77 to 6.53 and 4.93 to 6.73 mm in 2016-17 and 2017-18. During 2016-17 the maximum (6.53 mm) pericarp thickness was observed in 2016/TODVAR-10 followed by 2016/TODVAR-1 (6.52 mm) and 2016/TODVAR-2 (6.40 mm). However entry 2016/TODVAR-8 produced fruits of thin pericarp (4.77 mm). 2016/TODVAR-2 and 2016/TODVAR-1 were at par with 2016/TODVAR-10. In 2017-18 entry 2016/TODVAR-1 produced fruits with thick pericarp (6.73 mm) which was followed by 2016/TODVAR-10 (6.55 mm) and 2016/TODVAR-2 (6.21 mm). The minimum (4.93 mm) pericarp thickness was recorded in 2016/TODVAR-8 (4.93 mm) whereas 2016/TODVAR-10 and 2016/TODVAR-1 were at par with each other. The pooled mean of both years showed significant variation in pericarp thickness among the entries and ranged from 4.85 to 6.62 mm. The maximum (6.62 mm) pericarp thickness was noted in 2016/TODVAR-1 followed by 2016/TODVAR-10 (6.54 mm) and 2016/TODVAR-2 (6.31 mm). Fruits with thin (4.85 mm) pericarp were obtained from 2016/TODVAR-8 whereas 2016/TODVAR-1 and 2016/TODVAR-10 were at par with each other for pericarp thickness.

The TSS content in fruits of eleven 2016/ToDVAR entries evaluated was significantly ranged from 3.09 to 4.53 and 3.56 to 4.63 °Brix in 2016-17 and 2017-18 respectively (Table 4.91b). In both the experimental seasons the maximum total soluble solids content (4.53 and 4.63 °Brix) was recorded in 2016/TODVAR-4 followed by 2016/TODVAR-1 (4.50 and 4.58 °Brix) and 2016/TODVAR-5 (4.21 and 4.33 °Brix). In both years the minimum total soluble solids content (3.09 and 3.56 °Brix) was recorded in 2016/TODVAR-3 whereas 2016/TODVAR-1 and 2016/TODVAR-1 were at par with each other. The pooled mean of 2016-17 and

Table 4.91a: Quality parameters of 2016/TODVAR entries

Entry	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/TODVAR-1	51.04	53.25	52.14	63.98	63.77	63.87	3.13	2.93	3.03
2016/TODVAR-2	51.34	54.49	52.91	48.15	50.48	49.32	3.20	3.33	3.27
2016/TODVAR-3	58.73	62.57	60.65	53.06	58.59	55.83	3.73	3.53	3.63
2016/TODVAR-4	49.04	48.85	48.95	55.00	56.62	55.81	2.73	2.80	2.77
2016/TODVAR-5	57.10	58.19	57.64	56.05	57.98	57.02	2.53	2.47	2.50
2016/TODVAR-6	48.97	49.93	49.45	46.12	47.01	46.56	4.33	4.40	4.37
2016/TODVAR-7	64.35	68.05	66.20	47.00	51.33	49.16	6.20	6.07	6.13
2016/TODVAR-8	47.98	48.77	48.38	48.11	47.16	47.64	2.73	2.60	2.67
2016/TODVAR-10	60.97	60.83	60.90	53.13	54.05	53.59	4.20	4.20	4.20
2016/TODVAR-11	55.03	57.39	56.21	51.01	53.61	52.31	4.93	5.07	5.00
2016/TODVAR-12	63.31	65.41	64.36	55.13	56.59	55.86	4.67	4.73	4.70
Sem±	1.462	1.435	0.891	0.819	1.211	0.806	0.088	0.109	0.069
CD (p=0.05)	4.314*	4.232*	2.628*	2.416*	3.571*	2.377*	0.261*	0.322*	0.204*
CV	4.584	4.354	2.747	2.706	3.862	2.616	3.968	4.937	3.112

Table 4.91b: Quality parameters of 2016/TODVAR entries

Entry	Pericarp thickness (mm)			TSS (Brix %)			Fruit shape	Fruit colour
	2016-17	2017-18	Mean	2016-17	2017-18	Mean		
2016/TODVAR-1	6.52	6.73	6.62	4.50	4.58	4.54	Oval - oblong	Red - Deep red
2016/TODVAR-2	6.40	6.21	6.31	3.82	3.91	3.86	Round	Red - Deep red
2016/TODVAR-3	5.25	5.06	5.15	3.09	3.56	3.33	Round	Red
2016/TODVAR-4	5.61	5.87	5.74	4.53	4.63	4.58	Oblong	Red - Deep red
2016/TODVAR-5	5.81	5.70	5.76	4.21	4.33	4.27	Round	Light red - Red
2016/TODVAR-6	6.01	6.11	6.06	4.02	4.09	4.05	Round	Red - Deep red
2016/TODVAR-7	5.82	5.40	5.61	4.01	4.35	4.18	Round	Red - Deep red
2016/TODVAR-8	4.77	4.93	4.85	4.11	4.09	4.10	Round	Red - Deep red
2016/TODVAR-10	6.53	6.55	6.54	3.81	3.93	3.87	Round	Red - Deep red
2016/TODVAR-11	5.76	5.68	5.72	3.91	4.03	3.97	Round	Red - Deep red
2016/TODVAR-12	5.03	5.16	5.09	4.12	4.29	4.20	Round	Light red - Deep red
Sem±	0.076	0.109	0.071	0.060	0.097	0.060		
CD (p=0.05)	0.225*	0.323*	0.210*	0.176*	0.286*	0.178*		
CV	2.284	3.287	2.138	2.578	4.030	2.562		

2017-18 also showed significant variation in total soluble solids content (TSS) among the entries and ranged from 3.33 to 4.58 °Brix. The maximum total soluble solids content (4.58 °Brix) was obtained in 2016/TODVAR-4 followed by 2016/TODVAR-1 (4.54 °Brix) and 2016/TODVAR-5 (4.27 °Brix). The minimum total soluble solids content (3.33 °Brix) was recorded in 2016/TODVAR-3 whereas 2016/TODVAR-1 and 2016/TODVAR-4 were at par with each other.

One (2016/ToDVAR-1) out of eleven entries was oval to oblong shaped another one (2016/ToDVAR-4) was oblong shaped and rest of the 2016/ToDVAR entries was either round or flattish round in shape. In case of colour one (2016/ToDVAR-5) was light red to red colour, one (2016/ToDVAR-3) was red and another one (2016/ToDVAR-12) was light red to deep red in colour and remaining others were red to deep red in colour (Table 4.91b).

4.4.6.6 Other parameters of 2016/ToDVAR entries/ varieties

Some other parameters such as Plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF) were recorded for each and every entry during 2016-17 and 2017-18 and presented in Table 4.92a and 4.92b.

Data presented in Table 4.92a showed significant variation in plant height of entries significantly ranged from 33.41 to 61.40 and 35.34 to 63.91 cm in 2016-17 and 2017-18 respectively. In both years the maximum plant height (61.40 and 63.91 cm) was recorded in 2016/ToDVAR-5. This was followed by 2016/ToDVAR-1 (53.97 cm) and 2016/ToDVAR-7 (53.69 cm) in 2016-17 and 2016/ToDVAR-7 (57.01 cm) and 2016/ToDVAR-3 (56.17 cm) in 2017-18. 2016/ToDVAR-12 (47.91 cm), 2016/ToDVAR-3 (50.92 cm) and 2016/ToDVAR-7 (53.69 cm) were at par with 2016/ToDVAR-1 (53.97 cm) in 2016-17 whereas 2016/ToDVAR-7 (57.01 cm) and 2016/ToDVAR-5 (63.91 cm) were at par with each other. The lowest plant height was registered in 2016/ToDVAR-2 (33.41 cm) and 2016/ToDVAR-4 (35.34 cm) in 2016-17 and 2017-18 respectively. The pooled mean of both years exhibited that significant highest (62.65 cm) plant height was recorded in 2016/ToDVAR-5 followed by 2016/ToDVAR-7 (55.35 cm) and

2016/ToDVAR-1 (54.10 cm). The lowest (34.74 cm) plant height was noted in 2016/ToDVAR-2. However 2016/ToDVAR-3 (53.55 cm) and 2016/ToDVAR-1 (54.10 cm) were at par with 2016/ToDVAR-7 (55.35 cm).

The number of primary branches plant⁻¹ varied significantly from 4.80 to 7.40 and 4.93 to 7.40 in 2016-17 and 2017-18 respectively (Table 4.92a). In both years the highest (7.40) number of branches was observed in 2016/ToDVAR-5 followed by 2016/ToDVAR-11 (7.13 and 7.27) and 2016/ToDVAR-1 (6.80 and 6.93) however the least number of branches (4.80 and 4.93) were observed in 2016/ToDVAR-6. The number of primary branches of 2016/ToDVAR-1 and 2016/ToDVAR-11 were at par with 2016/ToDVAR-5 in 2016-17 whereas 2016/ToDVAR-3 (6.73), 2016/ToDVAR-2 (6.80), 2016/ToDVAR-1 (6.93) and 2016/ToDVAR-11 (7.27) were at par with 2016/ToDVAR-5 (7.40). It was revealed from the pooled mean of 2016-17 and 2017-18 that among all the 2016/ToDVAR entries evaluated the significant highest (7.40) number of primary branches plant⁻¹ was found in 2016/ToDVAR-5 followed by 2016/ToDVAR-11 (7.20) and 2016/ToDVAR-1 (6.87). The least number of branches were recorded from 2016/ToDVAR-6 (4.87) however 2016/ToDVAR-1 and 2016/ToDVAR-11 were at par with 2016/ToDVAR-5.

The number of secondary branches plant⁻¹ varied significantly from 4.47 to 9.73 and 4.53 to 9.67 in 2016-17 and 2017-18 respectively (Table 4.92a). In both years the highest (9.73 and 9.67) number of secondary branches was observed in 2016/ToDVAR-1 followed by 2016/ToDVAR-5 (9.27 and 9.40) and 2016/ToDVAR-7 (8.53 and 8.93). The least number of branches were recorded in 2016/ToDVAR-10 (4.47 and 4.53). Number of secondary branches of 2016/ToDVAR-1 and 2016/ToDVAR-5 were at par with each other in 2016-17 whereas 2016/ToDVAR-7 and 2016/ToDVAR-5 were at par with 2016/ToDVAR-1 in 2017-18. It was revealed from the pooled mean of 2016-17 and 2017-18 that among all the 2016/ToDVAR entries evaluated the significant highest (9.70) number of secondary branches plant⁻¹ was found in 2016/ToDVAR-1 followed by 2016/ToDVAR-5 (9.33) and 2016/ToDVAR- (8.73). The least number of branches were recorded in 2016/ToDVAR-10 (4.50) whereas 2016/ToDVAR-1 and 2016/ToDVAR-5 were at par with each other.

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.92b. In both years days to first flowering significantly varied from 23.33 to 30.33 days and 22.67 to 30.67 days in 2016-17 and 2017-18 respectively. In both years the minimum (23.33 and 22.67 days) days to first flowering were observed in 2016/ToDVAR-5 and 2016/ToDVAR-12. This was followed by 2016/ToDVAR-10 (24 days) and 2016/ToDVAR-8 (25.00 days) in 2016-17 and 2016/ToDVAR-10 (23.33 days) and 2016/ToDVAR-7 (24.67 days) in 2017-18. However 2016/ToDVAR-5, 2016/ToDVAR-10 and 2016/ToDVAR-12 were at par with each other in both year and the maximum (30.33 and 30.67 days) days to first flowering were observed in 2016/ToDVAR-4. It was revealed from the pooled mean of 2016-17 and 2017-18 that among all the 2016/ToDVAR entries evaluated the significant lowest (23.00 days) days to first flowering were recorded in 2016/ToDVAR-5 followed by 2016/ToDVAR-10 (23.67) and 2016/ToDVAR-7 (25.00 days) and maximum (30.50 days) was observed in 2016/ToDVAR-5.

The days to 50% flowering significantly ranged from 30.67 to 42.67 and 29.67 to 43.67 days in 2016-17 and 2017-18 respectively (Table 4.92b). In both years the minimum (30.67 and 29.67 days) days to 50% flowering were observed in 2016/ToDVAR-5 followed by 2016/ToDVAR-12 (31.33 days) and 2016/ToDVAR-10 (32.67 and 32.00 days) whereas maximum (42.67 and 43.67 days) days to 50% flowering were observed in 2016/ToDVAR-4. Days to 50% flowering of 2016/ToDVAR-5 and 2016/ToDVAR-12 were at par with each other in 2016-17 however 2016/ToDVAR-5 and 2016/ToDVAR-10 were at par with each other in 2017-18. It was revealed from the pooled mean of 2016-17 and 2017-18 that among all the 2016/ToDVAR entries evaluated the significant least (30.17 days) days to 50% flowering were observed in 2016/ToDVAR-5 followed by 2016/ToDVAR-12 (31.33 days) and 2016/ToDVAR-10 (32.33 days) and also these two entries were at par with each other. The maximum (43.17 days) days to 50% flowering were observed in 2016/ToDVAR-4.

The days to first fruiting significantly ranged from 29.00 to 40.00 days and 29.00 to 40.33 days in 2016-17 and 2017-18 respectively (Table 4.92b). In both years the minimum (29.00 days) days to first fruiting were observed in 2016/ToDVAR-5. This was followed by 2016/ToDVAR-12 (29.67 days) and

Table 4.92a: Other parameters of 2016/TODVAR entries

Entry	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/TODVAR-1	53.97	54.23	54.10	6.80	6.93	6.87	9.73	9.67	9.70
2016/TODVAR-2	33.41	36.07	34.74	6.67	6.80	6.73	8.00	8.13	8.07
2016/TODVAR-3	50.92	56.17	53.55	6.13	6.73	6.43	6.13	6.60	6.37
2016/TODVAR-4	35.27	35.34	35.31	6.07	6.13	6.10	4.60	4.53	4.57
2016/TODVAR-5	61.40	63.91	62.65	7.40	7.40	7.40	9.27	9.40	9.33
2016/TODVAR-6	41.44	42.03	41.74	4.80	4.93	4.87	7.13	7.40	7.27
2016/TODVAR-7	53.69	57.01	55.35	5.53	6.00	5.77	8.53	8.93	8.73
2016/TODVAR-8	40.04	41.17	40.60	5.80	5.93	5.87	6.13	6.07	6.10
2016/TODVAR-10	41.83	42.11	41.97	5.40	5.47	5.43	4.47	4.53	4.50
2016/TODVAR-11	40.47	42.08	41.27	7.13	7.27	7.20	7.27	7.33	7.30
2016/TODVAR-12	47.91	50.05	48.98	6.33	6.53	6.43	6.00	6.13	6.07
Sem±	2.309	2.501	1.521	0.287	0.265	0.195	0.325	0.265	0.217
CD (p=0.05)	6.811*	7.379*	4.487*	0.847*	0.782*	0.575*	0.959*	0.783*	0.641*
CV	8.792	9.162	5.680	8.040	7.197	5.371	8.017	6.422	5.303

Table 4.92b: Other parameters of 2016/TODVAR entries

Entry	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
2016/TODVAR-1	29.33	30.00	29.67	42.33	41.67	42.00	39.67	40.33	40.00
2016/TODVAR-2	27.33	26.67	27.00	36.33	35.67	36.00	35.67	35.33	35.50
2016/TODVAR-3	25.33	26.00	25.67	35.67	36.00	35.83	34.00	34.67	34.33
2016/TODVAR-4	30.33	30.67	30.50	42.67	43.67	43.17	40.00	40.33	40.17
2016/TODVAR-5	23.33	22.67	23.00	30.67	29.67	30.17	29.00	29.00	29.00
2016/TODVAR-6	26.33	27.00	26.67	35.33	36.33	35.83	33.67	34.33	34.00
2016/TODVAR-7	25.33	24.67	25.00	33.67	33.33	33.50	32.33	31.67	32.00
2016/TODVAR-8	25.00	25.67	25.33	35.33	35.67	35.50	34.00	33.67	33.83
2016/TODVAR-10	24.00	23.33	23.67	32.67	32.00	32.33	30.33	29.33	29.83
2016/TODVAR-11	25.33	26.00	25.67	36.33	35.67	36.00	33.00	33.67	33.33
2016/TODVAR-12	23.33	22.67	23.00	31.33	31.33	31.33	29.67	29.33	29.50
Sem±	0.437	0.546	0.328	0.451	0.348	0.349	0.547	0.417	0.383
CD (p=0.05)	1.289*	1.610*	0.966*	1.329*	1.027*	1.029*	1.613*	1.230*	1.129*
CV	2.921	3.645	2.189	2.188	1.696	1.697	2.806	2.137	1.963

2016/ToDVAR-10 (30.33 days) in 2016-17 and 2016/ToDVAR-10 and 2016/ToDVAR-12 (29.33 days) in 2017-18. In both years 2016/ToDVAR-10 and 2016/ToDVAR-12 were at par with each other whereas the maximum (40.00 and 40.33 days) days to first fruiting were observed in 2016/ToDVAR-4. It was revealed from pooled mean of 2016-17 and 2017-18 that among all the 2016/ToDVAR entries evaluated the significant least (29.00 days) days to first fruiting were observed in 2016/ToDVAR-5 followed by 2016/ToDVAR-12 (29.50 days) and 2016/ToDVAR-10 (29.83 days) and also these were at par with each other. However the maximum (40.17 days) days to first fruiting were observed in 2016/ToDVAR-4.

4.4.6.7 Overall performance of 2016/ToDVAR entries/ varieties

The overall performance of all the 2016/ToDVAR entries were analyzed for both the years 2016-17 and 2017-18 and presented in Table 4.93 to 4.95.

It was visible from the experimental data presented in Table 4.93 that in 2016-17 2016/TODVAR-12 gave best overall performance and found to be resistant against ToLCD with maximum yield (343.13 q ha^{-1}). This was followed by 2016/TODVAR-5 and 2016/TODVAR-10 that showed resistant and moderately resistant reaction with yield of 330.11 and 289.12 q ha^{-1} respectively. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2016/TODVAR-12 with average fruit weight of 83.08 g followed by 2016/TODVAR-3 (81.32 g) and 2016/TODVAR-7 (80.08 g). The largest round fruits were recorded in 2016/TODVAR-7 with equatorial diameter of 64.35 mm followed by 2016/TODVAR-12 (63.31 mm) and 2016/TODVAR-10 (60.97 mm). However 2016/TODVAR-1 was recorded for the longest fruit with polar diameter of 63.98 mm followed by 2016/TODVAR-5 (56.05 mm) and 2016/TODVAR-12 (55.13 mm). 2016/TODVAR-10 had the maximum (6.53 mm) pericarp thickness followed by 2016/TODVAR-1 (6.52 mm) and 2016/TODVAR-2 (6.40 mm). In case of TSS the maximum total soluble solids content (4.53 °Brix) was found in 2016/TODVAR-4 followed by 2016/TODVAR-1 (4.50 °Brix) and 2016/TODVAR-5 (4.21 °Brix). However the minimum (29.00

days) days to first fruiting were observed in 2016/TODVAR-5 followed by 2016/TODVAR-12 (29.67 days) and 2016/TODVAR-10 (30.33 days).

It was revealed from the Table 4.94 that in 2017-18 2016/TODVAR-12 attained best overall performance followed by 2016/TODVAR-5 and 2016/TODVAR-10. These entries showed resistant reaction with yield of 345.03, 334.03 and 301.62 q ha⁻¹ respectively. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2016/TODVAR-12 with average fruit weight of 83.16 g followed by 2016/TODVAR-3 (82.02 g) and 2016/TODVAR-7 (81.08 g). The largest round fruits were recorded in 2016/TODVAR-7 with equatorial diameter of 68.05 mm followed by 2016/TODVAR-12 (65.41 mm) and 2016/TODVAR-3 (62.57 mm). However the longest fruit (63.77 mm) was found in 2016/TODVAR-1 followed by 2016/TODVAR-3 (58.59 mm) and 2016/TODVAR-5 (57.98 mm). 2016/TODVAR-1 had the maximum (6.73 mm) pericarp thickness followed by 2016/TODVAR-10 (6.55 mm) and 2016/TODVAR-2 (6.21 mm). In case of TSS the maximum total soluble solids content (4.63 °Brix) was found in 2016/TODVAR-4 followed by 2016/TODVAR-1 (4.58 °Brix) and 2016/TODVAR-7 (4.35 °Brix). However the minimum (29.00 days) days to first fruiting were observed in 2016/TODVAR-5 followed by 2016/TODVAR-10 and 2016/TODVAR-12 (29.33 days).

It was revealed from the average of both the years (2016-17 and 2017-18) that 2016/TODVAR-12 attained best overall performance followed by 2016/TODVAR-5 and 2016/TODVAR-10 (Table 4.95). These entries showed resistant reaction with yield of 344.08, 332.07 and 295.37 q ha⁻¹ respectively. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2016/TODVAR-12 with average fruit weight of 83.12 g followed by 2016/TODVAR-3 (81.67 g) and 2016/TODVAR-7 (80.58 g). The largest round fruits were recorded in 2016/TODVAR-7 with equatorial diameter of 66.20 mm followed by 2016/TODVAR-12 (64.36 mm) and 2016/TODVAR-10 (60.90 mm). However the longest fruit (63.87 mm) was obtained from 2016/TODVAR-1 followed by 2016/TODVAR-5 (57.02 mm) and 2016/TODVAR-12 (55.86 mm). 2016/TODVAR-1 had the maximum (6.62 mm)

Table 4.93: Overall performance of 2016/TODVAR entries in 2016-17

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/TODVAR-1	90.78	69.66	S	77.41	136.95	51.04	63.98	6.52	4.50	39.67
2016/TODVAR-2	85.94	63.48	S	74.24	177.01	51.34	48.15	6.40	3.82	35.67
2016/TODVAR-3	84.69	63.26	S	81.32	207.52	58.73	53.06	5.25	3.09	34.00
2016/TODVAR-4	90.93	69.36	S	80.07	122.27	49.04	55.00	5.61	4.53	40.00
2016/TODVAR-5	17.03	10.63	R	72.31	330.11	57.10	56.05	5.81	4.21	29.00
2016/TODVAR-6	84.89	63.61	S	64.07	151.41	48.97	46.12	6.01	4.02	33.67
2016/TODVAR-7	85.70	63.35	S	80.08	178.87	64.35	47.00	5.82	4.01	32.33
2016/TODVAR-8	87.07	65.50	S	55.13	190.19	47.98	48.11	4.77	4.11	34.00
2016/TODVAR-10	25.59	16.79	MR	77.92	289.12	60.97	53.13	6.53	3.81	30.33
2016/TODVAR-11	65.96	46.46	S	73.96	160.37	55.03	51.01	5.76	3.91	33.00
2016/TODVAR-12	19.06	12.93	R	83.08	343.13	63.31	55.13	5.03	4.12	29.67
Sem±				1.988	9.739	1.462	0.819	0.076	0.060	0.547
CD (p=0.05)				5.865*	28.731*	4.314*	2.416*	0.225*	0.176*	1.613*
CV				4.622	8.114	4.584	2.706	2.284	2.578	2.806

Table 4.94: Overall performance of 2016/TODVAR entries in 2017-18

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/TODVAR-1	87.64	65.94	S	77.52	141.20	53.25	63.77	6.73	4.58	40.33
2016/TODVAR-2	73.10	50.84	S	74.93	185.07	54.49	50.48	6.21	3.91	35.33
2016/TODVAR-3	51.64	34.18	MS	82.02	235.65	62.57	58.59	5.06	3.56	34.67
2016/TODVAR-4	92.41	68.26	S	80.01	122.62	48.85	56.62	5.87	4.63	40.33
2016/TODVAR-5	10.56	6.72	R	72.44	334.03	58.19	57.98	5.70	4.33	29.00
2016/TODVAR-6	74.43	52.48	S	64.68	155.67	49.93	47.01	6.11	4.09	34.33
2016/TODVAR-7	52.41	35.76	MS	81.08	210.65	68.05	51.33	5.40	4.35	31.67
2016/TODVAR-8	81.19	60.65	S	55.17	195.37	48.77	47.16	4.93	4.09	33.67
2016/TODVAR-10	20.59	13.82	R	77.95	301.62	60.83	54.05	6.55	3.93	29.33
2016/TODVAR-11	50.10	34.99	MS	74.33	169.17	57.39	53.61	5.68	4.03	33.67
2016/TODVAR-12	12.22	6.49	R	83.16	345.03	65.41	56.59	5.16	4.29	29.33
Sem±				1.780	10.946	1.435	1.211	0.109	0.097	0.417
CD (p=0.05)				5.250*	32.289*	4.232*	3.571*	0.323*	0.286*	1.230*
CV				4.118	8.703	4.354	3.862	3.287	4.030	2.137

Table 4.95: Overall performance of 2016/TODVAR entries in both the years (2016-17 and 2017-18)

Entry	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2016/TODVAR-1	89.21	67.80	S	77.47	139.08	52.14	63.87	6.62	4.54	40.00
2016/TODVAR-2	79.52	57.16	S	74.59	181.04	52.91	49.32	6.31	3.86	35.50
2016/TODVAR-3	68.16	48.72	S	81.67	221.59	60.65	55.83	5.15	3.33	34.33
2016/TODVAR-4	91.67	68.81	S	80.04	122.44	48.95	55.81	5.74	4.58	40.17
2016/TODVAR-5	13.80	8.68	R	72.37	332.07	57.64	57.02	5.76	4.27	29.00
2016/TODVAR-6	79.66	58.05	S	64.38	153.54	49.45	46.56	6.06	4.05	34.00
2016/TODVAR-7	69.06	49.56	S	80.58	194.76	66.20	49.16	5.61	4.18	32.00
2016/TODVAR-8	84.13	63.08	S	55.15	192.78	48.38	47.64	4.85	4.10	33.83
2016/TODVAR-10	23.09	15.31	R	77.94	295.37	60.90	53.59	6.54	3.87	29.83
2016/TODVAR-11	58.03	40.73	S	74.15	164.77	56.21	52.31	5.72	3.97	33.33
2016/TODVAR-12	15.64	9.71	R	83.12	344.08	64.36	55.86	5.09	4.20	29.50
SED				1.811	9.519	1.260	1.140	0.101	0.085	0.541
Sem±				1.281	6.731	0.891	0.806	0.071	0.060	0.383
CD (1%)				5.154**	27.083**	3.584**	3.243**	0.287**	0.243**	1.540**
CD (p=0.05)				3.778*	19.855*	2.628*	2.377*	0.210*	0.178*	1.129*
CV				2.971	5.477	2.747	2.616	2.138	2.562	1.963

Table 4.96: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2016/TODVAR entries

Parameters	Mean	
	Disease incidence	PDI
PDI	0.999 ^{**}	-
No of fruits plant⁻¹	-0.866 ^{**}	-0.868 ^{**}
Fruit yield plant⁻¹ (kg)	-0.961 ^{**}	-0.966 ^{**}
Average fruit weight (g)	-0.283 ^{NS}	-0.290 ^{NS}
Marketable yield q ha⁻¹	-0.933 ^{**}	-0.929 ^{**}
Unmarketable yield q ha⁻¹	-0.694 ^{**}	-0.694 ^{**}
Total yield (q ha⁻¹)	-0.946 ^{**}	-0.942 ^{**}
Equatorial diameter of fruit (mm)	-0.646 [*]	-0.661 [*]
Polar diameter of fruit (mm)	-0.180 ^{NS}	-0.153 ^{NS}
Number of locules fruit⁻¹	-0.175 ^{NS}	-0.202 ^{NS}
Thickness of pericarp (mm)	0.079 ^{NS}	0.083 ^{NS}
TSS (% Brix)	0.131 ^{NS}	0.164 ^{NS}
Plant height (cm)	-0.423 ^{NS}	-0.413 ^{NS}
No. of primary branches plant⁻¹	-0.218 ^{NS}	-0.215 ^{NS}
No. of secondary branches plant⁻¹	0.078 ^{NS}	0.078 ^{NS}
First flowering (DAT)	0.843 ^{**}	0.853 ^{**}
50 per cent flowering (DAT)	0.821 ^{**}	0.835 ^{**}
First fruiting (DAT)	0.863 ^{**}	0.875 ^{**}



Fig 4.35: Experimental plots of 2014/TODVAR entries



Fig 4.36: Experimental plots of 2016/TODVAR entries

pericarp thickness followed by 2016/TODVAR-10 (6.54 mm) and 2016/TODVAR-2 (6.31 mm). In case of TSS the maximum total soluble solids content (4.58 °Brix) was found in 2016/TODVAR-4 followed by 2016/TODVAR-1 (4.54 °Brix) and 2016/TODVAR-5 (4.27 °Brix). However the minimum (29.00 days) days to first fruiting were observed in 2016/TODVAR-5 followed by 2016/TODVAR-12 (29.50 days) and 2016/TODVAR-10 (29.83 days).

4.4.6.8 Correlation of leaf curl disease with different parameters of 2016/TODVAR entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2016/TODVAR entries/ varieties for the year 2016-17 and 2017-18 and presented in table 4.96. Percent disease index of leaf curl significant and negatively correlated with number of fruits plant⁻¹ ($r = -0.868$, $p = 0.001$), fruit yield plant⁻¹ ($r = -0.966$, $p = 0.001$), marketable yield q ha⁻¹ ($r = -0.929$, $p = 0.001$), unmarketable yield q ha⁻¹ ($r = -0.694$, $p = 0.001$), total yield ($r = -0.942$, $p = 0.001$) and equatorial diameter of fruit ($r = -0.661$, $p = 0.005$). It was also revealed from the data that first flowering ($r = 0.853$, $p = 0.001$), 50 percent flowering ($r = 0.835$, $p = 0.001$) and first fruiting ($r = 0.875$, $p = 0.001$) expressed significant positive correlation with percent disease index of leaf curl. However rest other parameters showed either non significant positive or negative correlation with percent disease index.

4.4.7 2015/TOCVAR entries/ varieties

A sum of seven 2015/TOCVAR entries/ varieties were evaluated against tomato leaf curl disease (ToLCD) during *rabi* 2015-16 and 2016-17 and results were presented in Table 4.97a to 4.98b (Fig 4.37).

4.4.7.1 Disease incidence and percent disease index (PDI)

Considerable variability was found in incidence and percent disease index (PDI) of all 2015/TOCVAR entries/ varieties evaluated. During 2015-16 disease incidence was varied from 0.0 to 3.78, 0.0 to 10.51, 4.48 to 21.82, 9.06 to 36.87, 19.40 to 61.25 and 36.07 to 90.04 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The percent disease index (PDI) was varied

from 0.0 to 2.34, 0.0 to 6.74, 2.09 to 15.19, 6.28 to 27.09, 13.30 to 45.82 and 24.67 to 68.84 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Only one entry viz. 2015/TOCVAR-5 was free from the disease up to 30 days after transplanting but in the rest other, symptoms of tomato leaf curl was appeared either 15 or 30 days after transplanting (Table 4.97a – 4.98b).

However, during 2016-17 disease incidence was varied from 0.0 to 1.59, 0.0 to 4.84, 4.88 to 21.74, 12.21 to 38.70, 20.48 to 66.94 and 26.16 to 81.48 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The calculated percent disease index (PDI) was varied from 0.0 to 0.68, 0.0 to 2.99, 3.02 to 14.11, 7.57 to 28.78, 13.00 to 51.49 and 19.16 to 63.72 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The entry 2015/TOCVAR-4 was free from the disease up to 30 days after transplanting but others showed first symptoms of tomato leaf curl disease either 15 or 30 DAT (Table 4.97a – 4.98b).

During 2015-16 at 90 DAT the lowest percent incidence and PDI was recorded in 2015/TOCVAR-5 (36.07, 24.67 %) followed by 2015/TOCVAR-1 (47.19, 34.71 %). The highest infection of leaf curl was recorded in Swarna Ratan with incidence and percent disease index of 90.04 and 68.84 percent respectively (Table 4.97a – 4.98b).

Whereas during 2016-17 at 90 DAT the lowest percent incidence was noted in 2015/TOCVAR-4 (26.16, 19.16 %) followed by 2015/TOCVAR-3 (47.03, 33.84 %). However the maximum disease incidence and percent disease index of leaf curl was recorded in Swarna Ratan (81.48, 63.72 %) (Table 4.97a – 4.98b).

4.4.7.2 Reaction and level of resistance of 2015/TOCVAR entries/ varieties of tomato against ToLCD

Among the seven entries/ varieties evaluated during 2015-16 and 2016-17 none of the entry found resistant against tomato leaf curl disease in both the years. However in 2015-16 one entry (2015/TOCVAR-5) showed moderately resistant reaction and another one (2015/TOCVAR-1) exhibited moderately susceptible reaction and remaining four entries viz. 2015/TOCVAR-2, 2015/TOCVAR-3, 2015/TOCVAR-6 and Swarna Ratan showed susceptible reaction which were kept under rating 7 (Table 4.99).

Table 4.97a: Percent incidence of tomato leaf curl disease in 2015/TOCVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)					
	15		30		45	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	0.63	0.79	4.69	4.01	12.14	16.30
2015/TOCVAR-2	1.36	0.79	6.22	2.42	15.21	15.48
2015/TOCVAR-3	0.00	0.00	3.96	0.79	9.31	9.68
2015/TOCVAR-4	-	0.00	-	0.00	-	4.88
2015/TOCVAR-5	0.00	0.79	0.00	3.38	4.48	19.16
2015/TOCVAR-6	3.78	-	9.25	-	21.82	-
Swarna Ratan	3.22	1.59	10.51	4.84	21.71	21.74

Table 4.97b: Percent incidence of tomato leaf curl disease in 2015/TOCVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)					
	60		75		90	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	22.56	27.66	35.58	38.95	47.19	53.54
2015/TOCVAR-2	25.63	27.83	40.88	42.13	56.55	57.85
2015/TOCVAR-3	17.55	21.86	30.57	34.06	57.34	47.03
2015/TOCVAR-4	-	12.21	-	20.48	-	26.16
2015/TOCVAR-5	9.06	35.90	19.40	59.61	36.07	74.57
2015/TOCVAR-6	34.08	-	54.22	-	80.54	-
Swarna Ratan	36.87	38.70	61.25	66.94	90.04	81.48

Table 4.98a: Evaluation of 2015/TOCVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)					
	15		30		45	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	0.09	0.11	3.16	1.93	7.36	11.15
2015/TOCVAR-2	0.97	0.11	3.45	1.28	9.90	10.83
2015/TOCVAR-3	0.00	0.00	1.55	0.11	5.56	6.69
2015/TOCVAR-4	-	0.00	-	0.00	-	3.02
2015/TOCVAR-5	0.00	0.57	0.00	2.16	2.09	11.98
2015/TOCVAR-6	2.34	-	5.83	-	15.19	-
Swarna Ratan	2.30	0.68	6.74	2.99	15.12	14.11

Table 4.98b: Evaluation of 2015/TOCVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)						Reaction (at final observation)	
	60		75		90		2015-16	2016-17
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17		
2015/TOCVAR-1	15.37	18.60	25.63	29.22	34.71	40.57	MS	S
2015/TOCVAR-2	17.54	19.90	29.20	31.25	40.78	44.14	S	S
2015/TOCVAR-3	12.31	14.46	21.84	24.33	40.92	33.84	S	MS
2015/TOCVAR-4	-	7.57	-	13.00	-	19.16	-	MR
2015/TOCVAR-5	6.28	23.89	13.30	44.31	24.67	56.74	MR	S
2015/TOCVAR-6	24.52	-	40.45	-	60.19	-	S	-
Swarna Ratan	27.09	28.78	45.82	51.49	68.84	63.72	S	S

Table 4.99: Classification of 2015/TOCVAR entries in different reaction categories

Year	Reaction category	No. of entry/ variety	Name of entry/ variety
Entries/ varieties with constant reaction in both the years 2015-16	Resistant	0	
	Moderately resistant	1	2014/TOCVAR-5
	Moderately susceptible	0	
	Susceptible	3	2014/TOCVAR-2, 2014/TOCVAR-3, 2014/TOCVAR-6
	Resistant	0	
	Moderately resistant	1	2015/TOCVAR-5
	Moderately susceptible	1	2015/TOCVAR-1
	Susceptible	4	2015/TOCVAR-2, 2015/TOCVAR-3, 2015/TOCVAR-6, Swarna Ratan
	Resistant	0	
	Moderately resistant	1	2015/TOCVAR-4
2016-17	Moderately susceptible	1	2015/TOCVAR-3
	Susceptible	4	2015/TOCVAR-1, 2015/TOCVAR-2, 2015/TOCVAR-5, Swarna Ratan

In 2016-17 one entry (2015/TOCVAR-4) showed moderately resistant reaction and another one (2015/TOCVAR-3) exhibited moderately susceptible reaction and remaining four entries viz. 2015/TOCVAR-1, 2015/TOCVAR-2, 2015/TOCVAR-5 and Swarna Ratan were shown susceptible reaction with rating 7 (Table 4.99).

4.4.7.3 Yield parameters of 2015/TOCVAR entries/ varieties

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ and average fruit weight were worked out during 2015-16 and 2016-17 and presented in Table 4.100.

During 2015-16 the number of fruits plant⁻¹ significantly ranged from 131.57 to 201.02 (Table 4.100). The significant maximum number of fruits plant⁻¹ (201.02) was recorded in Swarna Ratan followed by 2015/TOCVAR-1 (161.47). The lowest number of fruits plant⁻¹ (131.57) was recorded in 2015/TOCVAR-6 whereas 2015/TOCVAR-1 and 2015/TOCVAR-3 were at par with each other. During 2016-17 the number of fruits plant⁻¹ significantly ranged from 126.21 to 209.11. The significant maximum number of fruits plant⁻¹ (209.11) was recorded in Swarna Ratan followed by 2015/TOCVAR-4 (169.71). The lowest number of fruits plant⁻¹ (126.21) was recorded in 2015/TOCVAR-5 whereas 2015/TOCVAR-3 and 2015/TOCVAR-4 were at par with each other.

The significant variation was observed in fruit yield plant⁻¹ of 2015/TOCVAR entries and ranged from 0.79 to 1.46 and 0.75 to 1.52 kg in 2015-16 and 2016-17 respectively (Table 4.100). In both years the significant maximum fruit yield plant⁻¹ was obtained from Swarna Ratan with 1.46 and 1.52 kg fruit plant⁻¹ in 2015-16 and 2016-17 respectively. This was followed by 2015/TOCVAR-5 (1.36 kg) in 2015-16 and 2015/TOCVAR-4 (1.48 kg) in 2016-17. In both years the least (0.79 and 0.75 kg) fruit yield plant⁻¹ was found in 2015/TOCVAR-2. In 2015-16 2015/TOCVAR-5 and Swarna Ratan were at par with each other for per plant fruit yield while 2015/TOCVAR-4 and Swarna Ratan were at par with each in 2016-17.

The significant variation was observed in average fruit weight of 2015/TOCVAR entries which ranged from 5.41 to 8.71 g and 5.41 to 8.72 g in

2015 and 2016-17 respectively (Table 4.100). In 2015-16 the heaviest fruit (8.71 g) was observed in 2015/TOCVAR-5 followed by 2015/TOCVAR-3 (8.38 g) and also both were at par with each other. However in 2016-17 the maximum average fruit weight (8.72 g) was recorded from 2015/TOCVAR-4 followed by 2015/TOCVAR-3 (8.39 g) and also both were at par with each other. In both years the lowest average fruit weight (5.41 g) was noted in 2015/TOCVAR-2.

4.4.7.4 Yield of 2015/TOCVAR entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or entry. Marketable yield ha^{-1} , Unmarketable yield ha^{-1} and Total yield ha^{-1} were computed for all the 2015/TOCVAR entries evaluated in both the years (2015-16 and 2016-17) and depicted in Table 4.101.

The marketable yield ha^{-1} significantly ranged from 141.09 to 262.44 and 118.21 to 299.54 q in 2015-16 and 2016-17 respectively (Table 4.101). In both the years significant maximum marketable yield ha^{-1} (262.44 and 299.54 q) was noted in Swarna Ratan. This was followed by 2015/TOCVAR-5 (252.88 q) and 2015/TOCVAR-4 (280.85 q) in 2015-16 and 2016-17 respectively. In both years the minimum (141.09 and 118.21 q) marketable yield ha^{-1} was recorded in 2015/TOCVAR-2. The marketable yield ha^{-1} of 2015/TOCVAR-5 and Swarna Ratan were at par with each other in 2015-16 however 2015/TOCVAR-4 and Swarna Ratan were at par with each other in 2016-17.

Substantial deviation was observed in unmarketable yield ha^{-1} among the entries evaluated in both the years and significantly ranged from 21.07 to 39.21 and 18.57 to 31.55 q in 2015-16 and 2017-18 (Table 4.101). In 2015-16 the minimum unmarketable yield ha^{-1} (21.07 q) was obtained from 2015/TOCVAR-2 followed by 2015/TOCVAR-6 (22.52 q) however both were at par with each other. In 2016-17 the minimum unmarketable yield ha^{-1} (18.57 q) was obtained from 2015/TOCVAR-5 followed by 2015/TOCVAR-3 (23.25 q). In both years the maximum unmarketable yield ha^{-1} (6.59 and 5.30 q) was observed in Swarna Ratan.

The significant difference was observed in total yield ha^{-1} of entries evaluated during 2015-16 and 2016-17 (Table 4.101). The total yield ha^{-1}

Table 4.100: Yield parameters of 2015/TOCVAR entries

Entry/ variety	No of fruits plant ⁻¹		Fruit yield plant ⁻¹ (kg)		Average fruits weight (g)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	161.47	150.22	1.10	0.93	6.79	6.19
2015/TOCVAR-2	145.32	138.07	0.79	0.75	5.41	5.41
2015/TOCVAR-3	148.14	156.93	1.24	1.32	8.38	8.39
2015/TOCVAR-4	-	169.71	-	1.48	-	8.72
2015/TOCVAR-5	155.61	126.21	1.36	0.82	8.71	6.53
2015/TOCVAR-6	131.57	-	0.86	-	6.53	-
Swarna Ratan	201.02	209.11	1.46	1.52	7.24	7.26
Sem±	4.476	4.244	0.040	0.034	0.128	0.110
CD (p=0.05)	13.491*	12.793*	0.121*	0.104*	0.387*	0.330*
CV	5.695	5.359	7.092	6.066	3.577	3.095

Table 4.101: Yield performance of 2015/TOCVAR entries

Entry/ variety	Marketable yield (q ha ⁻¹)		Unmarketable yield (q ha ⁻¹)		Total yield (q ha ⁻¹)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	207.76	176.01	31.05	26.77	238.81	202.78
2015/TOCVAR-2	141.09	118.21	21.07	24.01	162.19	142.22
2015/TOCVAR-3	214.82	254.46	32.10	23.25	246.93	277.72
2015/TOCVAR-4	-	280.85	-	28.87	-	309.72
2015/TOCVAR-5	252.88	161.13	37.78	18.57	290.65	179.70
2015/TOCVAR-6	150.85	-	22.52	-	173.37	-
Swarna Ratan	262.44	299.54	39.21	31.55	301.64	331.09
Sem±	7.658	9.191	1.472	1.166	9.826	10.763
CD (p=0.05)	23.083*	27.705*	4.436*	3.514*	29.620*	32.444*
CV	7.472	8.548	9.612	9.143	8.342	8.949

significantly ranged from 162.19 to 301.64 and 142.22 to 331.09 q in 2015-16 and 2016-17 respectively. In both years the maximum total yield ha^{-1} (301.64 and 331.09 q) was noted in Swarna Ratan. This was followed by 2015/TOCVAR-5 (290.65 q) and 2015/TOCVAR-4 (309.72 q) in 2015-16 and 2016-17 respectively. 2015/TOCVAR-5 and Swarna Ratan were at par with each other in 2015-16 whereas 2015/TOCVAR-4 and Swarna Ratan were at par with each other in 2016-17. The significant lowest (162.19 and 142.22 q) total yield ha^{-1} was recorded in 2015/TOCVAR-2.

4.4.7.5 Quality parameters of 2015/TOCVAR entries/ varieties

Quality parameters of fruit are one of the important factors that directly or indirectly influence the market value of yield. Quality parameters such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each entry were studied during 2015-16 and 2016-17 and mentioned in Table 4.102a and 4.102b.

The significant difference was noticed in equatorial diameter of fruits. The equatorial diameter of fruits significantly ranged from 17.10 to 26.33 mm in 2015-16 and 16.32 to 29.26 mm in 2016-17 (Table 4.102a). In both years the largest fruit (26.33 and 29.26 mm) was gained from 2015/TOCVAR-3 followed by 2015/TOCVAR-5 (23.75 and 23.74 mm). However 2015/TOCVAR-5 and 2015/TOCVAR-6 were at par with each other. The minimum equatorial diameter was recorded in 2015/TOCVAR-1 with equatorial diameter of 17.10 and 16.32 mm in 2015-16 and 2017-18 respectively.

The significant variation was observed in polar diameter of entries evaluated. During 2015-16 polar diameter ranged from 18.81 to 32.49 mm (Table 4.102a). The longest fruit was obtained from 2015/TOCVAR-5 with polar diameter of 32.49 mm followed by 2015/TOCVAR-1 (27.97 mm). Whereas 2015/TOCVAR-1 and 2015/TOCVAR-3 (25.81 mm) were at par with each other. The significant variation was noticed in polar diameter among the evaluated entries in 2016-17 which ranged from 17.59 to 33.26 mm. The longest fruit (33.26 mm) was recorded from 2015/TOCVAR-4 followed by 2015/TOCVAR-1 (25.38 mm). However 2015/TOCVAR-1 and 2015/TOCVAR-5 (23.91 mm) were at par with

each other. In both years the lowest fruit height (18.81 and 17.59 mm) was obtained from 2015/TOCVAR-2.

The number of locules significantly ranged from 2.08 to 2.85 and 1.95 to 2.90 in 2015-16 and 2016-17 respectively (Table 4.102a). In both years the maximum number of locules (2.85 and 2.90) was recorded from 2015/TOCVAR-3. This was followed by 2015/TOCVAR-5 (2.23) and 2015/TOCVAR-4 (2.65) in 2015-16 and 2016-17 respectively. In both years the minimum number of locules (2.08 and 1.95) was recorded in Swarna Ratan.

A significant variation was observed on pericarp thickness among evaluated entries in both the years 2015-16 and 2016-17 (Table 4.102b). The pericarp thickness ranged from 1.25 to 3.07 and 1.21 to 3.18 mm in 2015-16 and 2016-17 respectively. In 2015-16 fruits of 2015/TOCVAR-5 were found to have thick pericarp (3.07 mm) which was followed by 2015/TOCVAR-3 (2.65 mm). Whereas in 2016-17 2015/TOCVAR-4 produced fruits with maximum (3.18 mm) pericarp thickness which was followed by 2015/TOCVAR-3 (2.69 mm). In both years fruits of 2015/TOCVAR-2 had the minimum pericarp thickness of 1.25 and 1.21 mm.

The significant variation was observed in total soluble solids (TSS) content of entries evaluated and ranged from 4.68 to 6.63 and 4.55 to 6.52 °Brix. In both years the maximum total soluble solids content (6.63 and 6.52 °Brix) was found in 2015/TOCVAR-2. This was followed by 2015/TOCVAR-1 (6.11 °Brix) and 2015/TOCVAR-5 (6.05 °Brix) in 2015-16 and 2016-17 respectively. In 2015-16 2015/TOCVAR-1 (6.11 °Brix) and 2015/TOCVAR-6 (6.00 °Brix) were at par with each other and 2015/TOCVAR-3 (5.86 °Brix) and 2015/TOCVAR-1 (6.01 °Brix) were at par with 2015/TOCVAR-5 (6.05 °Brix). However in both years the minimum total soluble solids content (4.68 and 4.55 °Brix) was recorded in Swarna Ratan (Table 4.102b).

Among the seven entries evaluated during 2015-16 and 2016-17 one (2015/TOCVAR-1) was oblong to pear shaped and remaining all entries were either round or flattish round in shape. In case of colour one entry (2015/TOCVAR-1) was orange yellow, two (2015/TOCVAR-5 and 2015/TOCVAR-6) were red to deep red and four (2015/TOCVAR-2,

Table 4.102a: Quality parameters of 2015/TOCVAR entries

Entry/ variety	Equatorial diameter of fruit (mm)		Polar diameter of fruit (mm)		Number of locules fruit ⁻¹	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	17.10	16.32	27.97	25.38	2.10	2.10
2015/TOCVAR-2	18.84	16.98	18.81	17.59	2.20	2.15
2015/TOCVAR-3	26.33	29.26	25.81	27.61	2.85	2.90
2015/TOCVAR-4	-	21.09	-	33.26	-	2.65
2015/TOCVAR-5	23.75	23.74	32.49	23.91	2.23	2.00
2015/TOCVAR-6	22.99	-	23.73	-	2.10	-
Swarna Ratan	21.63	20.45	20.71	21.32	2.08	1.95
Sem±	0.549	0.720	0.777	0.644	0.100	0.069
CD (p=0.05)	1.654*	2.170*	2.342*	1.941*	0.302*	0.208*
CV	5.039	6.757	6.236	5.184	8.881	6.015

Table 4.102b: Quality parameters of 2015/TOCVAR entries

Entry/ variety	Pericarp thickness (mm)		TSS (Brix %)		Fruit shape	Fruit colour
	2015-16	2016-17	2015-16	2016-17		
2015/TOCVAR-1	2.05	2.21	6.11	6.01	Oblong-pear	Orange yellow
2015/TOCVAR-2	1.25	1.21	6.63	6.52	Round	Deep red
2015/TOCVAR-3	2.65	2.69	5.77	5.86	Round	Deep red
2015/TOCVAR-4	-	3.18	-	5.45	Round	Deep red
2015/TOCVAR-5	3.07	1.99	5.39	6.05	Round	Red - Deep red
2015/TOCVAR-6	2.09	-	6.00	-	Round	Red - Deep red
Swarna Ratan	1.55	1.64	4.68	4.55	Round	Deep red
Sem±	0.044	0.032	0.109	0.064		
CD (p=0.05)	0.131*	0.097*	0.327*	0.194		
CV	4.123	2.995	3.766	2.247		

2015/TOCVAR-3, 2015/TOCVAR-4 and Swarna Ratan) were deep red in colour (Table 4.102b).

4.4.7.6 Other parameters of 2015/TOCVAR entries/ varieties

Some other parameters such as Plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF) were recorded for each and every entry during 2015-16 and 2016-17 and presented in Table 4.103a and 4.103b.

The plant height was ranged significantly from 84.07 to 186.78 and 90.60 to 176.59 cm in 2015-16 and 2016-17 respectively. In both years the maximum (186.78 and 176.59 cm) plant height was recorded in 2015/TOCVAR-2 followed by 2015/TOCVAR-3 (158.41 and 163.93 cm). The lowest plant height (84.07 and 90.60 cm) was registered in Swarna Ratan. However 2015/TOCVAR-2 and 2015/TOCVAR-3 were at par with each other in both years (Table 4.103a).

The number of primary branches plant⁻¹ varied significantly from 6.27 to 12.47 and 5.53 to 10.80 in 2015-16 and 2016-17 respectively (Table 4.103a). The highest (12.47 and 10.80) number of primary branches was observed in 2015/TOCVAR-2 with least in 2015/TOCVAR-1 (6.27 and 5.53).

The number of secondary branches plant⁻¹ varied significantly from 3.20 to 6.73 and 2.95 to 5.90 in 2015-16 and 2016-17 respectively (Table 4.103a). In both years the highest (6.73 and 5.90) number of secondary branches were observed in 2015/TOCVAR-1 followed by 2015/TOCVAR-3 (4.27 and 4.60) whereas the least number of branches were recorded in 2015/TOCVAR-2 (3.20 and 2.95).

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.103b. In both years there was non significant difference was observed in days to first flowering. The days to 50% flowering was non significant in 2015-16 however it was significantly varied from 28.25 to 31.00 days with minimum (28.25 days) in 2015/TOCVAR-2 and maximum (31.00 days) in 2015/TOCVAR-5 and Swarna Ratan.

The days to first fruiting significantly ranged from 26.25 to 30.25 and 26.25 to 30.50 days in 2015-16 and 2016-17 respectively. In 2015-16 the minimum

Table 4.103a: Other parameters of 2015/TOCVAR entries

Entry/ variety	Plant height (cm)		No. of primary branches plant ⁻¹		No. of secondary branches plant ⁻¹	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	98.76	84.03	6.27	5.53	6.73	5.90
2015/TOCVAR-2	186.78	176.59	12.47	10.80	3.20	2.95
2015/TOCVAR-3	158.41	163.93	8.27	9.60	4.27	4.60
2015/TOCVAR-4	-	142.69	-	10.27	-	3.65
2015/TOCVAR-5	131.17	131.83	9.53	9.60	3.40	4.05
2015/TOCVAR-6	124.81	-	8.60	-	3.93	-
Swarna Ratan	84.07	90.60	8.73	9.60	3.27	3.75
Sem±	5.377	4.624	0.585	0.489	0.182	0.147
CD (p=0.05)	16.209*	13.937*	1.762*	1.473*	0.548*	0.444*
CV	8.231	7.026	13.021	10.583	8.792	7.094

Table 4.103b: Other parameters of 2015/TOC VAR entries

Entry/ variety	First flowering (DAT)		50 per cent flowering (DAT)		First fruiting (DAT)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
2015/TOCVAR-1	22.00	21.75	29.00	28.50	27.50	27.50
2015/TOCVAR-2	22.00	21.25	28.25	28.25	29.50	29.25
2015/TOCVAR-3	22.50	21.75	29.00	29.50	29.75	29.75
2015/TOCVAR-4	-	21.25	-	28.75	-	26.25
2015/TOCVAR-5	21.00	22.75	29.00	31.00	26.25	29.00
2015/TOCVAR-6	22.25	-	30.25	-	29.00	-
Swarna Ratan	22.75	22.50	30.00	31.00	30.25	30.50
Sem±	0.587	0.662	0.691	0.594	0.574	0.565
CD (p=0.05)	1.769 (NS)	1.995 (NS)	2.084 (NS)	1.790*	1.731*	1.702*
CV	5.315	6.052	4.726	4.027	4.001	3.933

(26.25 days) days to first fruiting were observed in 2015/TOCVAR-5 followed by 2015/TOCVAR-1 (27.50 days) and also both were at par with each other. In 2016-17 the minimum (26.25 days) days to first fruiting were observed in 2015/TOCVAR-4 followed by 2015/TOCVAR-1 (27.50 days) and also both were at par with each other. However in both years the maximum (30.25 and 30.50 days) days to first fruiting were observed in Swarna Ratan (Table 4.103b).

4.4.7.7 Overall performance of 2015/TOCVAR entries/ varieties

The overall performance of all the 2015/TOCVAR entries were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.104 to 4.105.

It was seen from the experimental data presented in Table 4.104 that in 2015-16 2015/TOCVAR-5 attained best overall performance followed by 2015/TOCVAR-1. Though these two entries attained commendable overall performance and showed moderately resistant and moderately susceptible reaction but Swarna Ratan recorded maximum (301.64 q) per ha total yield followed by 2015/TOCVAR-4 (290.65 q) with moderately susceptible reaction. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2015/TOCVAR-5 with average fruit weight of 8.71 g followed by 2015/TOCVAR-3 (8.38 g). The largest round fruits were recorded in 2015/TOCVAR-3 with equatorial diameter of 26.33 mm followed by 2015/TOCVAR-5 (23.75 mm). However 2015/TOCVAR-5 was recorded for the longest (32.49 mm) fruit with maximum (3.07 mm) pericarp thickness followed by 2015/TOCVAR-1 (27.97 mm polar diameter) and 2015/TOCVAR-3 (2.65 mm pericarp thickness). In case of TSS the maximum total soluble solids content (6.63 °Brix) was found in 2015/TOCVAR-2 followed by 2015/TOCVAR-1 (6.11 °Brix). However the minimum (26.25 days) days to first fruiting were observed in 2015/TOCVAR-5 followed by 2015/TOCVAR-1 (27.50 days).

It was revealed from the experimental data presented in Table 4.105 that in 2016-17 2015/TOCVAR-4 attained best overall performance followed by 2015/TOCVAR-3. Though these entries were superfine in overall performance and showed moderately resistant and moderately susceptible reaction respectively but Swarna Ratan recorded maximum (331.09 q) per ha total yield followed by

Table 4.104: Overall performance of 2015/TOCVAR entries in 2015-16

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/TOCVAR-1	47.19	34.71	MS	6.79	238.81	17.10	27.97	2.05	6.11	27.50
2015/TOCVAR-2	56.55	40.78	S	5.41	162.19	18.84	18.81	1.25	6.63	29.50
2015/TOCVAR-3	57.34	40.92	S	8.38	246.93	26.33	25.81	2.65	5.77	29.75
2015/TOCVAR-4	-	-	-	-	-	-	-	-	-	-
2015/TOCVAR-5	36.07	24.67	MR	8.71	290.65	23.75	32.49	3.07	5.39	26.25
2015/TOCVAR-6	80.54	60.19	S	6.53	173.37	22.99	23.73	2.09	6.00	29.00
Swarna Ratan	90.04	68.84	S	7.24	301.64	21.63	20.71	1.55	4.68	30.25
Sem±				0.128	9.826	0.549	0.777	0.044	0.109	0.574
CD (p=0.05)				0.387*	29.620*	1.654*	2.342*	0.131*	0.327*	1.731*
CV				3.577	8.342	5.039	6.236	4.123	3.766	4.001

Table 4.105: Overall performance of 2015/TOCVAR entries in 2016-17

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/TOCVAR-1	53.54	40.57	S	6.19	202.78	16.32	25.38	2.21	6.01	27.50
2015/TOCVAR-2	57.85	44.14	S	5.41	142.22	16.98	17.59	1.21	6.52	29.25
2015/TOCVAR-3	47.03	33.84	MS	8.39	277.72	29.26	27.61	2.69	5.86	29.75
2015/TOCVAR-4	26.16	19.16	MR	8.72	309.72	21.09	33.26	3.18	5.45	26.25
2015/TOCVAR-5	74.57	56.74	S	6.53	179.70	23.74	23.91	1.99	6.05	29.00
2015/TOCVAR-6	-	-	-	-	-	-	-	-	-	-
Swarna Ratan	81.48	63.72	S	7.26	331.09	20.45	21.32	1.64	4.55	30.50
Sem±				0.110	10.763	0.720	0.644	0.032	0.064	0.565
CD (p=0.05)				0.330*	32.444*	2.170*	1.941*	0.097*	0.194*	1.702*
CV				3.095	8.949	6.757	5.184	2.995	2.247	3.933

Table 4.106: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2015/TOCVAR entries

Parameters	2015-16		2016-17	
	Disease incidence	PDI	Disease incidence	PDI
PDI	0.999 ^{**}	-	0.999 ^{**}	-
No of fruits plant⁻¹	0.347 ^{NS}	0.374 ^{NS}	0.122 ^{NS}	0.150 ^{NS}
Fruit yield plant⁻¹ (kg)	0.003 ^{NS}	0.017 ^{NS}	-0.241 ^{NS}	-0.226 ^{NS}
Average fruit weight (g)	-0.323 ^{NS}	-0.327 ^{NS}	-0.525 ^{NS}	-0.530 ^{NS}
Marketable yield q ha⁻¹	-0.073 ^{NS}	-0.054 ^{NS}	-0.172 ^{NS}	-0.160 ^{NS}
Unmarketable yield q ha⁻¹	-0.073 ^{NS}	-0.055 ^{NS}	-0.134 ^{NS}	-0.094 ^{NS}
Total yield (q ha⁻¹)	-0.073 ^{NS}	-0.054 ^{NS}	-0.173 ^{NS}	-0.159 ^{NS}
Equatorial diameter of fruit (mm)	0.091 ^{NS}	0.061 ^{NS}	-0.079 ^{NS}	-0.118 ^{NS}
Polar diameter of fruit (mm)	-0.696 ^{NS}	-0.688 ^{NS}	-0.745 ^{NS}	-0.748 ^{NS}
Number of locules fruit⁻¹	-0.243 ^{NS}	-0.272 ^{NS}	-0.778 ^{NS}	-0.801 ^{NS}
Thickness of pericarp (mm)	-0.553 ^{NS}	-0.562 ^{NS}	-0.758 ^{NS}	-0.766 ^{NS}
TSS (% Brix)	-0.385 ^{NS}	-0.398 ^{NS}	-0.241 ^{NS}	-0.265 ^{NS}
Plant height (cm)	-0.362 ^{NS}	-0.396 ^{NS}	-0.390 ^{NS}	-0.411 ^{NS}
No. of primary branches plant⁻¹	-0.019 ^{NS}	-0.041 ^{NS}	-0.033 ^{NS}	-0.031 ^{NS}
No. of secondary branches plant⁻¹	-0.316 ^{NS}	-0.292 ^{NS}	-0.077 ^{NS}	-0.092 ^{NS}
First flowering (DAT)	0.805 ^{NS}	0.802 ^{NS}	0.820 [*]	0.810 ^{NS}
50 per cent flowering (DAT)	0.747 ^{NS}	0.754 ^{NS}	0.723 ^{NS}	0.715 ^{NS}
First fruiting (DAT)	0.779 ^{NS}	0.764 ^{NS}	0.769 ^{NS}	0.752 ^{NS}

2015/TOCVAR-4 (309.72 q) with moderately resistant reaction. Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2015/TOCVAR-4 with average fruit weight of 8.72 g followed by 2015/TOCVAR-3 (8.39 g). The largest round fruits were recorded in 2015/TOCVAR-3 with equatorial diameter of 29.26 mm followed by 2015/TOCVAR-5 (23.74 mm). However 2015/TOCVAR-4 was recorded for the longest (33.26 mm) fruit with maximum (3.18 mm) pericarp thickness followed by 2015/TOCVAR-3 with 27.61 mm of polar diameter and 2.69 mm pericarp thickness. In case of TSS the maximum total soluble solids content (6.52 °Brix) was found in 2015/TOCVAR-2 followed by 2015/TOCVAR-5 (6.05 °Brix). However the minimum (26.25 days) days to first fruiting were observed in 2015/TOCVAR-4 followed by 2015/TOCVAR-1 (27.50 days).

4.4.7.8 Correlation of leaf curl disease with different parameters of 2015/TOCVAR entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2015/TOCVAR entries/ varieties for the year 2015-16 and 2016-17 and presented in table 4.106. None of the parameters showed significant correlation with the disease in both the years.

4.4.8 2015/TOINDVAR entries/ varieties

Seven 2015/TOINDVAR entries/ varieties were evaluated against tomato leaf curl disease (ToLCD) during *rabi* 2015-16 and 2016-17 and results were presented in Table 4.107a to 4.117 (Fig 4.38).

4.4.8.1 Disease incidence and percent disease index (PDI)

Considerable variability was found in incidence and percent disease index (PDI) of all 2015/TOINDVAR entries/ varieties evaluated under the study. During 2015-16 disease incidence was varied from 0.0 to 5.00, 0.61 to 11.84, 3.83 to 21.76, 8.48 to 40.95, 16.23 to 60.87 and 29.83 to 88.44 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The calculated percent disease index (PDI) was varied from 0 to 2.50, 0.26 to 6.68, 1.66 to 15.15, 5.86 to 29.79, 11.42 to 45.86 and 20.75 to 67.92 percent at 15, 30, 45, 60, 75 and 90 days

after transplanting (DAT) respectively. The entries 2015/TOINDVAR-3, 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were free from the disease up to 15 days after transplanting but in the rest other, symptoms of tomato leaf curl was appeared at 15 days after transplanting (Table 4.107a – 4.108b).

While during 2016-17 disease incidence was varied from 0.0 to 4.51, 0.0 to 11.33, 3.10 to 21.00, 10.87 to 34.34, 17.06 to 62.72 and 21.68 to 80.89 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The percent disease index (PDI) was varied from 0.0 to 1.72, 0.0 to 4.86, 1.10 to 13.44, 6.86 to 25.63, 12.17 to 46.12 and 16.15 to 63.46 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. Two entries viz. 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were free from the disease up to 30 days after transplanting but others showed first symptoms of tomato leaf curl disease either 15 or 30 DAT (Table 4.107a – 4.108b).

The average incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) displayed that disease incidence was varied from 0.0 to 3.61, 0.32 to 10.17, 3.72 to 20.68, 9.77 to 37.65, 18.43 to 61.80 and 25.98 to 84.67 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The computed percent disease index (PDI) was varied from 0.0 to 1.62, 0.14 to 5.26, 1.48 to 13.02, 6.44 to 26.67, 13.06 to 45.99 and 18.81 to 65.69 percent at 15, 30, 45, 60, 75 and 90 days after transplanting (DAT) respectively. The entries 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were free from the disease up to 15 days after transplanting but in the rest other, the first symptoms of tomato leaf curl disease was observed at 15 DAT (Table 4.107a – 4.108b).

During 2015-16 at 90 DAT the lowest infection of leaf curl was recorded in 2015/TOINDVAR-4 with percent incidence of 29.83 and percent disease index (PDI) of 20.75 percent followed by 2015/TOINDVAR-5 (30.27, 21.46 %) and highest was recorded in 2015/TOINDVAR-1 (88.44, 67.97 %) (Table 4.107a – 4.108b).

Whereas during 2016-17 at 90 DAT the lowest incidence and percent disease index was noted in 2015/TOINDVAR-5 (21.68, 16.15%) followed by 2015/TOINDVAR-4 (35.70, 25.73 %) and highest was recorded in 2015/TOINDVAR-1 (80.89, 63.46%) (Table 4.107a – 4.108b).

The average percent incidence and percent disease index (PDI) of both years (2015-16 and 2016-17) showed that at 90 DAT the lowest percent incidence and percent disease index (PDI) of leaf curl was observed in 2015/TOINDVAR-5 (25.98, 18.81 %) followed by 2015/TOINDVAR-4 (32.77 and 23.24%). The highest mean percent incidence and percent disease index (PDI) was recorded in 2015/TOINDVAR-1 (84.67 and 65.69 %) (Table 4.107a – 4.108b).

4.4.8.2 Reaction and level of resistance of 2015/TOINDVAR entries/ varieties of tomato against ToLCD

Among the seven entries/ varieties evaluated during 2015-16, none of the entry was found resistant against tomato leaf curl disease but two entries viz. 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were categorized as moderately resistant with rating 3. Of them two entries/ varieties viz. 2015/TOINDVAR-3 and Arka Vikash exhibited moderately susceptible reaction with rating 5. Three entries viz. 2015/TOINDVAR-1, 2015/TOINDVAR-2 and 2015/TOINDVAR-6 were classified under the susceptible reaction with rating 7 (Table 4.109).

Out of seven entries evaluated during 2016-17, none of the entry was found resistant against tomato leaf curl disease. Of them two entries viz. 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were regarded as moderately resistant with rating 3. Three entries/ varieties viz. 2015/TOINDVAR-3, 2015/TOINDVAR-6 and Arka Vikash were categorized as moderately susceptible and assigned with rating 5. Two entries 2015/TOINDVAR-1 and 2015/TOINDVAR-2 were shown as susceptible with rating 7 (Table 4.109).

The result of evaluation for both years (2015-16 and 2016-17) displayed that the performance of six entries were constant. Of them two entries viz. 2015/TOINDVAR-4 and 2015/TOINDVAR-5 were found moderately resistant against ToLCD with rating 3. Two entries/ varieties viz. 2015/TOINDVAR-3 and Arka Vikash were moderately susceptible and rated 5. Two entries viz. 2015/TOINDVAR-1 and 2015/TOINDVAR-2 were put in reaction category susceptible and fall under rating 7 (Table 4.109).

Table 4.107a: Percent incidence of tomato leaf curl disease in 2015/TOINDVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)						
	15			30			45
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16
2015/TOINDVAR-1	5.00	2.22	3.61	11.84	8.50	10.17	21.76
2015/TOINDVAR-2	2.45	4.51	3.48	7.45	11.33	9.39	16.84
2015/TOINDVAR-3	0.00	3.82	1.91	3.78	9.41	6.60	7.64
2015/TOINDVAR-4	0.00	0.00	0.00	0.61	3.01	1.81	3.83
2015/TOINDVAR-5	0.00	0.00	0.00	0.64	0.00	0.32	4.35
2015/TOINDVAR-6	2.50	2.96	2.73	6.90	8.39	7.65	14.54
Arka Vikash	0.00	1.50	0.75	1.86	5.24	3.55	6.98
							10.61
							8.80

Table 4.107b: Percent incidence of tomato leaf curl disease in 2015/TOINDVAR entries

Entry/ variety	Percent disease incidence at 15-day intervals (DAT)						
	60			75			90
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16
2015/TOINDVAR-1	40.95	34.34	37.65	60.87	62.72	61.80	88.44
2015/TOINDVAR-2	29.96	34.34	32.15	47.16	57.83	52.50	66.59
2015/TOINDVAR-3	13.33	26.78	20.05	25.30	36.23	30.77	38.64
2015/TOINDVAR-4	8.48	19.00	13.74	16.23	29.64	22.94	29.83
2015/TOINDVAR-5	8.67	10.87	9.77	19.79	17.06	18.43	30.27
2015/TOINDVAR-6	23.41	26.43	24.92	40.54	35.76	38.15	60.11
Arka Vikash	13.99	18.18	16.09	22.91	31.82	27.37	36.94
							39.39
							84.67
							73.54
							42.53
							32.77
							25.98
							53.10
							38.17

Table 4.108a: Evaluation of 2015/TOINDVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)								
	15			30			45		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	2.50	0.74	1.62	6.68	3.84	5.26	15.15	10.89	13.02
2015/TOINDVAR-2	1.39	1.72	1.55	4.58	4.86	4.72	10.88	13.44	12.16
2015/TOINDVAR-3	0.00	1.42	0.71	1.29	3.59	2.44	4.54	12.06	8.30
2015/TOINDVAR-4	0.00	0.00	0.00	0.26	1.72	0.99	1.66	7.15	4.41
2015/TOINDVAR-5	0.00	0.00	0.00	0.27	0.00	0.14	1.86	1.10	1.48
2015/TOINDVAR-6	1.43	1.06	1.24	3.86	3.16	3.51	9.11	9.08	9.10
Arka Vikash	0.00	0.42	0.21	1.15	2.24	1.70	4.25	5.41	4.83

Table 4.108b: Evaluation of 2015/TOINDVAR entries against tomato leaf curl disease

Entry/ variety	Percent disease index at 15-day intervals (DAT)						Reaction (at final observation)					
	60			75			90					
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Constant
2015/TOINDVAR-1	29.79	23.56	26.67	45.86	46.12	45.99	67.92	63.46	65.69	S	S	S
2015/TOINDVAR-2	20.68	25.63	23.16	34.95	43.51	39.23	49.89	61.05	55.47	S	S	S
2015/TOINDVAR-3	9.52	20.27	14.90	17.71	27.02	22.37	27.77	35.41	31.59	MS	MS	MS
2015/TOINDVAR-4	5.86	12.71	9.29	11.42	19.88	15.65	20.75	25.73	23.24	MR	MR	MR
2015/TOINDVAR-5	6.02	6.86	6.44	13.96	12.17	13.06	21.46	16.15	18.81	MR	MR	MR
2015/TOINDVAR-6	16.00	18.46	17.23	29.51	25.84	27.67	44.23	35.39	39.81	S	MS	MS
Arka Vikash	8.88	14.50	11.69	16.54	23.81	20.18	26.74	30.30	28.52	MS	MS	MS

Table 4.109: Classification of 2015/TOINDVAR entries in different reaction categories

Year	Reaction category	No. of entry/ variety	Name of entry/ variety
Entries/ varieties with constant reaction in both the years 2015-16	Resistant	0	-
	Moderately resistant	2	2015/TOINDVAR-4, 2015/TOINDVAR-5
	Moderately susceptible	2	2015/TOINDVAR-3, Arka Vikash
	Susceptible	2	2015/TOINDVAR-1, 2015/TOINDVAR-2
	Resistant	0	-
	Moderately resistant	2	2015/TOINDVAR-4, 2015/TOINDVAR-5
	Moderately susceptible	2	2015/TOINDVAR-3, Arka Vikash
	Susceptible	3	2015/TOINDVAR-1, 2015/TOINDVAR-2, 2015/TOINDVAR-6
	Resistant	0	-
	Moderately resistant	2	2015/TOINDVAR-4, 2015/TOINDVAR-5
2016-17	Moderately susceptible	3	2015/TOINDVAR-3, 2015/TOINDVAR-6, Arka Vikash
	Susceptible	2	2015/TOINDVAR-1, 2015/TOINDVAR-2

4.4.8.3 Yield parameters of 2015/TOINDVAR entries/ varieties

Yield contributing parameters/ characters such as number of fruits plant⁻¹, fruit yield plant⁻¹ were worked out during 2015-16 and 2016-17 and presented in Table 4.110.

The number of fruits plant⁻¹ significantly ranged from 73.88 to 221.91 and 79.80 to 236.42 in 2015-16 and 2017-18 respectively (Table 4.110). In both years the significant maximum number of fruits plant⁻¹ (221.91 and 236.42) was recorded in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (214.60 and 189.23) and lowest number of fruits plant⁻¹ (73.88 and 79.80) was recorded in 2015/TOINDVAR-5. However in 2015-16 2015/TOINDVAR-1 and 2015/TOINDVAR-2 were at par with each other. During 2016-17 2015/TOINDVAR-3 (90.58), 2015/TOINDVAR-4 (80.35) and 2015/TOINDVAR-6 (82.58) were at par with each other. The mean number of fruits plant⁻¹ of both years (2015-16 and 2016-17) exhibited that the significant maximum number of fruits plant⁻¹ (229.16) was observed in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (201.92) and lowest number of fruits plant⁻¹ (76.84) was recorded in 2015/TOINDVAR-5. However 2015/TOINDVAR-5 (76.84), 2015/TOINDVAR-6 (80.05) and Arka Vikash (82.36) were at par with 2015/TOINDVAR-4 (84.22).

There was significant variation was observed among 2015/TOINDVAR entries for fruit yield plant⁻¹ (Table 4.110). The fruit yield plant⁻¹ significantly ranged from 1.26 to 4.58 kg and 1.13 to 4.83 kg in 2015-6 and 2016-17 respectively. In both the years the significant maximum (4.58 and 4.83 kg) fruit yield plant⁻¹ was obtained from 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (3.78 and 4.06 kg) and least fruit yield plant⁻¹ was recorded from 2015/TOINDVAR-2. However 2015/TOINDVAR-4 (3.66) and 2015/TOINDVAR-6 (3.78) were at par with each other. The pooled mean of both years (2015-16 and 2016-17) expressed that the significant maximum fruit yield plant⁻¹ (4.71 kg) was noted in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (3.92 kg) and minimum (1.20 kg) was observed in 2015/TOINDVAR-2.

The significant variation was observed in average fruit weight of 2015/TOINDVAR entries evaluated during 2015-16 and 2016-17 (Table 4.110). The average fruit weight significantly ranged from 5.87 to 62.02 g in 2015-16 and 5.99 to 60.57 g in 2016-17. In both the years significant maximum (62.02 and 60.57 g) average fruit weight was recorded in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (48.81 and 49.16 g) and minimum (5.87 and 5.99 g) was observed in 2015/TOINDVAR-2. The pooled mean of both years (2015-16 and 2016-17) displayed that the average fruit weight significantly ranged from 5.93 to 61.30 g. The significant maximum average fruit weight (61.30 g) was observed in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (48.98 g) and minimum (5.93 g) was recorded in 2015/TOINDVAR-2.

4.4.8.4 Yield of 2015/TOINDVAR entries/ varieties

Yield is one of the most important parameters for selection of any crop and/or entry. Marketable yield ha^{-1} , Unmarketable yield ha^{-1} and Total yield ha^{-1} were computed for all the 2015/TOINDVAR entries evaluated in both the years (2015-16 and 2016-17) and depicted in Table 4.111.

The significant variation was observed in marketable yield ha^{-1} of entries evaluated during 2015-16 and 2016-17 (Table 4.111). The marketable yield ha^{-1} significantly ranged from 84.78 to 357.35 and 69.08 to 376.49 q in 2015-16 and 2016-17 respectively. In both the years significant maximum marketable yield ha^{-1} (357.35 and 376.49 q) was noted in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (313.05 and 296.01 q) and minimum (84.78 and 69.08 q) was observed in 2015/TOINDVAR-2. In 2015-16 2015/TOINDVAR-6 (234.32 q) and Arka Vikash (228.15 q) were at par with each other. It was revealed from the pooled mean marketable yield ha^{-1} of both years (2015-16 and 2016-17) that the fruit yield significantly ranged from 76.93 to 366.92 q. The significant maximum marketable yield plot^{-1} (366.92 q) was observed in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (304.53 q) and minimum in 2015/TOINDVAR-2 (76.93 q).

The significant difference was observed in unmarketable yield ha^{-1} among the entries evaluated in both the years, 2015-16 and 2016-17 (Table 4.11). The

unmarketable yield ha^{-1} significantly ranged from 1.22 to 18.20 and 1.57 to 17.72 q in 2015-16 and 2016-17 respectively. In both years the significant minimum unmarketable yield ha^{-1} (1.22 to 1.57 q) was obtained from 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.23 and 7.16 q). The maximum unmarketable yield ha^{-1} was observed in 2015/TOINDVAR-5 (18.20 q) and 2015/TOINDVAR-4 (17.72 q) in 2015-16 and 2016-17 respectively. In 2015-16 2015/TOINDVAR-6 (15.41 q), 2015/TOINDVAR-4 (16.51 q) and 2015/TOINDVAR-5 (18.20 q) were at par with each other however in 2016-17 Arka Vikash (13.54 q), 2015/TOINDVAR-5 (16.77 q) and 2015/TOINDVAR-6 (17.44 q) were at par with 2015/TOINDVAR-4 (17.72 q). The pooled mean of unmarketable yield ha^{-1} of both years (2015-16 and 2016-17) showed that the unmarketable yield ha^{-1} significantly ranged from 1.39 to 17.49 q. The significant minimum unmarketable yield ha^{-1} (1.39 q) was recorded in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.69 q). The maximum unmarketable yield ha^{-1} (17.49 q) was observed in 2015/TOINDVAR-5. However 2015/TOINDVAR-6 (16.43 q) and 2015/TOINDVAR-4 (17.12 q) were at par with 2015/TOINDVAR-5 (17.49 q).

The significant variation was observed in total yield ha^{-1} of entries evaluated during 2015-16 and 2016-17 (Table 4.111). The total yield ha^{-1} significantly ranged from 91.01 to 375.56 and 76.24 to 393.26 q in 2015-16 and 2016-17 respectively. In both the years significant maximum total yield ha^{-1} (375.56 and 393.26 q) was noted in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (329.56 and 313.74 q) and minimum was recorded in 2015/TOINDVAR-2 (91.01 and 76.24 q). In 2015-16 2015/TOINDVAR-6 (249.74 q) and Arka Vikash (242.61 q) were at par with each other. It was revealed from the pooled mean of total yield ha^{-1} that the average fruit weight significantly ranged from 83.62 to 384.41 q. The significant maximum total yield ha^{-1} (384.41 q) was observed in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (321.65 q) and minimum in 2015/TOINDVAR-2 (83.62 q).

4.4.8.5 Quality parameters of 2015/TOINDVAR entries/ varieties

Quality parameters of fruit are one of the important factors that directly or indirectly influence the market value of yield. Quality parameters such as

Table 4.110: Yield parameters of 2015/TOINDVAR entries

Entry/ variety	No of fruits plant ⁻¹			Fruit yield plant ⁻¹ (kg)			Average fruits weight (g)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	221.91	236.42	229.16	1.33	1.44	1.39	6.01	6.09	6.05
2015/TOINDVAR-2	214.60	189.23	201.92	1.26	1.13	1.20	5.87	5.99	5.93
2015/TOINDVAR-3	102.48	90.58	96.53	2.76	2.42	2.59	26.94	26.69	26.82
2015/TOINDVAR-4	88.08	80.35	84.22	3.66	3.32	3.49	41.52	41.36	41.44
2015/TOINDVAR-5	73.88	79.80	76.84	4.58	4.83	4.71	62.02	60.57	61.30
2015/TOINDVAR-6	77.52	82.58	80.05	3.78	4.06	3.92	48.81	49.16	48.98
Arka Vikash	85.26	79.45	82.36	2.91	2.69	2.80	34.15	33.83	33.99
Sem±	3.168	3.385	2.845	0.069	0.061	0.045	0.645	0.555	0.347
CD (p=0.05)	9.762*	10.430*	8.767*	0.213*	0.188*	0.139*	1.987*	1.710*	1.069*
CV	4.447	4.895	4.053	4.129	3.722	2.719	3.471	3.008	1.874

Table 4.111: Yield performance of 2015/TOINDVAR entries

Entry/ variety	Marketable yield q ha ⁻¹			Unmarketable yield q ha ⁻¹			Total yield q ha ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	125.77	132.41	129.09	1.22	1.57	1.39	126.99	133.98	130.48
2015/TOINDVAR-2	84.78	69.08	76.93	6.23	7.16	6.69	91.01	76.24	83.62
2015/TOINDVAR-3	193.51	180.25	186.88	11.64	12.43	12.04	205.15	192.68	198.91
2015/TOINDVAR-4	313.05	296.01	304.53	16.51	17.72	17.12	329.56	313.74	321.65
2015/TOINDVAR-5	357.35	376.49	366.92	18.20	16.77	17.49	375.56	393.26	384.41
2015/TOINDVAR-6	234.32	264.87	249.60	15.41	17.44	16.43	249.74	282.31	266.03
Arka Vikash	228.15	206.16	217.15	14.46	13.54	14.00	242.61	219.70	231.16
Sem±	9.214	9.806	4.769	1.120	1.298	0.585	10.047	8.467	5.104
CD (p=0.05)	28.391*	30.216*	14.695*	3.450*	4.000*	1.802*	30.958*	26.091*	15.726*
CV	7.269	7.795	3.776	16.223	18.165	8.327	7.516	6.369	3.829

equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour of each entry were studied during 2015-16 and 2016-17 and mentioned in Table 4.112a and 4.112b.

The significant difference was noticed in equatorial diameter of fruits. The equatorial diameter of fruits significantly ranged from 18.35 to 56.87 mm in 2015-16 and 17.93 to 58.11 mm in 2016-17 (Table 4.112a). In both years the largest fruit (56.87 and 58.11 mm) was gained from 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (47.83 and 48.39 mm) and minimum was recorded in 2015/TOINDVAR-2 (18.35 and 17.93 mm). In both years 2015/TOINDVAR-4 (43.57 and 41.86 mm) and Arka Vikash (43.70 and 43.87 mm) were at par with each other. The pooled mean of equatorial diameter from both years (2015-16 and 2016-17) significantly ranged from 18.14 to 57.49 mm. The largest fruit (57.89 mm) was observed in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (48.11 mm) and minimum was recorded in 2015/TOINDVAR-2 (18.14 mm). However 2015/TOINDVAR-4 (42.71 mm) and Arka Vikash (43.78 mm) were at par with each other.

The significant variation was observed in polar diameter of entries evaluated. The polar diameter ranged from 17.71 to 48.23 mm and 18.08 to 47.32 mm in 2015-16 and 2016-17 respectively (Table 4.112a). In both years the maximum (48.23 and 47.32 mm) polar diameter was recorded in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (47.38 and 46.65 mm) and both entries were at par with each other. However the minimum (17.71 and 18.08 mm) polar diameter was noted in 2015/TOINDVAR-2. The pooled mean of both the years (2015-16 and 2016-17) also displayed significant variation in polar diameter among entries which ranged from 17.90 to 47.78 mm (Table). The longest (47.78 mm) fruit was received from 2015/TOINDVAR-5 followed by 2015/TOINDVAR-6 (47.02 mm) and lowest (17.90 mm) was registered from 2015/TOINDVAR-2.

A significant variation was observed in the number of locules among evaluated entries in both the years 2015-16 and 2016-17 (Table 4.112a). The number of locules ranged from 2.27 to 4.93 and 2.20 to 5.07 in 2015-16 and 2016-17 respectively. In both years the maximum number of locules (4.93 and 5.07) was

registered in 2015/TOINDVAR-5 followed by Arka Vikash (4.20 and 4.27) and minimum (2.27 and 2.20) was noted in 2015/TOINDVAR-2. However 2015/TOINDVAR-1 (2.53 and 2.60) and 2015/TOINDVAR-6 (2.67 and 2.73) were at par with each other in both the years. The pooled mean of number of locules exhibited significant variation in number of locules among entries and ranged from 2.57 to 5.00. The maximum number of locules (5.00) was observed in 2015/TOINDVAR-5 followed by Arka Vikash (4.23) and minimum (2.23) was recorded in 2015/TOINDVAR-2. However 2015/TOINDVAR-1 (2.57) and 2015/TOINDVAR-6 (2.70) were at par with each other.

A significant variation was observed on pericarp thickness among evaluated entries in both the years 2015-16 and 2016-17 (Table 4.112b). The pericarp thickness ranged from 0.97 to 4.87 and 0.95 to 4.83 mm in 2015-16 and 2016-17. Among the entries the maximum pericarp thickness was observed in 2015/TOINDVAR-6 (4.87 mm) in 2015-16 and 2015/TOINDVAR-5 (4.83 mm) in 2016-17. This was followed by 2015/TOINDVAR-5 (4.73 mm) and 2015/TOINDVAR-6 (4.81 mm) in 2015-16 and 2016-17 respectively. However 2015/TOINDVAR-2 produced the fruits with thin (0.97 and 0.95 mm) pericarp thickness. 2015/TOINDVAR-5 and 2015/TOINDVAR-6 were at par with each other in 2015-16 whereas 2015/TOINDVAR-6 and 2015/TOINDVAR-5 were at par with each other in 2016-17. The pooled mean of 2015-16 and 2016-17 also showed significant variation in pericarp thickness among the entries and ranged from 0.96 to 4.84 mm. The maximum (4.84 mm) pericarp thickness was recorded in 2015/TOINDVAR-6 followed by 2015/TOINDVAR-5 (4.78 mm) and minimum pericarp thickness (0.96 mm) was recorded in 2015/TOINDVAR-2. However 2015/TOINDVAR-5 and 2015/TOINDVAR-6 were at par with each other.

The TSS significantly ranged from 3.56 to 6.71 and 3.51 to 6.75 °Brix among the seven 2015/TOINDVAR entries evaluated (Table 4.112b). In both the years the significant maximum total soluble solids content (6.71 and 6.75 °Brix) was found in fruits of 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.27 and 6.29 °Brix) and minimum (3.56 and 3.51 °Brix) was recorded in 2015/TOINDVAR-4. However 2015/TOINDVAR-6 (3.85 °Brix) and Arka Vikash (3.91 °Brix) were at par with each other in 2015-16 and whereas in 2016-17

Table 4.112a: Quality parameters of 2015/TOINDVAR entries

Entry/ variety	Equatorial diameter of fruit (mm)			Polar diameter of fruit (mm)			Number of locules fruit ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	19.41	20.81	20.11	18.30	19.18	18.74	2.53	2.60	2.57
2015/TOINDVAR-2	18.35	17.93	18.14	17.71	18.08	17.90	2.27	2.20	2.23
2015/TOINDVAR-3	36.20	35.14	35.67	34.69	33.85	34.27	3.47	3.40	3.43
2015/TOINDVAR-4	43.57	41.86	42.71	43.41	42.51	42.96	2.40	2.53	2.47
2015/TOINDVAR-5	56.87	58.11	57.49	48.23	47.32	47.78	4.93	5.07	5.00
2015/TOINDVAR-6	47.83	48.39	48.11	47.38	46.65	47.02	2.67	2.73	2.70
Arka Vikash	43.70	43.87	43.78	37.09	36.00	36.55	4.20	4.27	4.23
Sem±	1.215	1.323	0.873	0.733	0.862	0.508	0.078	0.054	0.047
CD (p=0.05)	3.743*	4.077*	2.691*	2.258*	2.657*	1.564*	0.241*	0.168*	0.144*
CV	5.538	6.029	3.981	3.599	4.291	2.510	4.228	2.895	2.495

2015/TOINDVAR-5 (3.80 °Brix) and 2015/TOINDVAR-6 (3.79 °Brix) were at par with each other. The pooled mean data of 2015-16 and 2016-17 also showed significant variation in total soluble solids (TSS) content among the entries and ranged from 3.54 to 6.73 °Brix. The maximum total soluble solids content (6.73 °Brix) was obtained in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.28 °Brix) and minimum (3.54 °Brix) was recorded in 2015/TOINDVAR-4. However 2015/TOINDVAR-5 (3.78 °Brix) and 2015/TOINDVAR-6 (3.82 °Brix) were at par with each other.

All the seven entries were either round or flattish round in shape however in case of colour five entries viz. 2015/TOINDVAR-3, 2015/TOINDVAR-4, 2015/TOINDVAR-5, 2015/TOINDVAR-6 and Arka Vikash were red to deep red colour in colour and two (2015/TOINDVAR-1 and 2015/TOINDVAR-2) were deep red in colour (Table 4.112b).

4.4.8.6 Other parameters of 2015/TOINDVAR entries/ varieties

Some other parameters such as Plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF) were recorded for each and every entry during 2015-16 and 2016-17 and presented in Table 4.113a and 4.113b.

In 2015-16 plant height was ranged from 76.82 to 150.78 cm and significantly highest (150.78 cm) plant height was recorded in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (135.09 cm). 2015/TOINDVAR-2 and 2015/TOINDVAR-5 (134.15 cm) were at par with each other. Data presented in Table 4.113a showed that plant height was significantly ranged from 74.50 to 154.40 cm in 2016-17. The highest (154.40 cm) plant height was recorded in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-5 (138.33 cm) and these both entries were at par with each other. In both years the lowest (76.82 and 74.50 cm) plant height was noted in Arka Vikash. The pooled mean of plant height exhibited that significant highest (152.59 cm) plant height was recorded in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-5 (136.24 cm) and lowest

(75.66 cm) plant height was noted in Arka Vikash. However 2015/TOINDVAR-2 (130.83 cm) and 2015/TOINDVAR-5 (136.24 cm) were at par with each other.

In both years the number of primary branches plant⁻¹ varied significantly (Table 4.113a). The highest (11.20 and 11.67) number of branches were recorded in 2015/TOINDVAR-1 followed by Arka Vikash (10.27 and 10.07) and the least number of branches (4.00 and 4.13) were noted in 2015/TOINDVAR-6. 2015/TOINDVAR-1 and Arka Vikash were at par with each other in 2015-16 and 2015/TOINDVAR-2 (8.20) and 2015/TOINDVAR-5 (7.87) were at par with each other in 2016-17. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2015/TOINDVAR entries evaluated the significant highest (11.43) number of primary branches plant⁻¹ was found in 2015/TOINDVAR-1 followed by Arka Vikash (10.17) and least number of branches were recorded from 2015/TOINDVAR-6 (4.07). However 2015/TOINDVAR-2 (8.40) and 2015/TOINDVAR-5 (7.77) were at par with each other.

In 2015-16 the number of secondary branches plant⁻¹ varied significantly from 2.0 to 10.67 (Table 4.113a). The highest (10.67) number of secondary branches was observed in 2015/TOINDVAR-6 followed by 2015/TOINDVAR-2 (7.00) and least number of branches were recorded in 2015/TOINDVAR-1 (2.00). However 2015/TOINDVAR-5 (6.00), 2015/TOINDVAR-3 (6.33) and Arka Vikash (6.67) were at par with 2015/TOINDVAR-2 (7.00). In 2016-17 there was significant difference was observed in number of secondary branches plant⁻¹ among the entries (Table 4.113a). The highest (11.00) number of branches was observed in 2015/TOINDVAR-6 followed by 2015/TOINDVAR-2 and 2015/TOINDVAR-5 (6.67). The least number of branches were recorded in 2015/TOINDVAR-1 (2.67). However 2015/TOINDVAR-3 (5.67), Arka Vikash (6.33), 2015/TOINDVAR-2 and 2015/TOINDVAR-5 (6.67) were at par with each other. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2015/TOINDVAR entries evaluated the significant highest (10.83) number of secondary branches plant⁻¹ was found in 2015/TOINDVAR-6 followed by 2015/TOINDVAR-2 (6.83) and least number of branches were recorded in 2015/TOINDVAR-1 (2.33). However 2015/TOINDVAR-2 (6.83) and Arka Vikash (6.50) were at par with each other.

The data on days to first flowering, 50% flowering and first fruiting were presented in Table 4.113b. In both years days to first flowering significantly varied from 21.00 to 27.00 and 21.33 to 28.00 days in 2015-16 and 2016-17 respectively. In both years the minimum (21.00 and 21.33 days) days to first flowering were recorded in 2015/TOINDVAR-4 followed by 2015/TOINDVAR-3 (21.67 and 22.00 days) and these both entries were at par with each other. The maximum (27.00 and 28.00 days) days to first flowering were observed in Arka Vikash. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2015/TOINDVAR entries evaluated the significant lowest (21.17 days) days to first flowering were observed in 2015/TOINDVAR-4 followed by 2015/TOINDVAR-3 (21.83 days) and maximum (27.50 days) days to first flowering were registered in Arka Vikash.

The days to 50% flowering significantly ranged from 26.33 to 32.33 days in 2015-16 and 26.67 to 33.33 days in 2016-17 (Table 4.113b). In both years the minimum (26.33 and 26.67 days) days to 50% flowering were noted in 2015/TOINDVAR-4 followed by 2015/TOINDVAR-3 (29.33 and 30.00 days) and maximum (32.33 and 33.33 days) days to 50% flowering were registered in 2015/TOINDVAR-5. It was revealed from the pooled mean of 2015-16 and 2016-17 that among all the 2015/TOINDVAR entries evaluated the significant least (26.50 days) days to 50% flowering were recorded in 2015/TOINDVAR-4 followed by 2015/TOINDVAR-3 (29.67 days) and maximum (32.83 days) days to 50% flowering were observed in Arka Vikash.

The days to first fruiting significantly ranged from 32.67 to 37.00 days and 32.33 to 36.33 days in 2015-16 and 2016-17 respectively (Table 4.113b). In both years the minimum (32.67 and 32.33 days) days to first fruiting were observed in 2015/TOINDVAR-1. This was followed by 2015/TOINDVAR-3 (34.00 days) in 2015-16 and 2015/TOINDVAR-4 (34.33 days) in 2016-17. The maximum days to first fruiting were observed in 2015/TOINDVAR-6 (37.00) in 2015-16 and 2015/TOINDVAR-6 and Arka Vikash (36.33 days) in 2016-17. It was revealed from pooled mean of 2015-16 and 2016-17 that among all the 2015/TOINDVAR entries evaluated the significant least (32.50 days) days to first fruiting were observed in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-4 (34.50 days)

Table 4.113a: Other parameters of 2015/TOINDVAR entries

Entry/ variety	Plant height (cm)			No. of primary branches plant ⁻¹			No. of secondary branches plant ⁻¹		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	150.78	154.40	152.59	11.20	11.67	11.43	2.00	2.67	2.33
2015/TOINDVAR-2	135.09	126.57	130.83	8.60	8.20	8.40	7.00	6.67	6.83
2015/TOINDVAR-3	87.14	84.67	85.90	5.93	5.67	5.80	6.33	5.67	6.00
2015/TOINDVAR-4	90.55	87.03	88.79	4.13	4.07	4.10	5.00	5.33	5.17
2015/TOINDVAR-5	134.15	138.33	136.24	7.67	7.87	7.77	6.00	6.67	6.33
2015/TOINDVAR-6	100.77	106.00	103.39	4.00	4.13	4.07	10.67	11.00	10.83
Arka Vikash	76.82	74.50	75.66	10.27	10.07	10.17	6.67	6.33	6.50
Sem±	4.929	5.559	3.827	0.457	0.349	0.228	0.371	0.405	0.253
CD (p=0.05)	15.186*	17.129*	11.792*	1.409*	1.077*	0.703*	1.143*	1.248*	0.781*
CV	7.707	8.736	5.999	10.700	8.200	5.343	10.302	11.076	6.981

Table 4.113b: Other parameters of 2015/TOINDVAR entries

Entry/ variety	First flowering (DAT)			50 per cent flowering (DAT)			First fruiting (DAT)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
2015/TOINDVAR-1	25.33	24.00	24.67	31.33	30.33	30.83	32.67	32.33	32.50
2015/TOINDVAR-2	26.00	26.67	26.33	31.67	32.33	32.00	34.33	35.33	34.83
2015/TOINDVAR-3	21.67	22.00	21.83	29.33	30.00	29.67	34.00	35.33	34.67
2015/TOINDVAR-4	21.00	21.33	21.17	26.33	26.67	26.50	34.67	34.33	34.50
2015/TOINDVAR-5	26.67	27.33	27.00	31.00	30.33	30.67	36.33	35.67	36.00
2015/TOINDVAR-6	26.33	26.00	26.17	31.00	30.00	30.50	37.00	36.33	36.67
Arka Vikash	27.00	28.00	27.50	32.33	33.33	32.83	35.67	36.33	36.00
Sem±	0.544	0.277	0.272	0.653	0.442	0.409	0.773	0.684	0.554
CD (p=0.05)	1.677*	0.853*	0.839*	2.011*	1.363*	1.260*	2.383*	2.109*	1.707*
CV	3.793	1.915	1.889	3.715	2.519	2.328	3.832	3.377	2.740

and maximum (36.67 days) days to first fruiting were observed in 2015/TOINDVAR-6.

4.4.8.7 Overall performance of 2015/TOINDVAR entries/ varieties

The overall performance of all the 2015/TOINDVAR entries were analyzed for both the years 2015-16 and 2016-17 and presented in Table 4.114 to 4.116.

It was seen from the experimental data presented in Table 4.114 that in 2015-16 2015/TOINDVAR-5 attained best overall performance followed by 2015/TOINDVAR-4. Though these entries attained commendable overall performance and showed moderately resistant reaction with 2015/TOINDVAR-5 recorded maximum (375.56 q) per ha total yield followed by 2015/TOINDVAR-4 (329.56 q). Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2015/TOINDVAR-5 with average fruit weight of 62.02 g followed by 2015/TOINDVAR-6 (48.81 g). The fruits of 2015/TOINDVAR-5 had maximum equatorial and polar diameter of 56.87 and 48.23 mm respectively followed by 2015/TOINDVAR-6 (47.83 and 47.38 mm). 2015/TOINDVAR-6 had the maximum (4.87 mm) pericarp thickness followed by 2015/TOINDVAR-5 (4.73 mm). In case of TSS the maximum total soluble solids content (6.71 °Brix) was found in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.27 °Brix) and the minimum (32.67 days) days to first fruiting were observed in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-3 (34.00 days).

It was revealed from the Table 4.115 that in 2016-17 2015/TOINDVAR-5 attained best overall performance followed by 2015/TOINDVAR-4. Though these entries were superfine in overall performance and showed moderately resistant reaction with maximum (393.26 q) per ha total yield was recorded in 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (313.74 q). Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2015/TOINDVAR-5 with average fruit weight of 60.57 g followed by 2015/TOINDVAR-6 (49.16 g). The fruits of 2015/TOINDVAR-5 had maximum equatorial (58.11 mm) and polar diameter (47.32 mm) with thick pericarp (4.83 mm) followed by 2015/TOINDVAR-6 with

48.39, 46.65 and 4.81 mm equatorial diameter, polar diameter and pericarp thickness respectively. In case of TSS the maximum total soluble solids content (6.75 °Brix) was found in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.29 °Brix) and the minimum (32.33 days) days to first fruiting were observed in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-4 (34.33 days).

It was revealed from the pooled mean of both the years (2015-16 and 2016-17) 2015/TOINDVAR-5 attained best overall performance followed by 2015/TOINDVAR-4 (Table 4.116). Though these entries attained commendable overall rank and showed moderately resistant reaction with 2015/TOINDVAR-5 recorded maximum (384.41 q) per ha total yield followed by 2015/TOINDVAR-4 (321.65 q). Moreover the performance of each entry was different for different parameter such as the heaviest fruit was obtained from 2015/TOINDVAR-5 with average fruit weight of 61.30 g followed by 2015/TOINDVAR-6 (48.98 g). The fruits of 2015/TOINDVAR-5 had maximum equatorial and polar diameter of 57.49 and 47.78 mm respectively followed by 2015/TOINDVAR-6 (48.11 and 47.02 mm). 2015/TOINDVAR-6 had the maximum (4.84 mm) pericarp thickness followed by 2015/TOINDVAR-5 (4.78 mm). In case of TSS the maximum total soluble solids content (6.73 °Brix) was found in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-2 (6.28 °Brix) and the minimum (32.50 days) days to first fruiting were observed in 2015/TOINDVAR-1 followed by 2015/TOINDVAR-4 (34.50 days).

4.4.8.8 Correlation of leaf curl disease with different parameters of 2015/TOINDVAR entries/ varieties

The relationship of leaf curl disease was worked out with various parameters of 2015/TOINDVAR entries/ varieties for the year 2015-16 and 2016-17 and presented in table 4.117. The percent disease index of leaf curl significant and negatively correlated with fruit yield plant⁻¹ ($r = -0.827$, $p = 0.001$), average fruit weight ($r = -0.845$, $p = 0.001$) marketable yield q ha⁻¹ ($r = -0.852$, $p = 0.001$), unmarketable yield q ha⁻¹ ($r = -0.920$, $p = 0.001$), total yield ($r = -0.863$, $p = 0.001$), equatorial diameter of fruit ($r = -0.871$, $p = 0.001$), and polar diameter of fruit ($r = -0.852$, $p = 0.001$) and thickness of pericarp ($r = -0.832$, $p = 0.001$). It was also revealed from the data that number of fruits plant⁻¹ ($r = 0.928$, $p = 0.001$)

Table 4.114: Overall performance of 2015/TOINDVAR entries in 2015-16

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/TOINDVAR-1	88.44	67.92	S	6.01	126.99	19.41	18.30	1.01	6.71	32.67
2015/TOINDVAR-2	66.59	49.89	S	5.87	91.01	18.35	17.71	0.97	6.27	34.33
2015/TOINDVAR-3	38.64	27.77	MS	26.94	205.15	36.20	34.69	2.69	3.64	34.00
2015/TOINDVAR-4	29.83	20.75	MR	41.52	329.56	43.57	43.41	3.97	3.56	34.67
2015/TOINDVAR-5	30.27	21.46	MR	62.02	375.56	56.87	48.23	4.73	3.76	36.33
2015/TOINDVAR-6	60.11	44.23	S	48.81	249.74	47.83	47.38	4.87	3.85	37.00
Arka Vikash	36.94	26.74	MS	34.15	242.61	43.70	37.09	4.45	3.91	35.67
Sem±				0.645	10.047	1.215	0.733	0.048	0.042	0.773
CD (p=0.05)				1.987*	30.958*	3.743*	2.258*	0.148*	0.128*	2.383*
CV				3.471	7.516	5.538	3.599	2.574	1.591	3.832

Table 4.115: Overall performance of 2015/TOINDVAR entries in 2016-17

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/TOINDVAR-1	80.89	63.46	S	6.09	133.98	20.81	19.18	1.10	6.75	32.33
2015/TOINDVAR-2	80.48	61.05	S	5.99	76.24	17.93	18.08	0.95	6.29	35.33
2015/TOINDVAR-3	46.42	35.41	MS	26.69	192.68	35.14	33.85	2.74	3.61	35.33
2015/TOINDVAR-4	35.70	25.73	MR	41.36	313.74	41.86	42.51	4.03	3.51	34.33
2015/TOINDVAR-5	21.68	16.15	MR	60.57	393.26	58.11	47.32	4.83	3.80	35.67
2015/TOINDVAR-6	46.08	35.39	MS	49.16	282.31	48.39	46.65	4.81	3.79	36.33
ARKA VIKASH	39.39	30.30	MS	33.83	219.70	43.87	36.00	4.56	3.96	36.33
Sem±				0.555	8.467	1.323	0.862	0.045	0.025	0.684
CD (p=0.05)				1.710*	26.091*	4.077*	2.657*	0.140*	0.077*	2.109*
CV				3.008	6.369	6.029	4.291	2.391	0.957	3.377

Table 4.116: Overall performance of 2015/TOINDVAR entries in both the years (2015-16 and 2016-17)

Entry/ variety	Disease incidence (%)	PDI	Reaction	Average fruit weight (g)	Total yield (q ha ⁻¹)	Equatorial diameter of fruit (mm)	Polar diameter of fruit (mm)	Thickness of pericarp (mm)	TSS (% Brix)	First fruiting (DAT)
2015/TOINDVAR-1	84.67	65.69	S	6.05	130.48	20.11	18.74	1.06	6.73	32.50
2015/TOINDVAR-2	73.54	55.47	S	5.93	83.62	18.14	17.90	0.96	6.28	34.83
2015/TOINDVAR-3	42.53	31.59	MS	26.82	198.91	35.67	34.27	2.71	3.63	34.67
2015/TOINDVAR-4	32.77	23.24	MR	41.44	321.65	42.71	42.96	4.00	3.54	34.50
2015/TOINDVAR-5	25.98	18.81	MR	61.30	384.41	57.49	47.78	4.78	3.78	36.00
2015/TOINDVAR-6	53.10	39.81		48.98	266.03	48.11	47.02	4.84	3.82	36.67
ARKA VIKASH	38.17	28.52	MS	33.99	231.16	43.78	36.55	4.50	3.93	36.00
Sem±				0.347	5.104	0.873	0.508	0.028	0.029	0.554
CD (p=0.05)				1.069*	15.726*	2.691*	1.564*	0.087*	0.088*	1.707*
CV				1.874	3.829	3.981	2.510	1.493	1.096	2.740

Table 4.117: Correlation of disease incidence and percent disease index of leaf curl with various plant parameters of 2015/TOINDVAR entries

Parameters	Mean	
	Disease incidence	PDI
PDI	1.000 ^{**}	-
No of fruits plant⁻¹	0.928 ^{**}	0.928 ^{**}
Fruit yield plant⁻¹ (kg)	-0.830 ^{**}	-0.827 ^{**}
Average fruit weight (g)	-0.848 ^{**}	-0.845 ^{**}
Marketable yield q ha⁻¹	-0.857 ^{**}	-0.852 ^{**}
Unmarketable yield q ha⁻¹	-0.915 ^{**}	-0.920 ^{**}
Total yield (q ha⁻¹)	-0.868 ^{**}	-0.863 ^{**}
Equatorial diameter of fruit (mm)	-0.877 ^{**}	-0.871 ^{**}
Polar diameter of fruit (mm)	-0.853 ^{**}	-0.852 ^{**}
Number of locules fruit⁻¹	-0.671 [*]	-0.652 ^{NS}
Thickness of pericarp (mm)	-0.836 ^{**}	-0.832 ^{**}
TSS (% Brix)	0.925 ^{**}	0.926 ^{**}
Plant height (cm)	0.591 ^{NS}	0.598 ^{NS}
No. of primary branches plant⁻¹	0.480 ^{NS}	0.499 ^{NS}
No. of secondary branches plant⁻¹	-0.282 ^{NS}	-0.293 ^{NS}
First flowering (DAT)	0.108 ^{NS}	0.118 ^{NS}
50 per cent flowering (DAT)	0.343 ^{NS}	0.354 ^{NS}
First fruiting (DAT)	-0.613 ^{NS}	-0.617 ^{NS}



Fig 4.37: Experimental plots of 2015/TOCVAR entries



Fig 4.38: Experimental plots of 2015/TOINDVAR entries

and TSS ($r = 0.926$, $p = 0.001$) expressed significant positive correlation with percent disease index of leaf curl. However rest other parameters showed either non significant positive or negative correlation with percent disease index.

Leaf curl is an important severe and destructive disease of tomato. There are so many methods have been developed for the management of the disease and with the exception of vector control through chemicals (insecticides) none of the methods are as effective as host plant resistance *i.e.* use of resistant/tolerant varieties. But the ToLCV overcomes resistance and make it susceptible after some period of time by bringing change in their genetic content consequently we need to search new source of resistance for the development of new varieties. Screening is one of the important steps for the development of new resistant variety and also it is a tedious and laborious work. Therefore we screened a total of seventy six entries / varieties of tomato from three major groups *viz.* tomato leaf curl virus resistance entries, popular commercial varieties and tomato entries. Among the thirty two tomato entries eighteen were from determinate, seven from indeterminate and remaining seven were from cherry tomato sub groups.

Among the twenty one tomato leaf curl virus resistance entries two (2014/ToLCVRES-3 and 2015/ToLCVRES-5) were resistant, five (2014/ToLCVRES-1, 2014/ToLCVRES-4, 2015/ToLCVRES-1, 2015/ToLCVRES-4 and 2016/ToLCVRES-1) were moderately resistant and remaining were moderately susceptible and susceptible in first year of experiment however in the second year none of the entry was found resistant against the ToLCD. The reaction of only one entry (2016/ToLCVRES-1) was constant as moderately resistant in both years. Arora, *et al.* (2011) screened twelve tomato genotypes, two resistant checks (56-14-7 and 58-11-1-1), two susceptible checks (Punjab Upma and Punjab Chhuhara) and eight advanced lines (11-22, 2-20-2, 6-2-3, 4-4-1-1, 7-4-5, 8-3-2, 8-5-2-1 and 1-2-3), for disease incidence of tomato leaf curl viral disease (ToLCVD). All eight advanced lines showed zero per cent infection and were found to be resistant to ToLCV and Punjab Upma and Punjab Chhuhara were susceptible.

Out of twenty three popular commercial varieties the performance of seventeen varieties was constant in both the years of which ten varieties *viz.*

Bharani, Bhagyan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham and NS 962 were found resistant and four (MHTM 256, Anvitha, Nun 7610 and Kundan) were moderately resistant and remaining were either moderately susceptible or susceptible. The results are in agreement with the findings of Rajasri and Vijayalakshmi, (2013) who found that among the twenty nine tomato genotypes including 15 hybrids, 13 varieties screened against ToLCD, one wild accession, EC251672 was immune without any symptoms, ten genotypes comprising of 9 hybrids viz. Akash-918, NS-539, NS-515, Siri-9005, STH-803, STH-807, To-1827, US-1196, US-2175 and one cv. Vybhav were resistant against ToLCD. Singh, (2014) reported that among thirty two tomato genotypes screened for its resistance/ susceptible reaction against tomato leaf curl disease, one wild accession, H-88-78-1 was immune without producing any symptoms of leaf curl disease, three genotypes viz. Hissar Lalima, TLBRH-6 and NS-515 were resistant and eight viz. Hissar Anmol, Kishi Vishesh, Kashi Amrit, Kashi Sharad, KS-17, KS-118, Avinash-2 and US-1008 were moderately resistant to ToLCV.

In determinate sub group two (2016/TODVAR-5 and 2016/TODVAR-12) were resistant, two (2014/TODVAR-5 and 2016/TODVAR-10) were moderately resistant and remaining were moderately susceptible and susceptible in first year of experiment whereas in the second year of experiment three (2016/TODVAR-5, 2016/TODVAR-10 and 2016/TODVAR-12) were resistant and two (2014/TODVAR-5 and H-86) were moderately resistant. The performance of eleven entries was constant in both the experimental years, of which two (2016/TODVAR-5 and 2016/TODVAR-12) were resistant, one (2014/TODVAR-5) was moderately resistant and remaining were moderately susceptible and susceptible. Similar kind of work done by Bora, *et al.* (2012) who tested a total of 18 tomato genotypes, received under AICRP against leaf curl virus under natural condition for three consecutive rabi seasons (2007-08 to 2009-10). The pooled data of 3 years revealed that tomato genotype 'H-24' exhibited lowest incidence of leaf curl virus of 9.60 per cent up to flowering and fruiting stage as against 20.40 per cent in the susceptible check 'Punjab Chhuhara'.

In cherry tomato sub group none of the entry was found resistant against tomato leaf curl disease in both the years however 2015/TOCVAR-5 and

2015/TOCVAR-3 were moderately resistant in 2015-16 and 2016-17 respectively and remaining were either moderately susceptible or susceptible. Among the seven indeterminate entries evaluated during 2015-16 and 2016-17 none of the entry was found resistant against tomato leaf curl disease in both the years but two entries (2015/TOINDVAR-4 and 2015/TOINDVAR-5) showed moderately resistant reaction. The present results are supported with the finding of Singh, *et al.* (2015) who did an evaluation study of 83 morphologically diverse tomato genotypes and found that none of genotypes was found highly resistant and resistant, only 6 were moderately resistant, while moderately susceptible, susceptible and highly susceptible were 39, 25 and 13, respectively.

In most of the resistant / moderately resistant entries / varieties the first symptoms of the ToLCD were appeared 30 and 45 days after transplanting however in moderately susceptible / susceptible entries / varieties the disease was occurred 15 and 30 days after transplanting. In earlier studies it has been reported that at 30 days after transplanting, all the accessions get infected with *Tomato leaf curl virus*. At 30 days after transplanting (Osei *et al.*, 2012). The incidence and percent disease index (PDI) of the disease were low in resistant and moderately resistant entries/ varieties at final observation (90 DAT) whereas in moderately susceptible and susceptible entries / varieties these were high (Jindal and Khan, 2014). Yield, quality and other parameters were better in most of the resistant and moderately resistant entries/ varieties than the moderately susceptible and susceptible (Camara *et al.*, 2013).

The number of fruits plant⁻¹, fruit yield plant⁻¹, average fruit weight, marketable yield plot⁻¹, unmarketable yield plot⁻¹ and total yield plot⁻¹ are the important yield attributes that contribute the final yield *i.e.* marketable yield ha⁻¹, unmarketable yield ha⁻¹ and total yield ha⁻¹. These parameters are influenced with the incidence and PDI of disease (Kashina *et al.*, 2004 and Sundharaiya *et al.*, 2009). In both years among the all tomato leaf curl virus resistance entries the number of fruits plant⁻¹ were higher in H-24, 2014/ToLCVRES-2, 2015/ToLCVRES-3, 2016/ToLCVRES-1, 2016/ToLCVRES-4 and 2016/ToLCVRES-7 than others and least in Punjab Chhuhara. The performance of five popular commercial varieties such as Arka Rakshak, Bhagyawan, Kundan,

Bharani and Priya-6636 were outstanding for number of fruits plant⁻¹ and lowest in Punjab Chhuhara. Five (2014/TODVAR-3, H-86, 2016/ToDVAR-5, 2016/ToDVAR-12 and 2016/ToDVAR-10), one (Swarna Ratan) and two (2015/TOINDVAR-1 followed by 2015/TOINDVAR-2) entries from determinate, cherry and indeterminate sub groups were found to produce higher number of fruits plant⁻¹ than the others. Shekhawat and Srivastava (2011) recorded maximum number of fruits plant⁻¹ from resistant crosses.

The performance of six entries viz. 2014/ToLCVRES-2, 2014/ToLCVRES-5, 2015/ToLCVRES-5, 2016/ToLCVRES-6, 2016/ToLCVRES-1 and H-24 from TOLCVRES group were quite more than the others to produce per plant fruit yield. Out of all popular commercial varieties evaluated the maximum fruit yield plant⁻¹ was obtained in Arka Rakshak, Bharani, Priya-6636, Bhagyawan and Kundan and minimum in Punjab Chhuhara. Five (H-86, 2014/TODVAR-3, 2016/TODVAR-12, 2016/TODVAR-5 and 2016/TODVAR-10), one (Swarna Ratan) and two (2015/TOINDVAR-5 and 2015/TOINDVAR-6) entries from determinate, cherry and indeterminate sub groups produced per plant maximum fruit yield. The resistant and moderately resistant genotypes produced highest fruit yield plant⁻¹ (Kashina *et al.*, 2004 and Sundharaiya *et al.*, 2009).

The fruits produced by 2015/ToLCVRES-1, 2014/ToLCVRES-1, 2015/ToLCVRES-5, 2016/ToLCVRES-4 and 2016/ToLCVRES-1 were heavier than the others. The average fruit weight of Anvitha, Arka Rakshak, VNR-3357, Karan and VNR-3348 was higher than the other commercial varieties. Five (H-86, 2014/ToDVAR-1, 2016/ToDVAR-12, 2016/ToDVAR-3 and 2016/ToDVAR-7), two (2015/TOCVAR-5 and 2015/TOCVAR-4) and two (2015/TOINDVAR-5 and 2015/TOINDVAR-6) entries from determinate, cherry and indeterminate sub groups respectively were found to produce heavy fruits. Our findings were supported with the findings of Sundharaiya *et al.* (2009) who observed significant negative correlation of tomato leaf curl incidence with yield and found significant positive correlation between number of fruits plant⁻¹ and yield plant⁻¹. Osei *et al.*, 2012 found that tomato accession G12 gave the highest number of fruits plant⁻¹ however B23 recorded the highest average fruit weight. Earlier worker like De

Castro *et al.*, (2005) reported that resistant genotype Anastasia yielded highest number of fruits plant⁻¹ with maximum average fruit weight.

Marketable yield represents the actual yield of crop which is being sold in the market. Among the twenty one tomato leaf curl virus resistance entries the plausible marketable yield ha⁻¹ was obtained in six entries viz. 2015/ToLCVRES-5, 2014/ToLCVRES-5, 2015/ToLCVRES-1, 2016/ToLCVRES-1, 2016/ToLCVRES-4 and 2016/ToLCVRES-6. The per hectare marketable yield of Arka Rakshak, Abhilash, Bharani, Bhagyanwan and Saksham were superior and it was inferior in Punjab Chhuhara and Pusa Ruby. The performance of four (H-86, 2016/TODVAR-12, 2016/TODVAR-5 and 2016/TODVAR-10), one (Swarna Ratan) and two (2015/TOINDVAR-5 and 2015/TOINDVAR-4) entries from determinate, cherry and indeterminate sub groups respectively were commendable to produce per hectare marketable yield. The finding of Ozores-Hampton *et al.* (2013) espoused the present results who explained that resistant or moderately resistant varieties/ lines produced more marketable yield than susceptible.

Hence it is not necessary that whole produce of the crop is being fit or able to be sold so this yield is denoted as unmarketable yield. The unmarketable yield was produced due to rough blossom end scars (BES), zippering, catfacing, sunscald, yellow shoulders, off shapes and radial or concentric cracking (Ozores-Hampton *et al.*, 2013). The unmarketable yield ha⁻¹ was found low in 2015/ToLCVRES-5, 2014/ToLCVRES-4, 2015/ToLCVRES-3, 2016/ToLCVRES-5 and 2016/ToLCVRES-1 however it was high in 2014/ToLCVRES-2 and 2016/ToLCVRES-4. Saksham, Kundan, NS 962, Lakshmi and Arka Rakshak were found to produce minimum unmarketable yield ha⁻¹ and maximum was in Bharani and Nun 7610. In determinate type entries the unmarketable yield ha⁻¹ of 2014/TODVAR-2, 2016/TODVAR-8, 2016/TODVAR-7 and 2016/TODVAR-3 were lower than the other determinate entries and unmarketable yield ha⁻¹ was greatest in 2014/TODVAR-3 and 2016/TODVAR-5. Among the cherry tomato the minimum yield ha⁻¹ in unmarketable category was obtained from 2015/TOCVAR-2 and 2015/TOCVAR-5 and maximum from Swarna Ratan. The unmarketable yield ha⁻¹ of 2015/TOINDVAR-1 and 2015/TOINDVAR-2 were inferior to others and maximum in 2015/TOINDVAR-5. In this study we have observed that

unmarketable yield increased with increase in percent disease index of tomato leaf curl disease (Ozores-Hampton *et al.*, 2013).

Total yield ha^{-1} represents the gross yield of crop which includes both marketable and unmarketable yield and it is one of the most important criteria for the selection of variety. In ToLCVRES group moderately resistant (2015/ToLCVRES-5 and 2016/ToLCVRES-1) and susceptible entries (2014/ToLCVRES-5 2015/ToLCVRES-1 2016/ToLCVRES-4 and 2016/ToLCVRES-6) produced higher total yield ha^{-1} rather than the resistant whereas lowest yield was gained from the susceptible checks (Punjab Chhuhara). In contrast to our results Bora, *et al.* (2012) achieved highest fruit yield from H-24. The yield performance of Arka Rakshak, Bharani, Abhilash, Bhagyawan and Priya-6636 were scrumptious than other commercial varieties and least in Punjab Chhuhara, Pusa Ruby and NS 962. The maximum total yield ha^{-1} was obtained in H-86, 2016/TODVAR-12, 2016/TODVAR-5 and 2016/TODVAR-10 from determinate, Swarna Ratan from cherry tomato and 2015/TOINDVAR-5 and 2015/TOINDVAR-4 from indeterminate group. However minimum yield was found in 2014/TODVAR-1 and 2016/TODVAR-4, 2015/TOCVAR-2 and 2015/TOINDVAR-2 from determinate, cherry and indeterminate sub groups respectively. Mihretu and Bhalekar, (2016) undertaken an investigation to evaluate F5 and F6 generations of tomato genotypes for yield potential during spring-summer 2009-10 and 2010-11. They recorded maximum yield in (T26, 87-2 $\times$ 18-1-1) in F5 and 57.35 t ha^{-1} (T25, 87-2 $\times$ 18-1-1) in F6 generation. Sain and Chadha, (2012) evaluated 30 improved lines of tomato for yield performance and field tolerance/resistance against *Tomato leaf curl virus*. In 2007, yield ranged from 27.92 to 83.74 t ha^{-1} , while in 2008 it ranged from 62 to 80 t ha^{-1} . Lines DR2-1 (BL1173), DR-4 (BL1176), and NC 3220 $\times$ 57-27-3 were found to be high yielding and stable throughout the two-year period.

Quality parameters of fruit such as equatorial diameter, polar diameter, number of locules per fruit, pericarp thickness, total soluble solid (TSS), fruit shape and colour are the important factors that directly or indirectly influence the market value of yield. The desirable qualities for a tomato cultivar to be used for processing includes high total soluble solids (4-8° Brix), acidity not less than 0.4%,

pH less than 4.5, uniform red colour, smooth surface, free from wrinkles, small core, firm flesh and uniform ripening (Adsule *et al.*, 1980, Chattopadhyay *et al.*, 2013).

The equatorial and polar diameters determine the fruit shape and size and the combinations of fruit shape, size and colour give various patterns of physical appearance to fruit. Thus these parameters directly influence the market value of fruits by fascinating consumer with their attractive physical appearance. The large fruits were harvested from 2015/ToLCVRES-5, 2014/ToLCVRES-1, 2015/ToLCVRES-4, 2016/ToLCVRES-4 (oblong shaped) and 2016/ToLCVRES-5 which were either round or flattish round in shape however smallest fruits were collected from Punjab Chhuhara which were pear shaped. The fruits of Kareena, Anvitha, MHTM 256, Arundhati 809 and Abhilash were large with higher equatorial diameter and all were round shaped while both the susceptible varieties Punjab Chhuhara and Pusa Ruby were smallest. Among the determinate entries H-86, 2014/TODVAR-3, 2016/TODVAR-7, 2016/TODVAR-12 and 2016/TODVAR-10 produced bigger and round shaped fruits and 2014/TODVAR-5 produced smallest fruits which were oval shaped (Bhati, 2017). However in cherry tomato entries the large fruits with maximum equatorial diameter were collected from 2015/TOCVAR-3 and 2015/TOCVAR-5 and these were round shaped. The fruits of 2015/TOCVAR-1 were smallest which were oblong to pear shaped. In indeterminate tomato the largest fruit was obtained from 2015/TOINDVAR-5, 2015/TOINDVAR-6 and minimum from 2015/TOINDVAR-2 however all the entries were either round or flattish round in shape (de Melo *et al.*, 2015).

The polar diameter represents the length/ height of fruit that determines the fruit shape and size. The polar diameter was maximum in oval (2015/ToLCVRES-1, 2014/ToLCVRES-4, 2016/ToLCVRES-2) and pear (Punjab Chhuhara) shaped fruits and minimum (H-24) in round shaper fruits. In commercial varieties group the polar diameter of Kundan, Punjab Chhohara, Kohinoor and Arka Rakshak were higher than the others and with the exception of Punjab Chhohara these four were oval in shaped however round shaped fruits (Pusa Ruby and S-22) had minimum polar diameter. Among the determinate entries 2014/TODVAR5,

2016/TODVAR-1 produced oval / oval to oblong shaped fruits with maximum polar diameter whereas fruits of 2014/TODVAR-4 had least polar diameter with round shape (Bhati, 2017). However in cherry tomato sub group one entry (2015/TOCVAR-1) was oblong to pear shaped and rests other was either round or flattish round in shape but fruits of 2015/TOCVAR-4 and 2015/TOCVAR-5 had higher polar diameter than the others. In indeterminate sub group entries all the seven entries were either round shaped and maximum polar diameter was measured in 2015/TOINDVAR-5 with lowest in 2015/TOINDVAR-2. Thus it was revealed from the results that the equatorial diameter indicates the globosity of fruits and generally round shaped fruits had wider equatorial diameter whereas polar diameter represents the length/ height of fruits and generally oval/ pear shaped fruits had higher polar diameter (Chattopadhyay *et al.*, 2013). Tiwari (1996) reported that entries/ hybrids with high polar diameter and having pear shape are desired for processing purpose.

The higher number of locules were counted in 2015/ToLCVRES-5, 2014/ToLCVRES-3, H-24, 2014/ToLCVRES-1 and 2016/ToLCVRES-4 with lowest in Punjab Chhuhara. In commercial varieties the maximum number of locules was seen in the fruits of Kareena, MHTM 256, Bharani, Karishma and Red Ruby and minimum in Kundan and Arka Rakshak. The fruits of five entries (2014/TODVAR-1, 2014/TODVAR-3, 2016/TODVAR-7, 2016/TODVAR-11 and 2016/TODVAR-12) from determinate, two (2015/TOCVAR-3 and 2015/TOCVAR-4) from cherry and two (2015/TOINDVAR-5 and Arka Vikash) from indeterminate sub groups carried maximum number of locules with minimum in 2014/TODVAR-6, Swarna Ratan and 2015/TOINDVAR-2 from determinate cherry and indeterminate sub groups respectively. The locules are directly derived from the carpels in the flower. Locule number affects fruit shape and can increase fruit size up to fifty per cent (Muños *et al.*, 2011). Thus, the increase in locule number is an important factor for development of large tomato fruit (Lippman and Tanksley, 2001 and Clevenger, 2013).

Thickness of pericarp influences the shelf life of fruits and bears an important quality attributes for processing purpose (Chattopadhyay *et al.*, 2013). The maximum pericarp thickness was measured in fruits of 2014/ToLCVRES-4,

2015/ToLCVRES-3, 2015/ToLCVRES-1, 2016/ToLCVRES-5 and 2016/ToLCVRES-1 and minimum in Punjab Chhuhara and 2014/ToLCVRES-2. Among the commercial varieties Abhilash, Kareena, Karan, Bhagyanwan and Nun 7610 produced fruits with thicker pericarp than other however Pusa ruby produced fruits with very thin pericarp. The fruits of five entries (2016/TODVAR-1, 2016/TODVAR-10, 2016/TODVAR-2 and 2014/TODVAR-6) from determinate, two (2015/TOCVAR-4 and 2015/TOCVAR-5) from cherry tomato and two (2015/TOINDVAR-6 and 2015/TOINDVAR-5) from indeterminate sub groups had thick pericarp than the other entries. In earlier study de Melo *et al.*, 2015 measured mesocarp thickness.

High total soluble solids (TSS) are the main quality component for nutrition and processing purposes (Kumari *et al.*, 1998 and Chattopadhyay *et al.*, 2013). The total soluble solids content was higher in 2014/ToLCVRES-1, 2016/ToLCVRES-2, 2014/ToLCVRES-3 and 2016/ToLCVRES-6 than other entries and lowest in H-24 and 2016/ToLCVRES-4. The performance of Kundan, Red Ruby, Karan, S-22 and Arundhati 809 were commendable for TSS content in fruits than other entries however Nun 7610 and Karishma presented poor performance. Among all the determinate entries the fruits of 2014/TODVAR-2, 2016/TODVAR-4, 2014/TODVAR-5 and 2016/TODVAR-1 had higher TSS content with minimum in 2014/TODVAR-3 and 2016/TODVAR-3 (Bhati, 2017). Out of all the cherry tomato entries, 2015/TOCVAR-2 produced fruits with maximum total soluble solids content and least in Swarna Ratan. In indeterminate entries the fruits of 2015/TOINDVAR-1 and 2015/TOINDVAR-2 contained higher TSS than the other entries and minimum in 2015/TOINDVAR-4. Sundharaiya *et al.* (2009) reported negative but non significant correlation between tomato leaf curl incidence and TSS.

Depending upon the relative levels of carotenoid pigments in the fruit, colour can range from yellow to orange, pink, red or even white. The specific carotenoid, lycopene provides the fruit with its red colour. Highest levels of beta-carotene provide an orange colour (Chattopadhyay *et al.*, 2013 and de Melo *et al.*, 2015). Among the seventy six entries / varieties from various groups of tomato evaluated against tomato leaf curl disease most of the entries / varieties were red to

deep red, some were either red or deep red, few were either light red to deep red or light red to red however very few were either light red to red or orange yellow.

The tomato leaf curl disease also affects the other parameters such as plant height, number of primary branches plant⁻¹, number of secondary branches plant⁻¹, days to first flowering (DT1F), days to 50% flowering (DT5F) and days to first fruiting (DTFF). The plants of most of the resistant and moderately resistant entries (2014/ToLCVRES-1, 2014/ToLCVRES-4, 2015/ToLCVRES-5, 2016/ToLCVRES-5 and 2016/ToLCVRES-6) were taller than the moderately susceptible and susceptible entries. Among the commercial varieties the maximum plant height was measured in Abhilash, Kundan, Saksham, Karan and Lakshmi and with the exception of Kundan (moderately resistant) these all were resistant against TOLCD. The plants of susceptible varieties were stunted whereas the plant height of other varieties was intermediate and least plant height was recorded in Red Ruby. In determinate tomato the plants of 2014/ToDVAR-3, 2014/ToDVAR-2, 2014/ToDVAR-4, H-86, and 2014/ToDVAR-2 and 2016/ToDVAR-5 were taller than the other entries and were shortest in 2016/ToDVAR-2 and 2014/ToDVAR-1. This was confirmed with the findings of Bhati (2017) who evaluated nine TODVAR for growth yield and quality characters. In case of cherry tomato the tallest plants were found in 2015/TOCVAR-2 and 2015/TOCVAR-3 minimum plant height was recorded from Swarna Ratan. Among the seven indeterminate entries evaluated during 2015-16 and 2016-17 the maximum plant height was measured from the population of 2015/TOINDVAR-1 and 2015/TOINDVAR-5 and lowest from Arka Vikash. These results are in corroboration with the findings of Sundharaiya *et al.* (2009) who observed significant negative correlation between tomato leaf curl incidence and plant height. Other workers like Thangam (2004) and Makesh (2004) found same result.

In ToLCVRES group the number of primary branches plant⁻¹ were maximum in H-24, 2014/ToLCVRES-1, 2016/ToLCVRES-6 and 2014/ToLCVRES-3 and minimum in 2015/ToLCVRES-2 and 2016/ToLCVRES-4. However the maximum number of secondary branches plant⁻¹ were counted in 2015/ToLCVRES-5 2014/ToLCVRES-2 and Punjab Chhuhara. The plants of Punjab Chhuhara, Pusa Ruby and Red Ruby had higher number of primary and

secondary branches plant⁻¹ than the other commercial varieties whereas Anvitha and MHTM 256 had least number of primary and secondary branches plant⁻¹ respectively. Among the determinate entries 2014/ToDVAR-4, 2014/ToDVAR-3, 2016/ToDVAR-5 and 2016/ToDVAR-11 produced higher number of primary branches and 2014/ToDVAR-4, 2014/ToDVAR-3, 2016/ToDVAR-1 and 2016/ToDVAR-5 produced maximum number of secondary branches plant⁻¹. The least number of primary and secondary branches plant⁻¹ were observed in 2014/ToDVAR-1 and 2016/ToDVAR-10 respectively. The plants of 2015/TOCVAR-2 and 2015/TOCVAR-1 hold maximum number of primary and secondary branches plant⁻¹ respectively than the other cherry tomato entries. In case of indeterminate tomato the plants of 2015/TOINDVAR-1 and 2015/TOINDVAR-6 had most number of primary and secondary branches plant⁻¹ and remaining entries had lower number of branches. The present results were justified with the findings of Sundharaiya *et al.* (2009) who observed that number of branches plant⁻¹ exhibited significant negative correlation with tomato leaf curl incidence and significant positive correlation with yield.

The days required for first flowering, 50% flowering and first fruiting may affect the yield and selection of variety. The Percent disease index (PDI) of ToLCD can influence these characters to the some extent. The first flowering were seen in 2015/ToLCVRES-2, 2015/ToLCVRES-5 and H-24 whereas H-24, 2015/ToLCVRES-2, 2015/ToLCVRES-5 and 2016/ToLCVRES-4 required minimum days for 50% flowering. The first fruits were seen in 2015/ToLCVRES-4 and 2015/ToLCVRES-2. The flowering and fruiting were comparatively early in NS 962, Priya-6636 and MHTM 256 than other commercial varieties with last in Punjab Chhuhara. Among the determinate entries 2016/ToDVAR-5, 2014/ToDVAR-1, 2016/ToDVAR-10, 2016/ToDVAR-7 and 2014/ToDVAR-6 formed early flowering and fruiting than the others. However 2014/ToDVAR-5 and 2016/ToDVAR-4 required maximum days for flowering and fruiting. The flowering was even in all the entries of cherry tomato however fruiting was uneven with early fruiting in 2015/TOCVAR-1 and 2015/TOCVAR-4 and late fruiting in Swarna Ratan. The first flower set, 50% flowering and first fruiting was occurred in 2015/TOINDVAR-4 and 2015/TOINDVAR-3 with delay flowering and fruiting

in Arka Vikash. Earlier workers like Ahirwar and Prashad (2013) and Shekhawat and Srivastava (2011) also studied the growth parameters of tomato genotypes/crosses.

Among the ToLCVRES entries 2016/ToLCVRES-1 and 2015/ToLCVRES-5 gave the outstanding overall performance. In case of commercial varieties evaluated Abhilash, Bhagyawan, Arundhati 809, Bharani Arka Rakshak displayed resistant reaction with good yield, quality and other traits. The overall performance of 2016/TODVAR-12, 2016/TODVAR-5, 2016/TODVAR-10 and H-86 were better than the other determinate entries. Bhati, 2017 found that among the nine genotypes, TODVAR-8 was found superior and recorded maximum number of fruits plant⁻¹, average fruit weight, yield ha⁻¹, equatorial diameter, polar diameter, total soluble solid content, plant height and number of branches plant⁻¹. Though among the cherry tomato 2015/TOCVAR-5 and 2015/TOCVAR-4 were better on overall performance but on yield basis Swarna Ratan was best. In indeterminate sub group the performance of 2015/TOINDVAR-5 and 2015/TOINDVAR-4 were superior over other indeterminate entries. Shekhawat and Srivastava (2011) and Sundharaiya *et al.* (2009) also evaluated the tomato genotypes/crosses for resistance to ToLCD with growth, yield and quality parameters.

4.5 To study the management of tomato leaf curl disease through vector control

Five insecticides were tested in combination with silver polythene mulch and maize as border crop to find out best and cost-effective strategy for management of tomato leaf curl disease through vector control. The data are presented in Table 4.118 to 4.161 (Fig 4.39 – 4.41).

4.5.1 Management of tomato leaf curl disease through vector control during 2015-16

During experimental year 2015-16 no symptoms of ToLCD was observed up to 3 days after 1st insecticide spray (vegetative stage) among the treated plots but in untreated control plots it appeared a day before the 1st spray with incidence and PDI of 0.86 and 0.12 percent that gradually increased and reached up to 3.51 percent incidence and 1.00 PDI at 5 days after 1st spray (Table 4.118). However, in treatment plots the disease first appeared in T₆ (1.67 and 0.24 percent) at the 5 day

after the 1st spray (Table 4.118) followed by in T₅ (0.86 and 0.12 percent) at 1 day before the 2nd spray, T₁ (1.70 and 0.24 percent) at 5 day after 2nd spray (Table 4.119), T₂ (2.59 and 0.85 percent) at 1 day before 3rd spray, T₄ (0.86 and 0.12 percent) at 1 day after 3rd spray and last in T₃ (0.83 and 0.12 percent) at 3 days after 3rd spray (Table 4.120). The initial alive population of adult whitefly was first noticed at 3 days after 1st spray in untreated control plots (0.15) while in treated plots the first activity of whitefly was observed in T₆ (0.10) at 5 days after 1st spray followed by in T₂ (0.40), T₃ (0.25), T₄ (0.15) and T₅ (0.10) at a day before 2nd spray with last appearance in T₁ (0.30) at 1 day after second spray.

It is clear from the results that the percent incidence of leaf curl is directly correlated with vector population and PDI of leaf curl is directly associated with percent leaf curl incidence. In all the treated and untreated plots leaf curl infected plants were seen at 3 days after 3rd spray with the range of 0.83 to 26.06 percent incidence and 0.12 to 13.99 PDI during this period the vector population ranged from 0.15 to 3.05 per ten leaves (Table 4.120). The percent incidence and PDI of leaf curl was lower in all the treated plots in comparison to untreated control. It was revealed from results that the percent incidence and PDI of leaf curl was very low in T₃, T₄ and T₅ with 0.83 and 0.86 percent incidence and 0.12 PDI at 3 days after 3rd spray (Table 4.120). During this period the lowest population of whitefly (0.15) was recorded in the treatment of silver polythene mulch and spray of Thiamethoxam (T₅) followed by T₃ (0.25) and T₄ (0.30) and they were at par with each other. At five days after 3rd spray (Table 4.120) the lowest incidence (0.83 %) and PDI (0.12 %) was recorded in the treatments of silver polythene mulch and spray of Cyantraniliprole / Cyazypyr (T₃) followed by T₅ (0.86 and 0.37%) and T₄ (1.73 and 0.25 %) and they were statistically at par with each other. During this period (Table 4.120) the minimum number of whitefly (0.25) was traced in T₅ followed by T₄ (0.40) and T₃ (0.45). The incidence and PDI of leaf curl was highest in control plots with 26.06 and 27.85 percent incidence and 13.99 and 15.78 PDI at 3 and 5 days after 3rd spray and during this period the vector population was also high (3.05 and 3.25) in control plots where no mulching and insecticides were applied (Table 4.120).

At 1 day before 4th spray the percent incidence and PDI of leaf curl were ranged from 1.70 to 37.77 percent and 0.49 to 22.88 percent respectively (Table 4.121). The percent incidence and PDI of leaf curl was significantly low in all the treated plots than control. With the exception of T₆ all the treatments provided similar trend of incidence however in T₅ the leaf curl incidence was numerically lowest (1.70 %). The lowest (0.49 %) PDI of leaf curl was noted in T₄ and T₅ followed by T₃ (0.72 %) and they were at par with each other (Table 4.121). During this period the minimum number of whitefly (0.75) was registered in the treatment of silver polythene mulch and spray of Thiamethoxam (T₅) followed by T₃ (0.85) and T₄ (0.90) however T₅ and T₃ were at par with each other. The disease incidence 37.77 % and PDI (22.88 %) were highest in control plots as they had maximum number (4.20) of vector population. At 1 day after 4th spray (Table 4.121) the lowest disease incidence (1.73 %) was observed in T₄ followed by T₅ (2.53 %) and T₃ (4.20 %) however lowest disease PDI (0.49 %) was recorded in T₄ and T₅ followed by T₃ (0.84 %) and they were at par with each other. During this period the vector population was found lowest (0.40) in T₅ followed by T₃ and T₄ (0.50) and they were statistically at par with each other. At 3 days after 4th spray (Table 4.121) the incidence of leaf curl was did not increased in all the treated plots as the vector population was suppressed by spray of insecticides but the PDI was increased in three treated plots T₃ (1.56 %), T₅ (0.61 %) and T₆ (10.03 %). The incidence and PDI of leaf curl was maximum in control plots with 39.55 and 41.37 percent incidence and 23.91 and 25.46 PDI at 1 and 3 days after 4th spray because of high vector population (4.05 and 4.30) during this period (Table 4.121). At 5 days after 4th spray the percent disease incidence and PDI were slightly increased. The percent incidence of leaf curl was minimum (2.53 %) in T₅ plots where vector population was found lowest (0.60) this was followed by T₄ (2.56 %) and T₃ (4.20 %) with 0.75 and 0.80 number of whitefly per ten leaves (Table 4.121). The percent incidence (44.94%) and PDI 28.54 %) was maximum in control plots might be due to high vector population (4.70).

At 1 day before 5th spray the percent incidence and PDI of leaf curl were ranged from 4.22 to 57.57 percent and 1.80 to 38.07 percent respectively (Table 4.122). The percent incidence and PDI of leaf curl was significantly low in all the

treated plots in comparison to control. The incidence (4.22 %) and PDI (1.80 %) of leaf curl was lowest in T₅ as it had minimum vector population of 1.20 whiteflies per ten leaves (Table 4.122). This was followed by T₄ (5.98 and 2.81 %) and T₃ (5.87 and 3.00 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 1.40 and 1.50 in T₄ and T₃. Since there was heavy infestation of whitefly (5.20 per ten leaves) therefore the incidence (57.57 %) and PDI was maximum in control plots. At 1 and 3 days after 5th spray (Table 4.122) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased in all the plots where plants were sprayed with insecticides however at 3 days after 5th spray the PDI of leaf curl was slightly increased in T₁ (6.10 %) and T₃ (3.60 %). The incidence and PDI of leaf curl was maximum in control plots with 59.39 and 61.18 percent incidence and 38.59 and 39.61 PDI at 1 and 3 days after 5th spray because the vector population (5.50 and 5.95) was very high during this period (Table 4.122). At 5 days after 5th spray the minimum percent incidence (5.06 %) and PDI (2.40 %) of leaf curl was recorded in T₅ plots where vector population was lowest (1.15) this was followed by T₄ (5.98 and 3.30 %) and T₃ (6.73 and 3.84 %) with 1.30 and 1.45 number of whitefly per ten leaves (Table 4.122).

At 1 day before 6th spray the percent incidence and PDI of leaf curl were ranged from 7.56 to 74.74 percent and 3.49 to 50.06 percent respectively (Table 4.123). The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to control. The lowest incidence (7.56 %) and PDI (3.49 %) of leaf curl was recorded in T₅ as it had minimum vector population of 1.90 whiteflies per ten leaves. This was followed by T₄ (8.56 and 4.89 %) and T₃ (9.23 and 4.91 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 2.05 and 2.15 in T₄ and T₃. Since there was very high population of whitefly (6.85 per ten leaves) in control plots therefore the incidence (74.74 %) and PDI (50.06 %) was highest in these plots. At 1 and 3 days after 6th spray (Table 4.123) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased in all the plots where

plants were sprayed with insecticides however at 3 days after 6th spray the PDI of leaf curl was slightly increased in T₁ (8.62 %) and T₄ (5.13 %). The maximum incidence and PDI of leaf curl was noted in control plots with 77.45 and 78.34 percent incidence and 52.01 and 52.14 PDI at 1 and 3 days after 6th spray because the vector population (6.60 and 6.40) was very high in control plots. At 5 days after 6th spray (Table 4.123) the minimum percent incidence (7.56 %) and PDI (3.73 %) of leaf curl was recorded in T₅ plots where vector population was lowest (1.35) this was followed by T₄ (8.56 and 5.13 %) and T₃ (9.23 and 5.38 %) with 1.55 and 1.70 number of whitefly per ten leaves. At 9 day after 6th spray (Table 4.123) the percent incidence and PDI of leaf curl were ranged from 7.56 to 86.48 percent and 3.96 to 58.46 percent respectively. The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to control. The lowest incidence (7.56 %) and PDI (3.96 %) of leaf curl was recorded in T₅ as it had minimum vector population of 1.20 whiteflies per ten leaves. This was followed by T₄ (8.56 and 5.13 %) and T₃ (10.09 and 6.23 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 1.40 and 1.50 in T₄ and T₃ which were statistically at par with each other. Since there was very high population of whitefly (5.90 per ten leaves) in control plots therefore the incidence (86.48 %) and PDI (58.46 %) was highest in these plots.

The data presented in Table 4.124 and 4.125 displayed that the percent incidence and PDI of leaf curl was very low in all the plots up to 2nd spray with range of 0.0 to 9.19 percent incidence (Table 4.124) and 0.0 to 4.84 PDI (Table 4.125). The control plots showed that the percent incidence and PDI of leaf curl was rapidly increased from 3rd to 6th spray with 25.16 to 79.79 percent incidence and PDI of 13.67 to 53.53 it may be because the vector population (3.03 to 6.37) also rapidly increased during this period (Table 4.126). However in the plots sprayed with insecticides the percent disease incidence (Table 4.124) and PDI (Table 4.125) was gradually increased because whitefly population (Table 4.126) was also slowly increased due to insecticides. After each spray the whitefly population was found very low in T₅, T₄ and T₃ therefore in these treated plots the percent incidence and PDI of leaf curl was lower than the other treated plots. It was

also revealed from the average data of six sprays that among all the treated and untreated plots the average disease incidence (2.67 %), PDI (1.10 %) and vector population (0.58) was lowest in T₅ (Table 4.124 to 4.126). The average percent incidence (36.14 %) and PDI (22.79 %) of leaf curl was noted highest in control plots as they were highly infested with whitefly (3.57).

It was revealed from the experimental data presented in Table 4.127 to 4.129 that a day before spray the disease incidence and PDI ranged from 2.53 to 33.42 and 1.00 to 21.19 percent with vector population of 0.74 to 3.38. In all the plots where insecticide sprayed the percent incidence (Table 4.127) and PDI (Table 4.128) of leaf curl was gradually increased before spray because during this period the vector population (Table 4.129) was also slightly high in these plots (T₁: 1.13, T₂: 1.05, T₃: 0.91, T₄: 0.85 and T₅: 0.74). But in control (33.42 and 21.19 %) and T₆ (14.12 and 8.05 %) plots the percent disease incidence and PDI was quickly increased as they had higher vector population (3.38 and 2.08) (Table 4.129). It was observed that the disease incidence almost did not increased in plots sprayed with insecticide up to 3 days after spray as in these plots the vector population was suppressed by insecticides. But the disease incidence was appeared to gradually increase 5 days after spray in the crops sprayed with insecticide because in these plots the population of whitefly was starting to recover. However 1 to 5 days after spray the percent incidence and PDI of leaf curl was also gradually increased in control and T₆ plots. The results displayed that at 9 days after last spray the vector population (Table 4.129) was greatly increased therefore the percent incidence (Table 4.127) of leaf curl was also quickly increased with higher PDI (Table 4.128) in all the treated and control plots.

4.5.2 Management of tomato leaf curl disease through vector control during 2016-17

The disease was not occurred at a days before 1st spray in all the treated and untreated plots (Table 4.130). The leaf curl symptoms were started to appear at 1 day after 1st spray in few plants of T₆ and control plots with incidence of 0.83 percent PDI of and 0.36 and 0.12 percent respectively and during this period the vector population was nil in all the plots. At 3 days after spray the disease was also appeared in T₂ (1.67 %) and T₄ (0.83 %) with PDI of 0.48 and 0.36 percent

Table 4.118: Effect of spray on leaf curl disease and vector population (First spray at 10 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ
T ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)
T ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)
T ₄	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)
T ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)
T ₆	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)
T ₇	0.86	0.12	0.00	0.86	0.12	0.00	1.73	0.25	0.15	1.67	0.24	0.10
	(1.00) ^δ	(0.71) ^δ	(0.71)	(1.00) ^δ	(0.71) ^δ	(0.71)	(1.29) ^δ	(0.71) ^δ	(0.63) ^δ	(1.88) ^δ	(0.97) ^δ	(0.54) ^δ
Sem±	0.109	0.001	0.000	0.109	0.001	0.000	0.125	0.001	0.023	0.121	0.057	0.035
CD (p=0.05)	0.323	0.003	0.000	0.323	0.003	0.000	0.373*	0.003*	0.069	0.360*	0.170*	0.103*
CV	4.134	0.038	0.000	4.134	0.038	0.000	4.526	0.044	0.949	3.622	2.198	1.478

^δ Value in parentheses are square root transformed, [¶] Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.119: Effect of spray on leaf curl disease and vector population (Second spray at 20 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.30	1.70	0.24	0.75
	(0.71) ^δ	(0.71) ^δ	(0.70) ^δ	(0.71) ^δ	(0.71) ^δ	(0.54) ^δ	(0.71) ^δ	(0.71) ^δ	(0.54) ^δ	(1.28) ^δ	(0.70) ^δ	(0.86) ^δ
T ₂	0.00	0.00	0.40	0.00	0.00	0.20	0.00	0.00	0.25	0.00	0.00	0.60
	(0.71)	(0.71)	(0.63)	(0.71)	(0.71)	(0.45)	(0.71)	(0.71)	(0.50)	(0.71)	(0.71)	(0.77)
T ₃	0.00	0.00	0.25	0.00	0.00	0.10	0.00	0.00	0.25	0.00	0.00	0.50
	(0.71)	(0.71)	(0.50)	(0.71)	(0.71)	(0.58)	(0.71)	(0.71)	(0.50)	(0.71)	(0.71)	(0.70)
T ₄	0.00	0.00	0.15	0.00	0.00	0.10	0.00	0.00	0.20	0.00	0.00	0.45
	(0.71)	(0.71)	(0.52)	(0.71)	(0.71)	(0.58)	(0.71)	(0.71)	(0.45)	(0.71)	(0.71)	(0.67)
T ₅	0.86	0.12	0.10	0.86	0.12	0.05	0.86	0.12	0.10	0.86	0.12	0.30
	(1.00)	(0.71)	(0.58)	(1.00)	(0.71)	(0.65)	(1.00)	(0.71)	(0.40)	(1.00)	(0.71)	(0.54)
T ₆	3.39	0.72	0.70	3.39	0.72	1.05	3.39	0.72	1.30	4.26	0.84	1.55
	(1.75)	(0.87)	(0.83)	(1.75)	(0.87)	(1.02)	(1.75)	(0.87)	(1.13)	(2.04)	(0.87)	(1.23)
T ₇	7.11	4.08	1.15	7.17	4.11	1.65	10.78	5.13	2.10	11.68	6.03	2.30
	(2.62)	(1.99)	(1.08)	(2.63)	(1.99)	(1.28)	(3.26)	(2.23)	(1.44)	(3.39)	(2.44)	(1.51)
Sem±	0.207	0.102	0.050	0.207	0.101	0.051	0.196	0.103	0.078	0.183	0.08	0.053
CD (p=0.05)	0.615*	0.303*	0.147*	0.616*	0.301*	0.153*	0.582*	0.307*	0.233*	0.545*	0.237*	0.158*
CV	5.044	3.187	2.057	5.040	3.159	2.015	4.428	3.105	3.169	3.733	2.333	1.698

^δ Value in parentheses are square root transformed, ^ρ Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.120: Effect of spray on leaf curl disease and vector population (Third spray at 30 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	2.53 (1.55) ^δ	1.57 (1.26) ^δ	0.95 (0.97) ^δ	3.36 (9.05) ^β	2.16 (1.44) ^δ	0.35 (0.58) ^δ	4.20 (11.68) ^β	2.28 (1.44) ^δ	0.50 (0.70) ^δ	4.20 (11.68) ^β	2.76 (1.65) ^δ	0.65 (0.80) ^δ
T ₂	2.59 (1.57)	0.85 (0.92)	0.75 (0.86)	3.42 (10.66)	1.22 (1.04)	0.30 (0.54)	3.42 (10.66)	1.22 (1.04)	0.35 (0.59)	3.42 (10.66)	1.70 (1.26)	0.55 (0.73)
T ₃	0.00 (0.71)	0.00 (0.71)	0.70 (0.83)	0.00 (0.00)	0.00 (0.71)	0.25 (0.50)	0.83 (2.63)	0.12 (0.71)	0.25 (0.50)	0.83 (2.63)	0.12 (0.71)	0.45 (0.67)
T ₄	0.00 (0.71)	0.00 (0.71)	0.60 (0.77)	0.86 (2.68)	0.12 (0.71)	0.25 (0.61)	0.86 (2.68)	0.12 (0.71)	0.30 (0.54)	1.73 (5.36)	0.25 (0.71)	0.40 (0.63)
T ₅	0.86 (1.00)	0.12 (0.71)	0.50 (0.70)	0.86 (2.68)	0.12 (0.71)	0.15 (0.52)	0.86 (2.68)	0.12 (0.71)	0.15 (0.52)	0.86 (2.68)	0.37 (0.84)	0.25 (0.50)
T ₆	8.54 (2.91)	3.91 (1.97)	1.95 (1.39)	8.54 (16.92)	3.91 (1.97)	1.90 (1.37)	9.40 (17.80)	5.49 (2.34)	1.50 (1.22)	10.26 (18.56)	5.61 (2.36)	1.85 (1.36)
T ₇	22.45 (4.71)	11.94 (3.44)	2.85 (1.69)	24.27 (29.40)	12.97 (3.58)	2.95 (1.71)	26.06 (30.58)	13.99 (3.72)	3.05 (1.74)	27.85 (31.65)	15.78 (3.94)	3.25 (1.80)
Sem±	0.230	0.126	0.043	2.156	0.152	0.056	2.014	0.154	0.050	2.012	0.134	0.031
CD (p=0.05)	0.683*	0.375*	0.128*	6.405*	0.451*	0.167*	5.983*	0.459*	0.148*	5.979*	0.398*	0.093*
CV	3.496	2.602	1.197	6.040	2.991	1.938	5.117	2.900	1.721	4.837	2.341	0.964

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.121: Effect of spray on leaf curl disease and vector population (Fourth spray at 40 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	6.70 (14.77) ^β	3.83 (1.93) ^δ	1.15 (1.07) ^δ	7.53 (15.64) ^β	4.19 (2.03) ^δ	0.70 (0.83) ^δ	7.53 (15.64) ^β	4.19 (2.03) ^δ	0.90 (0.95) ^δ	9.23 (17.51) ^β	4.91 (12.68)	1.15 (1.07) ^δ
T ₂	5.12 (12.90)	2.67 (1.61)	1.10 (1.05)	5.12 (12.90)	2.67 (1.61)	0.55 (0.73)	5.12 (12.90)	2.67 (1.61)	0.85 (0.92)	6.01 (14.06)	3.29 (10.37)	1.00 (1.00)
T ₃	3.36 (9.05)	0.72 (0.87)	0.85 (0.92)	4.20 (11.68)	0.84 (0.87)	0.50 (0.70)	4.20 (11.68)	1.56 (1.21)	0.70 (0.83)	4.20 (11.68)	2.05 (7.90)	0.80 (0.89)
T ₄	1.73 (5.36)	0.49 (0.84)	0.90 (0.95)	1.73 (5.36)	0.49 (0.84)	0.50 (0.70)	1.73 (5.36)	0.49 (0.84)	0.70 (0.83)	2.56 (7.99)	0.61 (3.74) ^β	0.75 (0.86)
T ₅	1.70 (5.31)	0.49 (0.83)	0.75 (0.86)	2.53 (7.94)	0.49 (0.83)	0.40 (0.61)	2.53 (7.94)	0.61 (0.83)	0.60 (0.77)	2.53 (7.94)	1.09 (4.96)	0.60 (0.77)
T ₆	16.26 (23.70)	9.41 (3.06)	2.20 (1.48)	17.13 (24.38)	9.78 (3.12)	2.20 (1.48)	17.13 (24.38)	10.03 (3.16)	2.40 (1.55)	19.69 (26.31)	11.85 (20.13)	2.70 (1.64)
T ₇	37.77 (37.84)	22.88 (4.77)	4.20 (2.05)	39.55 (38.87)	23.91 (4.87)	4.05 (2.01)	41.37 (39.98)	25.46 (5.04)	4.30 (2.07)	44.94 (42.05)	28.54 (32.26)	4.70 (2.17)
Sem±	2.383	0.144	0.040	1.863	0.147	0.056	1.769	0.153	0.040	1.838	1.274	0.054
CD (p=0.05)	7.082*	0.427*	0.118*	5.534*	0.438*	0.166*	5.256*	0.454*	0.120*	5.460*	3.784*	0.160*
CV	4.377	2.068	0.950	3.191	2.080	1.581	3.001	2.079	1.022	2.882	2.768	1.282

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.122: Effect of spray on leaf curl disease and vector population (Fifth spray at 50 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	10.89 (17.84) ^β	5.86 (13.80) ^β	1.80 (1.34) ^δ	10.89 (19.12) ^β	5.86 (13.80) ^β	1.35 (1.16) ^δ	10.89 (19.12) ^β	6.10 (14.06) ^β	1.40 (1.18) ^δ	11.75 (20.00) ^β	6.70 (14.87) ^β	1.65 (1.28) ^δ
T ₂	9.40 (16.67)	5.00 (12.76)	1.75 (1.32)	9.40 (17.80)	5.00 (12.76)	1.30 (1.14)	9.40 (17.80)	5.00 (12.76)	1.45 (1.20)	10.30 (18.58)	5.38 (13.24)	1.60 (1.26)
T ₃	5.87 (11.83)	3.00 (9.94)	1.50 (1.22)	5.87 (13.91)	3.00 (9.94)	1.05 (1.02)	6.73 (15.04)	3.60 (10.88)	1.30 (1.14)	6.73 (15.04)	3.84 (11.21)	1.45 (1.20)
T ₄	5.98 (13.08)	2.81 (9.65)	1.40 (1.18)	5.98 (14.04)	2.81 (9.65)	1.10 (1.04)	5.98 (14.04)	2.81 (9.65)	1.20 (1.08)	5.98 (14.04)	3.30 (10.38)	1.30 (1.14)
T ₅	4.22 (9.90)	1.80 (7.46)	1.20 (1.10)	4.22 (11.70)	1.80 (7.46)	0.90 (0.94)	4.22 (11.70)	1.80 (7.46)	1.10 (1.04)	5.06 (12.81)	2.40 (8.91)	1.15 (1.06)
T ₆	25.69 (29.38)	15.16 (22.89)	3.25 (1.80)	26.55 (30.95)	15.77 (23.35)	3.20 (1.79)	26.55 (30.95)	16.02 (23.53)	3.45 (1.86)	27.39 (31.53)	16.14 (23.63)	3.90 (1.97)
T ₇	57.57 (48.63)	38.07 (38.09)	5.20 (2.28)	59.39 (50.44)	38.59 (38.40)	5.50 (2.35)	61.18 (51.51)	39.61 (39.00)	5.95 (2.44)	62.07 (52.05)	40.25 (39.37)	6.50 (2.55)
Sem±	1.401	0.899	0.047	1.288	0.891	0.056	1.345	0.968	0.060	1.313	0.789	0.051
CD (p=0.05)	4.164*	2.670*	0.138*	3.826*	2.648*	0.168*	3.997*	2.876*	0.178*	3.900*	2.345*	0.150*
CV	1.902	1.569	0.911	1.631	1.545	1.196	1.680	1.650	1.210	1.600	1.298	0.969

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.123: Effect of spray on leaf curl disease and vector population (Sixth spray at 60 DAT) 2015-16

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray			9 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	15.09 (21.37) ^β	7.90 (16.10) ^β	2.40 (1.54) ^δ	15.09 (22.71) ^β	7.90 (16.10) ^β	1.70 (1.30) ^δ	15.09 (22.71) ^β	8.62 (16.88) ^β	1.80 (1.34) ^δ	15.09 (22.71) ^β	8.86 (17.09) ^β	1.90 (1.37) ^δ	15.09 (22.71) ^β	9.59 (17.88) ^β	1.85 (1.35) ^δ
T ₂	12.88 (20.14)	7.02 (15.10)	2.30 (1.51)	12.88 (20.88)	7.02 (15.10)	1.55 (1.24)	12.88 (20.88)	7.02 (15.10)	1.70 (1.30)	12.88 (20.88)	7.49 (15.63)	1.75 (1.32)	12.88 (20.88)	7.73 (15.92)	1.70 (1.30)
T ₃	9.23	4.91	2.15	9.23	4.91	1.35	9.23	4.91	1.55	9.23	5.38	1.70	10.09	6.23	1.50
T ₄	8.56 (15.86)	4.89 (12.71)	2.05 (1.43)	8.56 (16.93)	4.89 (12.71)	1.30 (1.14)	8.56 (16.93)	5.13 (13.04)	1.45 (1.20)	8.56 (16.93)	5.13 (13.04)	1.55 (1.24)	8.56 (16.93)	5.13 (13.04)	1.40 (1.18)
T ₅	7.56 (15.10)	3.49 (10.72)	1.90 (1.37)	7.56 (15.90)	3.49 (10.72)	1.20 (1.09)	7.56 (15.90)	3.49 (10.97)	1.30 (1.13)	7.56 (15.90)	3.73 (11.10)	1.35 (1.15)	7.56 (15.10)	3.96 (11.42)	1.20 (1.10)
T ₆	30.83 (32.41)	19.08 (25.83)	4.40 (2.10)	30.83 (33.65)	19.32 (26.01)	4.20 (2.05)	30.83 (33.65)	19.32 (26.01)	4.05 (2.01)	30.83 (33.65)	20.06 (26.54)	3.90 (1.98)	31.67 (34.20)	21.40 (27.51)	3.90 (1.98)
T ₇	74.74 (59.89)	50.06 (45.03)	6.85 (2.62)	77.45 (61.70)	52.01 (46.16)	6.60 (2.57)	78.34 (62.35)	52.14 (46.23)	6.40 (2.53)	81.94 (64.92)	54.97 (47.86)	6.10 (2.47)	86.48 (68.59)	58.46 (49.89)	5.90 (2.43)
Sem±	1.218	0.920	0.052	1.074	0.895	0.058	1.087	0.905	0.060	1.138	0.902	0.052	1.193	0.953	0.051
CD (p=0.05)	3.619*	2.734*	0.154*	3.192*	2.660*	0.172*	3.230*	2.689*	0.177*	3.382*	2.680*	0.155*	3.546*	2.831*	0.151*
CV	1.343	1.334	0.862	1.135	1.286	1.098	1.145	1.286	1.109	1.183	1.250	0.964	1.218	1.271	0.966

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.124: Effect of spray on leaf curl incidence (2015-16)

Treatment	Average percent disease incidence of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	0.43	3.57	7.75	11.11	15.09	6.32
T ₂	0.00	0.00	3.21	5.34	9.63	12.88	5.18
T ₃	0.00	0.00	0.42	3.99	6.30	9.40	3.35
T ₄	0.00	0.00	0.86	1.94	5.98	8.56	2.89
T ₅	0.00	0.86	0.86	2.32	4.43	7.56	2.67
T ₆	0.42	3.61	9.19	17.55	26.55	31.00	14.72
T ₇	1.74	9.19	25.16	40.91	60.05	79.79	36.14

Table 4.125: Effect of spray on percent disease index of leaf curl (2015-16)

Treatment	Average percent disease index of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	0.06	2.19	4.28	6.13	8.57	3.54
T ₂	0.00	0.00	1.25	2.83	5.10	7.26	2.74
T ₃	0.00	0.00	0.06	1.29	3.36	5.27	1.66
T ₄	0.00	0.00	0.12	0.52	2.93	5.03	1.43
T ₅	0.00	0.12	0.18	0.70	1.95	3.63	1.10
T ₆	0.06	0.75	4.73	10.27	15.77	19.84	8.57
T ₇	0.37	4.84	13.67	25.20	39.13	53.53	22.79

Table 4.126: Effect of spray on population of whitefly (2015-16)

Treatment	Average whitefly population						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	0.46	0.61	0.98	1.55	1.93	0.92
T ₂	0.00	0.36	0.49	0.88	1.53	1.80	0.84
T ₃	0.00	0.28	0.41	0.71	1.33	1.65	0.73
T ₄	0.00	0.23	0.39	0.71	1.25	1.55	0.69
T ₅	0.00	0.14	0.26	0.59	1.09	1.39	0.58
T ₆	0.03	1.15	1.80	2.38	3.45	4.09	2.15
T ₇	0.11	1.80	3.03	4.31	5.79	6.37	3.57

Table 4.127: Efficacy of insecticide spray on incidence of leaf curl (2015-16)

Treatment	Percent disease incidence (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	5.87	6.15	6.29	7.00	15.09
T ₂	5.00	5.14	5.14	5.44	12.88
T ₃	3.08	3.22	3.50	3.50	10.09
T ₄	2.71	2.86	2.86	3.14	8.56
T ₅	2.53	2.67	2.67	2.81	7.56
T ₆	14.12	14.41	14.55	15.68	31.67
T ₇	33.42	34.78	36.58	38.67	86.48

Table 4.128: Efficacy of insecticide spray on percent disease index of leaf curl (2015-16)

Treatment	Percent disease index (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	3.19	3.35	3.53	3.91	9.59
T ₂	2.59	2.65	2.65	2.98	7.73
T ₃	1.44	1.46	1.70	1.90	6.23
T ₄	1.37	1.39	1.43	1.55	5.13
T ₅	1.00	1.02	1.02	1.29	3.96
T ₆	8.05	8.25	8.60	9.12	21.40
T ₇	21.19	21.95	22.76	24.43	58.46

Table 4.129: Efficacy of insecticide spray on population of whitefly (2015-16)

Treatment	Population of whitefly (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	1.13	0.73	0.82	1.02	1.85
T ₂	1.05	0.65	0.77	0.92	1.70
T ₃	0.91	0.54	0.68	0.82	1.50
T ₄	0.85	0.54	0.64	0.74	1.40
T ₅	0.74	0.45	0.54	0.61	1.20
T ₆	2.08	2.09	2.12	2.33	3.90
T ₇	3.38	3.46	3.66	3.86	5.90

respectively. During this period the vector population was observed only in T₆ (0.15) and control (0.30) plots. Up to 5 days after spray the disease was occurred in all the plots except T₁ where plants were free from disease however the whitefly was noticed in these plots (0.20). At 5 days after spray the disease was visible in T₃ and T₄ with incidence of 0.83 percent and PDI of 0.12 and 0.36 percent respectively but whitefly was not observed in these plots. Among the all treatments the maximum incidence (7.02 %) and PDI (2.01 %) was observed in control plot at 5 days after spray.

Up to a day before 2nd spray (Table 4.131) in all the treated and untreated plots the plants have been infected with leaf curl and the incidence and PDI were ranged 1.67 to 9.70 and 0.72 to 4.66 percent respectively. During this period the vector population ranged from 0.05 to 0.85 per ten leaves. The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to untreated control. The data showed that the percent incidence of leaf curl was very low (1.67 %) in T₄ and T₂ followed by T₁ (1.73 %). However the minimum PDI (0.72 %) was recorded from T₄ followed by T₁ (0.74 %) and T₃ (0.84 %). During this period the lowest population of whitefly (0.05) was recorded in T₂ followed by T₃ and T₅ (0.15) and they were statistically similar with each other. At a day before 2nd spray the maximum disease incidence (9.70 %), PDI (4.66 %) and vector population (0.85) were registered in control plots. At 1 day after 2nd spray the percent incidence (1.67 to 9.70 %) and PDI (0.95 to 6.42) were slightly increased in all the plots except T₂ where incidence was unchanged (1.67 %) and with the exception of T₁ (0.15) and T₄ (0.25) the vector population was also increased in all the plots even after spray. The minimum disease incidence (1.67 %) was recorded in T₂ followed by T₄ (2.50 %) and T₁ (3.48 %). The lowest disease PDI (0.95 %) was noted in T₃ followed by T₂ (1.19 %) and T₄ (1.55 %). However the minimum number of whitefly (0.15) was traced in T₁ followed by T₂, T₃ and T₅ (0.20). The maximum disease incidence (9.70 %) and PDI (6.42 %) was registered in control because they also had highest (1.55) vector population. In all the plots where crops were sprayed with insecticides the disease incidence was not increased at 3 days after 2nd spray but PDI and vector population showed very little increasing trend. The lowest percent incidence was recorded in T₂ (1.67 %) followed by T₄ (2.50 %)

and T₁ (3.48 %). However the minimum disease PDI was registered in T₂ (1.19 %) followed by T₃ (1.43 %) and T₄ (1.79 %). The vector population was noted lowest (0.15) in T₄ followed by T₁ (0.25), T₂ and T₃ (0.35). The maximum number of whitefly (2.25) was counted in control plots therefore the disease incidence (14.07 %) and PDI (8.03 %) was also recorded maximum in these plots. At 5 days after 2nd spray the percent incidence and PDI of leaf curl was gradually increased in some plots but vector population was increased in all the plots. The lowest incidence (1.67 %) was recorded in T₂ followed by T₄ (3.33 %) and T₁ (3.48 %). However the disease PDI was recorded maximum in T₂ (1.19 %) followed by T₃ (1.81 %) and T₄ (2.38 %). The vector population was noted very low in T₃ (0.50) this was followed by T₂ (0.70) and T₅ (0.75). The maximum number of whitefly (2.55) was recorded from control plots therefore the disease incidence (14.96 %) and PDI (9.18 %) was maximum in these plots.

At a day before 3rd spray (Table 4.132) the percent leaf curl incidence and PDI and vector population was significantly low in all the treated plots in comparison to control. The lowest percent incidence was recorded in T₂ and T₄ (3.33 %) followed by T₁ (3.48 %) and they were statistically similar with each other. However the minimum PDI (1.91 %) was recorded from T₂ followed by T₄ (2.38 %) and T₁ (2.49 %). During this period the lowest population of whitefly (0.80) was recorded in T₃ followed by T₂ (0.95) and T₁ (1.10) and they were statistically at par with each other. At a day before 3rd spray the maximum disease incidence (19.31 %), PDI (12.29 %) and vector population (2.90) were registered in control plots. At 1 day after 3rd spray (Table 4.132) the increasing trend was observed in percent incidence and PDI but decreasing trend was observed for the vector population in the crops sprayed with insecticides. The minimum disease incidence (3.33 %) was recorded in T₂ followed by T₄ (4.17 %) and T₃ (4.23 %). The lowest disease PDI (2.14 %) was noted in T₂ followed by T₁ (2.61 %) and T₄ (2.98 %). The vector population was traced lowest in T₃, T₄ and T₅ with 0.15 whitefly per ten leaves. The maximum disease incidence (21.06 %) and PDI (13.04 %) was registered in control because they also had highest (2.95) vector population. In all the plots where crops were sprayed with insecticides the disease incidence did not increased at 3 days after 3rd spray but slight increment was

noticed in PDI and vector population. The minimum disease PDI (2.14 %) and vector population (0.30) was recorded in T₂ followed by T₄ (2.98 % and 0.40) and T₃ (3.02 % and 0.45). The disease incidence (23.71 %) and PDI (14.68 %) was noted maximum in control plots as they had maximum number of whitefly (3.15). At 5 days after 3rd spray no increment was observed in percent disease incidence and PDI in all the treated and untreated plots but incidence and PDI was slightly increased in T₁ (5.27 %) and control (14.92 %) plots respectively. However the vector population was risen in all the plots with minimum (0.55) in T₂ and T₃ and maximum (3.15) in control.

At a day before 4th spray (Table 4.133) all the treated plots provided statistically similar disease incidence however numerically low incidence was observed in T₄ (5.00 %). The lowest (2.98 %) PDI of leaf curl was noted in T₂ followed by T₃ (3.21 %) and T₄ (3.33 %) and they were at par with each other. During this period the minimum number of whitefly (1.10) was counted in T₃ followed by T₂ (1.25) and T₅ (1.35) however T₂ and T₃ were at par with each other. The maximum disease incidence (33.34 %), PDI (21.07 %) and vector population (3.85) were recorded in control plots. At 1 day after 4th spray the disease incidence in T₂ (5.83 %), T₃ (5.20 %) and T₅ (7.58 %) was remained same as recorded a day before 4th spray and other treatments showed increment in disease incidence. The minimum disease incidence (5.11 %) was recorded in T₄ followed by T₃ (5.20 %) and T₂ (5.83 %). The lowest disease PDI (3.45 %) was noted in T₂ followed by T₃ (3.46 %) and T₄ (3.65 %). About half of the vector population declined after spray in the crops sprayed with insecticides. The lowest (0.45) vector population was traced in T₃ followed by T₂ (0.60), T₄ and T₅ (0.65). The maximum disease incidence (35.99 %) and PDI (22.45 %) was noted in control because they also had high (3.70) vector population. It was observed that the disease incidence was increased in some plots and also unchanged in some plots at 3 days after 4th spray whereas PDI of leaf curl and vector population was increased in all the plots. The lowest disease incidence (5.11 %) was noted in T₄ followed by T₃ (5.30 %) and T₂ (6.67 %). However the disease PDI was recorded minimum (3.53 %) in T₃ followed by T₄ (3.65 %) and T₂ (3.81 %) and they were statistically at par with each other. The activity of whitefly was observed minimum (0.85) in T₃ followed

by T₄ and T₅ (1.05). The maximum disease incidence (37.72 %) was noted in control plots as vector population was high (4.10) in these plots as well as the PDI was also highest (24.46 %) in untreated control. There was no increment have been observed in percent disease incidence at 5 days after 3rd spray in the treated plots however little and considerable increment was noticed in PDI and vector population respectively. The lowest disease incidence (5.11 %) and PDI (3.65 %) was recorded in T₄ followed by T₃ (5.30 and 3.78 %) and T₂ (6.67 and 4.05 %). The minimum (1.35) vector population was traced in T₃ followed by T₂ (1.70), T₄ and T₅ (1.80).

At 1 day before 5th spray (Table 4.134) the percent incidence and PDI of leaf curl were ranged from 6.13 to 48.28 and 3.90 to 30.98 percent respectively. The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to control. The lowest incidence (6.13 %) and PDI (3.90 %) of leaf curl was lowest in T₃ as it had lowest vector population of 1.65 whiteflies per ten leaves. This was followed by T₄ (7.65 and 4.49 %) and T₂ (8.33 and 5.48 %). However T₂, T₃ and T₄ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 2.30 and 2.35 in T₅ and T₄ respectively. Since there was heavy infestation of whitefly (5.35 per ten leaves) therefore the incidence (48.28 %) and PDI (30.98 %) was recorded maximum in control plots. At 1 day after 5th spray (Table 4.134) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased in all the plots where plants were sprayed with insecticides. There was little increment has been recorded in percent incidence and PDI of leaf curl along with vector population in almost all the plots at 3 days after 5th spray. The minimum disease incidence (6.96 %) and PDI (4.02 %) was recorded in T₃ followed by T₄ (7.65 and 5.22 %) and T₅ (8.42 and 5.54 %) and they were at par with each other. The lowest (0.90) vector population was also counted from T₃ followed by T₅ (1.45), T₂ and T₄ (1.55). The maximum disease incidence (54.40 %) and PDI (35.10 %) along with whitefly (5.90) were observed in control plots. There was no increment have been observed in percent disease incidence at 5 days after 5th spray in treated plots however little and considerable increment was noticed in PDI and vector population respectively. The lowest

disease incidence (6.96 %) and PDI (4.26 %) was recorded in T₃ followed by T₄ (7.65 and 5.22 %) and T₅ (8.42 and 5.54 %). The minimum (1.15) vector population was traced in T₃ followed by T₅ (1.85), T₁ and T₄ (1.90). The crops of control plots were severely infested with whitefly (6.40 per ten leaves) therefore the maximum percent disease incidence (57.05 %) and PDI (37.50 %) was recorded in control.

There was considerable increment have been observed on disease incidence, PDI and vector population in all the treatments at 1 day before 6th spray (Table 4.135). The minimum disease incidence (6.96 %) and PDI (4.97 %) was observed in T₃ as the vector population was very low in T₃ this was followed by T₄ (8.51 and 5.58 %) and T₅ (9.25 and 5.90). During this period the adult whitefly population was 2.60 and 2.80 in T₄ and T₅ respectively. Since there was very high infestation of whitefly (6.40 per ten leaves) therefore the incidence (65.83 %) and PDI (43.52 %) was recorded maximum in control plots. At 1 day after 6th spray (Table 4.135) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased nearly in all the plots where plants were sprayed with insecticides but little increment has been observed in percent incidence (9.37 %) and PDI (5.95 %) of T₄. The lowest (1.15) vector population was recorded in T₃ followed by T₄ (1.60) and T₂ (1.65). The highest disease incidence (68.45 %), PDI (46.15 %) and vector population (6.50) was observed in control plots. It was observed that the disease incidence was increased in some plots and also unchanged in some plots at 3 days after 6th spray whereas leaf curl PDI and vector population was increased almost in all the plots. The lowest disease incidence (6.96 %) and PDI (4.97 %) was noted in T₃ followed by T₅ (9.25 and 6.13 %) and T₄ (9.37 and 6.20 %) however they were statistically at par with each other. The activity of whitefly was observed minimum (1.35) in T₃ followed by T₄ (1.85) and T₅ (1.95). The maximum disease incidence (70.20 %) was noted in control plots as vector pressure was very high (6.15 whitefly per ten leaves) in these plots as well as the PDI was also highest (48.93 %) in untreated control. At 5 days after 6th spray the minimum percent incidence (6.96 %) and PDI (4.97 %) of leaf curl was recorded in T₃ followed by T₅ (9.25 and 6.13 %) and T₄ (10.23 and 7.05 %) and they were at par with each other. The lowest vector

population was registered (1.60) in T₃ followed by T₄ (1.95) and T₁ (2.15). The maximum disease incidence (73.71 %) and PDI (51.21 %) was noted in control plots as vector population was high (5.85) in these plots. At 9 day after 6th spray the percent incidence and PDI of leaf curl were ranged from 6.96 to 76.36 percent and 4.97 to 55.08 percent respectively. The lowest disease incidence (6.96 %) and PDI (4.97 %) was recorded in T₃ as it had minimum vector population of 1.60 whiteflies per ten leaves. This was followed by T₅ (10.11 and 6.74 %) and T₄ (11.09 and 7.67 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 2.00 and 2.15 in T₁ and T₄. Since there was very high population of whitefly (5.60 per ten leaves) in control plots therefore the incidence (76.36 %) and PDI (55.08 %) was highest in these plots.

The data presented in Table 4.136 and 4.137 displayed that the percent incidence and PDI of leaf curl was very low in all the plots up to 1st spray with range of 0.0 to 2.83 and 0.0 to 0.78 percent incidence and PDI respectively. The control plots showed that the percent incidence (Table 4.136) and PDI (Table 4.137) of leaf curl was rapidly increased from 2nd to 6th spray with 12.11 to 69.55 percent incidence and PDI of 7.07 to 47.45 because the vector population (1.80 to 6.30) also rapidly increased during this period (Table 4.138). However in the plots sprayed with insecticides the percent disease incidence and PDI was gradually increased because whitefly population was also slowly increased due to insecticides. After each spray the whitefly population was found very low in all the treated plots (Table 4.138) where insecticides were sprayed therefore in these plots the percent incidence (Table 4.136) and PDI (Table 4.137) of leaf curl was lower than the control and T₆ plots. It was also revealed from the average data of six sprays that among all the treated and untreated plots the lowest average disease incidence (4.42 %), PDI (2.78 %) and vector population (0.73) was observed in T₅. The highest average percent incidence (32.58 %) and PDI (21.10 %) of leaf curl was noted in control plots as they were highly infested with whitefly (3.53).

It was revealed from the experimental data presented in Table 4.139 to 4.141 that a day before spray the disease incidence and PDI ranged from 4.17 to 29.41 and 2.58 to 18.75 percent with vector population of 0.94 to 3.28. In all the

plots where insecticide sprayed the percent incidence (Table 4.139) and PDI (Table 4.140) of leaf curl was little speedily increased before spray because during this period the vector population (Table 4.141) was also slightly high in these plots (T_1 : 1.44, T_2 : 1.28, T_3 : 0.94, T_4 : 1.33 and T_5 : 1.28). But in control (29.41 and 18.75 %) and T_6 (10.15 and 5.61 %) plots the percent disease incidence and PDI was quickly increased as they had higher vector population (2.17 and 3.28). There was little increment has been observed in disease incidence and PDI of plots sprayed with insecticide up to 5 days after spray as in these plots the vector population was suppressed by insecticides. But 1 to 5 days after spray the percent incidence and PDI of leaf curl was gradually increased in control and T_6 plots. The results displayed that at 9 days after last spray the vector population was greatly increased therefore the percent incidence of leaf curl was also quickly increased with higher PDI in all the treated and control plots.

4.5.3 Management of tomato leaf curl disease through vector control during 2015-16 and 2016-17

It was revealed from the pooled data of management that the disease was not occurred at a day before 1st spray (Table 4.142) in all the treated plots but in untreated control plots it was appeared a day before 1st spray with incidence and PDI of 0.43 and 0.06 percent that gradually increased and reached up to 5.27 percent incidence with PDI of 1.51 percent at 5 days after 1st spray (Table 4.142). The leaf curl symptoms were started to appear at 1 day after spray in few plants of T_6 with percent incidence of 0.42 and 0.18 PDI. In all the treated and untreated plots the vector population was nil up to 1 day after 1st spray. At 3 days after spray the disease was also appeared in T_2 (0.84 %) and T_4 (0.42 %) also with PDI of 0.24 and 0.18 percent respectively. During this period the vector population was observed only in T_6 (0.08) and control (0.23) plots. Up to 5 days after spray the disease was occurred in all the plots except T_1 where plants were free from disease however the whitefly was noticed in these plots (0.10). At 5 days after spray the disease was visible in T_3 and T_5 with 0.42 and 1.25 percent incidence and 0.06 and 0.42 PDI respectively but whitefly was not observed in T_3 . Among the all treatments the maximum incidence (5.27 %) and PDI (1.51 %) was observed in control plot at 5 days after spray.

Table 4.130: Effect of spray on leaf curl disease and vector population (First spray at 10 DAT) 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.71) ^δ	(0.56) ^δ
T ₂	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.48	0.00	1.67	0.48	0.05
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(1.18)	(0.88)	(0.71)	(1.18)	(0.71)	(0.65)
T ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.12	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.99)	(0.71)	(0.71)
T ₄	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.36	0.00	0.83	0.36	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.99)	(0.83)	(0.71)	(0.99)	(0.71)	(0.71)
T ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.84	0.05
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(1.54)	(0.83)	(0.65)
T ₆	0.00	0.00	0.00	0.83	0.36	0.00	2.59	0.61	0.15	5.19	1.51	0.30
	(0.71)	(0.71)	(0.71)	(0.99)	(0.83)	(0.71)	(1.57)	(0.83)	(0.63)	(2.24)	(0.89)	(0.54)
T ₇	0.00	0.00	0.00	0.83	0.12	0.00	3.45	1.00	0.30	7.02	2.01	0.55
	(0.71)	(0.71)	(0.71)	(0.99)	(0.71)	(0.71)	(1.76)	(1.01)	(0.53)	(2.64)	(1.17)	(0.73)
Sem±	0.000	0.000	0.000	0.152	0.046	0.000	0.236	0.101	0.038	0.290	0.114	0.049
CD (p=0.05)	0.000	0.000	0.000	0.453	0.137	0.000	0.701*	0.301	0.113*	0.863*	0.340	0.146*
CV	0.000	0.000	0.000	5.517	1.818	0.000	6.188	3.560	1.616	5.750	3.993	2.159

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.131: Effect of spray on leaf curl disease and vector population (Second spray at 20 DAT) 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	1.73 (1.14) ^δ	0.74 (0.96) ^δ	0.35 (0.58) ^δ	3.48 (1.77) ^δ	2.24 (1.47) ^δ	0.15 (0.63) ^δ	3.48 (1.77) ^δ	2.49 (1.53) ^δ	0.25 (0.69) ^δ	3.48 (1.77) ^δ	2.49 (1.53) ^δ	0.80 (0.88) ^δ
T ₂	1.67 (1.18)	0.95 (1.02)	0.05 (0.65)	1.67 (1.18)	1.19 (1.08)	0.20 (0.56)	1.67 (1.18)	1.19 (1.08)	0.35 (0.67)	1.67 (1.18)	1.19 (1.08)	0.70 (0.80)
T ₃	2.50 (1.46)	0.84 (0.95)	0.15 (0.52)	3.33 (1.60)	0.95 (0.98)	0.20 (0.66)	3.33 (1.60)	1.43 (1.10)	0.35 (0.76)	4.23 (1.90)	1.81 (1.23)	0.50 (0.70)
T ₄	1.67 (1.27)	0.72 (0.96)	0.30 (0.81)	2.50 (1.54)	1.55 (1.25)	0.25 (0.60)	2.50 (1.54)	1.79 (1.33)	0.15 (0.52)	3.33 (1.73)	2.38 (1.49)	0.95 (0.93)
T ₅	3.33 (1.73)	2.14 (1.44)	0.15 (0.52)	5.00 (2.16)	3.33 (1.78)	0.20 (0.58)	5.00 (2.16)	3.33 (1.78)	0.45 (0.65)	5.83 (2.35)	3.93 (1.88)	0.75 (0.86)
T ₆	5.19 (2.24)	1.51 (1.16)	0.65 (0.77)	6.02 (2.43)	1.86 (1.33)	1.00 (0.96)	6.95 (2.58)	2.24 (1.45)	1.60 (1.24)	6.95 (2.58)	2.47 (1.51)	1.65 (1.28)
T ₇	9.70 (3.08)	4.66 (2.13)	0.85 (0.90)	9.70 (3.08)	6.42 (2.51)	1.55 (1.24)	14.07 (3.74)	8.03 (2.83)	2.25 (1.50)	14.96 (3.85)	9.18 (3.01)	2.55 (1.59)
Sem±	0.385	0.23	0.088	0.371	0.24	0.107	0.371	0.283	0.076	0.381	0.306	0.087
CD (p=0.05)	1.143*	0.683*	0.262*	1.103*	0.712*	0.318*	1.101*	0.840*	0.227*	1.132*	0.909*	0.260*
CV	6.368	5.341	3.731	5.401	4.610	4.103	5.090	5.103	2.533	4.964	5.219	2.487

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.132: Effect of spray on leaf curl disease and vector population (Third spray at 30 DAT) 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	3.48 (1.77) ^δ	2.49 (1.53) ^δ	1.10 (1.02) ^δ	4.37 (1.97) ^δ	2.61 (1.56) ^δ	0.40 (0.70) ^δ	4.37 (1.97) ^δ	3.12 (1.69) ^δ	0.65 (0.74) ^δ	5.27 (2.12) ^δ	3.51 (1.77) ^δ	1.00 (0.97) ^δ
T ₂	3.33 (1.73)	1.91 (1.32)	0.95 (0.95)	3.33 (1.73)	2.14 (1.41)	0.20 (0.56)	3.33 (1.73)	2.14 (1.41)	0.30 (0.65)	3.33 (1.73)	2.14 (1.41)	0.55 (0.82)
T ₃	4.23 (1.90)	2.54 (1.42)	0.80 (0.89)	4.23 (1.90)	3.02 (1.63)	0.15 (0.55)	4.23 (1.90)	3.02 (1.63)	0.45 (0.65)	4.23 (1.90)	3.02 (1.63)	0.55 (0.73)
T ₄	3.33 (1.73)	2.38 (1.49)	1.30 (1.10)	4.17 (1.88)	2.98 (1.62)	0.15 (0.52)	4.17 (1.88)	2.98 (1.62)	0.40 (0.62)	4.17 (1.88)	2.98 (1.62)	0.65 (0.80)
T ₅	5.83 (2.35)	3.93 (1.94)	1.10 (1.05)	6.67 (2.49)	4.29 (2.02)	0.15 (0.52)	6.67 (2.49)	4.29 (2.02)	0.55 (0.74)	6.67 (2.49)	4.29 (2.02)	0.60 (0.77)
T ₆	6.95 (2.58)	3.45 (1.84)	2.15 (1.46)	6.95 (2.58)	4.46 (2.07)	1.55 (1.20)	6.95 (2.58)	4.46 (2.07)	1.25 (1.10)	6.95 (2.58)	4.46 (2.07)	1.35 (1.16)
T ₇	19.31 (4.39)	12.29 (3.50)	2.90 (1.69)	21.06 (4.58)	13.04 (3.61)	2.95 (1.71)	23.71 (4.87)	14.68 (3.82)	3.15 (1.77)	23.71 (4.87)	14.92 (3.94)	3.15 (1.77)
Sem±	0.380	0.311	0.105	0.408	0.320	0.098	0.403	0.326	0.099	0.413	0.323	0.072
CD (p=0.05)	1.129*	0.925*	0.311*	1.211*	0.950*	0.290*	1.198*	0.967*	0.294*	1.227*	0.960*	0.215*
CV	4.620	4.778	2.562	4.763	4.598	3.402	4.635	4.568	3.154	4.704	4.471	2.069

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.133: Effect of spray on leaf curl disease and vector population (Fourth spray at 40 DAT) 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	7.88 (14.05) ^β	5.14 (2.10) ^δ	1.85 (1.34) ^δ	9.70 (17.50) ^β	5.65 (2.17) ^δ	0.75 (0.85) ^δ	9.70 (17.50) ^β	6.17 (2.34) ^δ	1.35 (1.14) ^δ	9.70 (17.50) ^β	6.93 (2.14) ^δ	2.20 (1.45) ^δ
T ₂	5.83 (11.73)	2.98 (1.63)	1.25 (1.08)	5.83 (11.73)	3.45 (1.72)	0.60 (0.83)	6.67 (12.59)	3.81 (1.81)	1.10 (1.03)	6.67 (12.59)	4.05 (1.31)	1.70 (1.28)
T ₃	5.20 (11.19)	3.21 (1.68)	1.10 (1.03)	5.20 (11.19)	3.46 (1.75)	0.45 (0.65)	5.30 (11.28)	3.53 (1.76)	0.85 (0.90)	5.30 (11.28)	3.78 (2.12)	1.35 (1.13)
T ₄	5.00 (10.61)	3.33 (1.68)	1.45 (1.20)	5.11 (10.71)	3.65 (1.76)	0.65 (0.78)	5.11 (10.71)	3.65 (1.76)	1.05 (1.01)	5.11 (10.71)	3.65 (1.49)	1.80 (1.33)
T ₅	7.58 (15.30)	5.18 (2.18)	1.35 (1.16)	7.58 (15.30)	5.18 (2.18)	0.65 (0.80)	7.58 (15.30)	5.42 (2.22)	1.05 (1.02)	7.58 (15.30)	5.42 (2.13)	1.80 (1.34)
T ₆	9.63 (17.60)	5.37 (2.25)	2.15 (1.46)	11.38 (19.42)	5.65 (2.31)	2.20 (1.47)	11.38 (19.42)	6.15 (2.40)	2.45 (1.55)	11.38 (19.42)	6.89 (2.12)	2.80 (1.65)
T ₇	33.34 (35.26)	21.07 (4.59)	3.85 (1.96)	35.99 (36.86)	22.45 (4.74)	3.70 (1.92)	37.72 (37.89)	24.46 (4.94)	4.10 (2.02)	38.58 (36.88)	26.09 (4.95)	4.40 (2.10)
Sem±	3.616	0.378	0.082	3.204	0.388	0.076	3.317	0.380	0.071	3.471	0.374	0.080
CD (p=0.05)	10.745*	1.122*	0.242*	9.520*	1.153*	0.225*	9.854*	1.130*	0.211*	10.313*	1.112*	0.238*
CV	6.249	4.689	1.766	5.223	4.671	2.077	5.320	4.412	1.640	5.613	4.609	1.561

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.134: Effect of spray on leaf curl disease and vector population (Fifth spray at 50 DAT) 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	11.49 (19.59) ^β	7.68 (15.69) ^β	2.55 (1.58) ^δ	11.49 (19.59) ^β	7.68 (15.69) ^β	1.45 (1.18) ^δ	11.49 (19.59) ^β	7.68 (15.69) ^β	1.65 (1.28) ^δ	11.49 (19.59) ^β	7.94 (16.09) ^β	1.90 (1.37) ^δ
T ₂	8.33 (15.97)	5.48 (12.93)	2.50 (1.57)	8.33 (15.97)	5.48 (12.93)	1.35 (1.14)	10.00 (18.19)	5.72 (13.37)	1.55 (1.23)	10.00 (18.19)	5.95 (13.75)	2.00 (1.40)
T ₃	6.13 (13.92)	3.90 (10.49)	1.65 (1.26)	6.13 (13.92)	3.90 (10.49)	0.75 (0.84)	6.96 (15.02)	4.02 (10.71)	0.90 (0.92)	6.96 (15.02)	4.26 (11.43)	1.15 (1.04)
T ₄	7.65 (15.61)	4.49 (11.67)	2.35 (1.52)	7.65 (15.61)	4.74 (12.18)	1.30 (1.10)	7.65 (15.61)	5.22 (12.72)	1.55 (1.22)	7.65 (15.61)	5.22 (12.72)	1.90 (1.36)
T ₅	8.42 (16.42)	5.54 (13.09)	2.30 (1.51)	8.42 (16.42)	5.54 (13.09)	1.35 (1.16)	8.42 (16.42)	5.54 (13.09)	1.45 (1.20)	8.42 (16.42)	5.54 (12.54)	1.85 (1.36)
T ₆	16.53 (23.80)	9.61 (17.88)	3.45 (1.85)	16.53 (23.80)	9.61 (17.88)	3.75 (1.93)	17.46 (24.42)	10.76 (18.88)	3.75 (1.93)	17.46 (24.42)	11.00 (19.63)	3.95 (1.99)
T ₇	48.28 (44.03)	30.98 (33.81)	5.35 (2.31)	50.86 (45.30)	32.59 (34.76)	5.50 (2.34)	54.40 (47.55)	35.10 (36.33)	5.90 (2.43)	57.05 (49.07)	37.50 (36.52)	6.40 (2.53)
Sem±	2.157	1.962	0.078	2.172	1.934	0.085	1.921	1.924	0.075	1.969	1.822	0.074
CD (p=0.05)	6.408*	5.829*	0.231*	6.452*	5.747*	0.253*	5.708*	5.716*	0.222*	5.851*	5.414*	0.219*
CV	2.889	3.396	1.341	2.884	3.306	1.759	2.450	3.185	1.465	2.488	2.971	1.335

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.135: Effect of spray on leaf curl disease and vector population (Sixth spray at 60 DAT) 2016-17

Treatment	1 Day before spray				1 Day after spray				3 Days after spray				5 Days after spray				9 Days after spray			
	Incidence	PDI	Whitefly		Incidence	PDI	Whitefly		Incidence	PDI	Whitefly		Incidence	PDI	Whitefly		Incidence	PDI	Whitefly	
T ₁	13.28 (21.24) ^β	8.71 (17.00) ^β	2.80 (1.66) ^δ		13.28 (21.24) ^β	8.71 (17.00) ^β	1.80 (1.32) ^δ		13.28 (21.24) ^β	8.98 (17.29) ^β	2.00 (1.38) ^δ		13.28 (21.24) ^β	8.98 (17.47) ^β	2.15 (1.45) ^δ		13.28 (21.24) ^β	9.24 (17.60) ^β	2.00 (1.41) ^δ	
T ₂	10.83 (19.06)	7.02 (15.07)	2.90 (1.69)		10.83 (19.06)	7.02 (15.07)	1.65 (1.26)		11.67 (19.80)	7.38 (15.42)	2.00 (1.40)		12.50 (20.67)	7.98 (16.23)	2.25 (1.48)		12.50 (20.67)	8.45 (16.79)	2.40 (1.54)	
T ₃	6.96 (15.03)	4.97 (12.65)	1.95 (1.38)		6.96 (15.03)	4.97 (12.65)	1.15 (1.04)		6.96 (15.03)	4.97 (12.65)	1.35 (1.13)		6.96 (15.03)	4.97 (12.65)	1.60 (1.25)		6.96 (15.03)	4.97 (12.65)	1.60 (1.24)	
T ₄	8.51 (16.74)	5.58 (13.32)	2.60 (1.60)		9.37 (17.43)	5.95 (13.82)	1.60 (1.25)		9.37 (17.43)	6.20 (14.17)	1.85 (1.35)		10.23 (18.31)	7.05 (15.19)	1.95 (1.39)		11.09 (19.07)	7.67 (15.86)	2.15 (1.45)	
T ₅	9.25 (17.28)	5.90 (13.65)	2.80 (1.67)		9.25 (17.28)	5.90 (13.65)	1.80 (1.34)		9.25 (17.28)	6.13 (13.96)	1.95 (1.39)		9.25 (17.28)	6.13 (13.96)	2.30 (1.51)		10.11 (20.77)	6.74 (14.62)	2.35 (1.53)	
T ₆	22.58 (28.25)	13.70 (21.54)	4.60 (2.15)		23.51 (28.82)	14.86 (22.39)	4.50 (2.12)		25.27 (30.00)	16.36 (23.57)	4.10 (2.02)		26.10 (30.58)	16.72 (23.88)	4.20 (2.05)		28.63 (32.28)	19.54 (26.07)	3.95 (1.98)	
T ₇	65.83 (54.43)	43.52 (41.41)	6.70 (2.59)		68.45 (56.00)	46.15 (42.99)	6.50 (2.55)		70.20 (56.94)	48.93 (44.38)	6.15 (2.48)		73.71 (59.34)	51.21 (45.69)	5.85 (2.42)		76.36 (61.02)	55.08 (47.93)	5.60 (2.37)	
Sem±	1.700	1.483	0.070		1.805	1.539	0.084		1.824	1.524	0.080		1.641	1.457	0.064		1.556	1.439	0.074	
CD (p=0.05)	5.051*	4.406*	0.209*		5.362*	4.573*	0.249*		5.418*	4.528*	0.237*		4.877*	4.330*	0.190*		4.622*	4.275*	0.219*	
CV	1.976	2.203	1.103		2.064	2.238	1.543		2.052	2.155	1.431		1.799	2.010	1.107		1.637	1.900	1.283	

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.136: Effect of spray on leaf curl incidence (2016-17)

Treatment	Average percent disease incidence of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	3.04	4.37	9.25	11.49	13.28	6.91
T ₂	0.84	1.67	3.33	6.25	9.17	11.46	5.45
T ₃	0.21	3.35	4.23	5.25	6.55	6.96	4.42
T ₄	0.42	2.50	3.96	5.08	7.65	9.37	4.83
T ₅	0.63	4.79	6.46	7.58	8.42	9.25	6.19
T ₆	2.15	6.28	6.95	10.94	17.00	24.37	11.28
T ₇	2.83	12.11	21.95	36.41	52.65	69.55	32.58

Table 4.137: Effect of spray on percent disease index of leaf curl (2016-17)

Treatment	Average percent disease index of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	1.99	2.93	5.97	7.75	8.92	4.59
T ₂	0.24	1.13	2.08	3.57	8.53	7.35	3.82
T ₃	0.03	1.26	2.90	3.50	4.02	4.97	2.78
T ₄	0.18	1.61	2.83	3.57	4.92	6.20	3.22
T ₅	0.21	3.18	4.20	5.30	5.54	6.02	4.07
T ₆	0.62	2.02	4.21	6.02	10.25	15.41	6.42
T ₇	0.78	7.07	13.73	23.52	34.04	47.45	21.10

Table 4.138: Effect of spray on population of whitefly (2016-17)

Treatment	Average whitefly population						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.05	0.39	0.79	1.54	1.89	2.15	1.13
T ₂	0.01	0.33	0.50	1.16	1.85	2.20	1.01
T ₃	0.00	0.30	0.49	0.94	1.11	1.51	0.73
T ₄	0.00	0.41	0.63	1.24	1.78	2.00	1.01
T ₅	0.01	0.39	0.60	1.21	1.74	2.21	1.03
T ₆	0.11	1.23	1.58	2.40	3.73	4.35	2.23
T ₇	0.21	1.80	3.04	4.01	5.79	6.30	3.53

Table 4.139: Efficacy of insecticide spray on incidence of leaf curl (2016-17)

Treatment	Percent disease incidence (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	6.31	7.05	7.05	7.20	13.28
T ₂	5.00	5.00	5.84	5.97	12.50
T ₃	4.17	4.31	4.46	4.75	6.96
T ₄	4.36	4.80	4.94	5.22	11.09
T ₅	5.74	6.15	6.15	6.71	10.11
T ₆	10.15	10.87	11.77	12.34	28.63
T ₇	29.41	31.15	33.93	35.84	76.36

Table 4.140: Efficacy of insecticide spray on percent disease index of leaf curl (2016-17)

Treatment	Percent disease index (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	4.13	4.48	4.74	4.98	9.24
T ₂	4.97	3.21	3.45	3.63	8.45
T ₃	2.58	2.72	2.83	2.99	4.97
T ₄	2.75	3.15	3.37	3.61	7.67
T ₅	3.78	4.04	4.12	4.36	6.74
T ₆	5.61	6.13	6.76	7.18	19.54
T ₇	18.75	20.13	22.03	23.49	55.08

Table 4.141: Efficacy of insecticide spray on population of whitefly (2016-17)

Treatment	Population of whitefly (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	1.44	0.76	0.98	1.38	2.00
T ₂	1.28	0.67	0.88	1.21	2.40
T ₃	0.94	0.45	0.65	0.86	1.60
T ₄	1.33	0.66	0.83	1.21	2.15
T ₅	1.28	0.69	0.91	1.23	2.35
T ₆	2.17	2.17	2.22	2.38	3.95
T ₇	3.28	3.37	3.64	3.82	5.60

At 1 day before 2nd spray (Table 4.143) the crop in all treated as well as untreated plots has been infected with leaf curl and incidence and PDI ranged from 0.84 to 8.41 and 0.36 to 4.37 percent respectively. During this period the vector population ranged from 0.13 to 1.00. The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to untreated control. The data showed that the percent incidence of leaf curl was very low (0.84 %) in T₂ and T₄ followed by T₁ (0.87 %) and they were statistically similar with each other. However the minimum PDI (0.36 %) was recorded from T₄ followed by T₁ (0.37 %) and T₃ (0.42 %) and they were at par with each other. During this period the lowest population of whitefly (0.13) was recorded in T₅ followed by T₃ (0.20), T₂ and T₄ (0.23) and they were statistically similar with each other. The pooled data showed that at a day before 2nd spray the maximum disease incidence (8.41 %), PDI (4.37 %) and vector population (1.00) were noted in control plots. At 1 day after 2nd spray (Table 4.143) the percent incidence (0.84 to 8.44 %) and PDI (0.48 to 5.27) were slightly increased in all the plots except T₂ where incidence was unchanged (0.84 %) however the vector population was subsumed in all the treated plots. The minimum disease incidence (0.84 %) was recorded in T₂ followed by T₄ (1.25 %) and T₃ (1.67 %). The lowest disease PDI (0.48 %) was noted in T₃ followed by T₂ (0.60 %) and T₄ (0.78 %). However the minimum number of whitefly (0.13) was traced in T₅ followed by T₃ (0.15) and T₄ (0.18). The maximum disease incidence (8.44 %) and PDI (5.27 %) was registered in control because they also had highest (1.60) vector population. In all the plots where crops were sprayed with insecticides the disease incidence was not increased at 3 days after 2nd spray but PDI and vector population were slightly increased. The lowest percent incidence was recorded in T₂ (0.84 %) followed by T₄ (1.25 %) and T₃ (1.67 %). However the minimum disease PDI was registered in T₂ (0.60 %) followed by T₃ (0.72 %) and T₄ (0.90 %). The vector population was noted lowest (0.18) in T₄ followed by T₁ and T₅ (0.28). The maximum number of whitefly (2.18) was counted in control plots therefore the disease incidence (12.43 %) and PDI (6.58 %) was also recorded maximum in these plots. At 5 days after 2nd spray the percent incidence, PDI and vector population were slightly increased nearly in all the plots. The lowest incidence (0.84 %) was recorded in T₂ followed by T₄

(1.67 %) and T₃ (2.12 %). However the maximum disease PDI was recorded in T₂ (0.60 %) followed by T₃ (0.91 %) and T₄ (1.19 %). The vector population was noted very low in T₃ (0.50) this was followed by T₅ (0.53) and T₂ (0.65). The maximum number of whitefly (2.43) was recorded from control plots therefore the disease incidence (13.32 %) and PDI (7.61 %) was also maximum in these plots.

At a day before 3rd spray (Table 4.144) the percent leaf curl incidence and PDI and vector population was significantly low in all the treated plots in comparison to control. The lowest percent incidence and PDI was recorded in T₄ (1.67 and 1.19 %) followed by T₃ (2.12 and 1.27 %) and T₂ (2.96 and 1.38 %). During this period the lowest population of whitefly (0.75) was recorded in T₃ followed by T₅ (0.80) and T₂ (0.85) and they were statistically at par with each other. At a day before 3rd spray the maximum disease incidence (20.88 %), PDI (12.12 %) and vector population (2.88) were recorded in control plots. It was visible from the pooled data that at 1 day after 3rd spray (Table 4.144) the increasing trend was observed in percent incidence and PDI but decreasing trend was observed for the vector population in the crops sprayed with insecticides. The minimum disease incidence (2.12 %) and PDI (1.51 %) was recorded in T₃ followed by T₄ (2.52 and 1.55 %) and T₂ (3.38 and 1.68 %). The vector population was traced lowest (0.15 whitefly per ten leaves) in T₅ followed by T₃ and T₄ (0.20). The maximum disease incidence (22.67 %) and PDI (13.01 %) was noted in control as they also had highest (2.95) vector population. The little increment has been observed in disease incidence, PDI and vector population of some plots at 3 days after 3rd spray. The minimum disease incidence (2.52 %) and PDI (1.55 %) was recorded in T₄ followed by T₃ (2.53 and 1.57 %) and T₂ (3.38 and 1.68 %). The lowest vector population was recorded in T₂ with per ten leaves 0.33 whitefly only this was followed by T₃, T₄ and T₅ (0.35). The disease incidence (24.89 %) and PDI (14.34 %) was noted maximum in control plots as they had maximum number of whitefly (3.10). At 5 days after 3rd spray slight increment was observed in percent disease incidence, PDI and vector population in some treated plots and untreated plots. The disease incidence and PDI were found minimum in T₃ (2.53 and 1.57 %) which was followed by T₄ (2.95 and 1.62 %) and T₂ (3.38 and 1.92 %). However the lowest vector population (0.43) was registered in T₅ followed T₃

(0.50) and T₄ (0.53). The maximum disease incidence (25.78 %), PDI (15.35 %) and vector population (3.20) were recorded from control plots.

At a day before 4th spray (Table 4.145) all the treated plots provided statistically similar disease incidence however numerically low incidence was observed in T₄ (3.37 %). The lowest (1.91 %) PDI of leaf curl was also noted in T₄ followed by T₃ (1.97 %) and T₂ (2.83 %). During this period the minimum number of whitefly (0.98) was counted in T₃ followed by T₅ (1.05), T₂ and T₄ (1.18). The maximum disease incidence (35.56 %), PDI (21.98 %) and vector population (4.03) were recorded in control plots. At 1 day after 4th spray (Table 4.145) the disease incidence in T₂ (5.48 %) was remained same and other treatments showed increment in disease incidence. The minimum disease incidence (3.42 %) and PDI (2.07 %) was recorded in T₄ followed by T₃ (4.70 and 2.15 %) and T₅ (5.06 and 2.90 %). About half of the vector population declined after spray in the crops sprayed with insecticides. The lowest (0.48) vector population was traced in T₃ followed by T₅ (0.53), T₂ and T₄ (0.58). The maximum disease incidence (37.77 %) and PDI (23.18 %) was noted in control because they also had high (3.88) vector population. It was observed that the disease incidence was increased in some plots and also unchanged in some plots at 3 days after 4th spray whereas PDI of leaf curl and vector population was increased almost in all the plots. The lowest disease incidence (3.42 %) and PDI (2.07 %) was noted in T₄ followed by T₃ (4.75 and 2.55 %) and T₅ (5.06 and 3.02 %). The activity of whitefly was observed minimum (0.78) in T₃ followed by T₅ (0.83) and T₄ (0.88). The maximum disease incidence (39.55 %) was noted in control plots as vector population was high (4.20) in these plots as well as the PDI was also highest (24.96 %) in untreated control. There was slight increment have been observed in percent disease incidence in some plots at 5 days after 3rd spray however little and considerable increment was noticed in PDI and vector population respectively in all the plots. The lowest disease incidence (3.84 %) and PDI (2.13 %) was recorded in T₄ followed by T₃ (4.75 and 2.92 %) and T₅ (5.06 and 3.26 %). The minimum (1.08) vector population was traced in T₃ followed by T₅ (1.20) and T₄ (1.28) and they were at par with each other. The maximum disease incidence (41.76 %) and PDI (27.32 %) along with whitefly (4.55) were observed in control plots.

At 1 day before 5th spray (Table 4.146) the percent incidence and PDI of leaf curl were ranged from 6.00 to 52.93 and 3.45 to 34.53 percent respectively. The percent incidence and PDI of leaf curl was significantly low in all the treated plots in comparison to control. The lowest incidence (6.00 %) and PDI (3.45 %) of leaf curl was lowest in T₃ as it had lowest vector population of 1.58 whiteflies per ten leaves. This was followed by T₄ (6.82 and 3.65 %) and T₅ (6.32 and 3.67 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 1.75 and 1.88 in T₅ and T₄ respectively. Since there was heavy infestation of whitefly (5.28 per ten leaves) therefore the incidence (52.93 %) and PDI (34.53 %) was recorded maximum in control plots. At 1 day after 5th spray (Table 4.146) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased nearly in all the plots where plants were sprayed with insecticides. The minimum vector population was recorded in T₃ (0.90) followed by T₅ (1.13) and T₄ (1.20). At 3 days after 5th spray the disease incidence was meagre increased in about half of the treatments but PDI of leaf curl along with vector population was increased in all the plots except T₅ where PDI was unchanged. The minimum disease incidence (6.32 %) was recorded in T₅ followed by T₄ (6.82 %) and T₃ (6.85 %) and they were at par with each other. However the minimum disease PDI (3.67 %) was registered in T₅ followed by T₃ (3.81 %) and T₄ (4.02 %). The lowest (1.10) vector population was also counted from T₃ followed by T₅ (1.28) and T₄ (1.38). The maximum disease incidence (57.79 %) and PDI (37.36 %) along with whitefly (5.93) were observed in control plots. There was slight increment has been observed in percent disease incidence at 5 days after 5th spray in all the plots except T₃ and T₄ where incidence was unchanged however little and considerable increment was noticed in PDI and vector population respectively. The lowest disease incidence (6.74 %) was recorded in T₅ followed by T₄ (6.82 %) and T₃ (6.85 %) and they were at par with each other. The lowest disease PDI (3.97 %) was noted in T₅ but this was followed by T₃ (4.05 %) and T₄ (4.26 %). The minimum (1.30) vector population was traced in T₃ followed by T₅ (1.50) and T₄ (1.60). The crops of control plots were severely

infested with whitefly (6.45 per ten leaves) therefore the maximum percent disease incidence (59.56 %) and PDI (38.88 %) was recorded in control.

There was considerable increment have been observed on disease incidence, PDI and vector population in the treatments at 1 day before 6th spray (Table 4.147). The minimum disease incidence (8.10 %) was observed in T₃ as the vector population was very low (2.05) in T₃ this was followed by T₅ (8.41 %) and T₄ (8.54 %). During this period the adult whitefly population was 2.33 and 2.35 in T₄ and T₅ respectively. However the minimum disease PDI (4.70 %) was observed in T₅ followed by T₃ (4.94 %) and T₄ (5.24 %). Since there was very high infestation of whitefly (6.78 per ten leaves) therefore the disease incidence (70.29 %) and PDI (46.79 %) was recorded maximum in control plots. At 1 day after 6th spray (Table 4.147) the vector population was reduced due to application of insecticides therefore the percent incidence and PDI of leaf curl was not increased nearly in all the plots where plants were sprayed with insecticides but little increment has been observed in percent incidence (8.97 %) and PDI (5.42 %) of T₄. The lowest (1.25) vector population was recorded in T₃ followed by T₄ (1.45) and T₅ (1.50). The highest disease incidence (72.95 %), PDI (49.08 %) and vector population (6.55) was observed in control plots. It was observed that the disease incidence and PDI were increased in some plots and also unchanged in some plots at 3 days after 6th spray whereas the vector population was increased almost in all the plots. The lowest disease incidence (8.10 %) was noted in T₃ followed by T₅ (8.41 %) and T₄ (8.97 %) and they were statistically at par with each other. However the minimum disease PDI (4.81 %) was registered in T₅ followed by T₃ (4.94 %) and T₄ (5.67 %). The activity of whitefly was observed minimum (1.45) in T₃ followed by T₅ (1.63) and T₄ (1.65). The maximum disease incidence (74.27 %) was noted in control plots as vector pressure was very high (6.28 whitefly per ten leaves) in these plots as well as the PDI was also highest (50.54 %) in untreated control. At 5 days after 6th spray (the disease incidence was increased in some plots but increasing trend was observed in disease PDI and vector population. The minimum disease incidence (8.10 %) was recorded in T₃ followed by T₅ (8.41 %) and T₄ (9.40 %) and they were at par with each other. However the lowest disease PDI (4.93 %) was recorded in T₅ followed by T₃ (5.18 %) and T₄ (6.09 %). The

lowest vector population was registered (1.65) in T₃ followed by T₄ (1.75) and T₅ (1.83). The maximum disease incidence (77.83 %) and PDI (53.09 %) was noted in control plots as vector population was high (5.98) in these plots. At 9 day after 6th spray (Table 4.147) the percent incidence and PDI of leaf curl were ranged from 8.53 to 81.42 percent and 5.35 to 56.77 percent respectively. The lowest disease incidence (8.53 %) was recorded in T₃ as it had minimum vector population of 1.55 whiteflies per ten leaves this was followed by T₅ (8.84 %) and T₄ (9.83 %). The minimum disease PDI (5.35 %) was recorded in T₅ followed by T₃ (5.60 %) and T₄ (6.40 %). However T₃, T₄ and T₅ were at par with each other for percent disease incidence and PDI. During this period the adult whitefly population was 1.78 in T₄ and T₅. Since there was very high population of whitefly (5.75 per ten leaves) in control plots therefore the incidence (81.42 %) and PDI (56.77 %) was highest in these plots.

The pooled data presented in Table 4.148 and 4.149 displayed that the percent incidence and PDI of leaf curl was very low in all the plots up to 1st spray with range of 0.0 to 2.29 and 0.0 to 0.58 percent incidence and PDI respectively. The control plots showed that the percent incidence (Table 4.148) and PDI (Table 4.149) of leaf curl was rapidly increased from 2nd to 6th spray with 10.65 to 75.35 percent incidence and PDI of 5.96 to 51.25 because the vector population (1.80 to 6.27) also rapidly increased during this period (Table 4.150). However in the plots sprayed with insecticides the percent disease incidence and PDI was gradually increased because whitefly population was also slowly increased due to insecticides. After each spray the whitefly population was found very low in all the treated plots where insecticides were sprayed therefore in these plots the percent incidence and PDI of leaf curl was lower than the control and T₆ plots. It was also revealed from the average data of six sprays that among all the treated and untreated plots the lowest average disease incidence (3.89 %), PDI (2.22 %) and vector population (0.73) was observed in T₃. The highest average percent incidence (34.48 %) and PDI (22.07 %) of leaf curl was noted in control plots as they were highly infested with whitefly (3.54).

It was revealed from the experimental data presented in Table 4.151 to 4.153 that a day before spray the disease incidence and PDI ranged from 3.54 to

31.42 and 2.01 to 19.98 percent with vector population of 0.93 to 3.33. In all the plots where insecticide sprayed the percent incidence (Table 4.151) and PDI (Table 4.152) of leaf curl was little speedily increased before spray because during this period the vector population (Table 4.153) was also slightly high in these plots (T_1 : 1.29, T_2 : 1.17, T_3 : 0.93, T_4 : 1.10 and T_5 : 1.01). But in control (31.42 and 19.98 %) and T_6 (12.14 and 6.83 %) plots the percent disease incidence and PDI was quickly increased as they had higher vector population (2.13 and 3.33). There was little increment has been observed in disease incidence and PDI of plots sprayed with insecticide up to 5 days after spray as in these plots the vector population was suppressed by insecticides. But 1 to 5 days after spray the percent incidence and PDI of leaf curl was gradually increased in control and T_6 plots. The results displayed that at 9 days after last spray the vector population was quickly increased therefore the percent incidence of leaf curl was also quickly increased with higher PDI in all the treated and control plots.

In 2015-16 throughout the period of experiment the percent disease incidence, PDI and vector population ranged from 2.67 to 36.14, 1.10 to 22.79 and 0.58 to 3.57 respectively (Table 4.154). The disease incidence, PDI and vector population were low in all the treated plots in comparison to control plots. The disease incidence and PDI were very low in T_3 , T_4 and T_5 than the other treated plots as the infestation of whitefly was also low in these plots.

In 2016-17 throughout the period of experiment the percent disease incidence, PDI and vector population were ranged 4.42 to 32.58, 2.78 to 21.10 and 0.73 to 3.53 respectively (Table 4.154). The disease incidence, PDI and vector population were low in all the treated plots in comparison to control plots. The disease incidence and PDI were very low in T_2 , T_3 and T_4 than the other treated plots as the infestation of whitefly was also low in these plots.

In both years (2015-16 and 2016-17) throughout the period of experiment the average percent disease incidence, PDI and vector population of both the years were ranged 3.89 to 34.48, 2.22 to 22.07 and 0.73 to 3.54 respectively (Table 4.154). The average disease incidence, PDI and vector population were low in all the treated plots in comparison to control plots. The disease incidence and PDI

Table 4.142: Effect of spray on leaf curl disease and vector population (First spray at 10 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.64)
T ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.24	0.00	0.84	0.24	0.03
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.94)	(0.79)	(0.71)	(0.94)	(0.71)	(0.68)
T ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.06	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.85)	(0.71)	(0.71)
T ₄	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.18	0.00	0.42	0.18	0.00
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.85)	(0.77)	(0.71)	(0.85)	(0.71)	(0.71)
T ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.42	0.03
	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(0.71)	(1.13)	(0.77)	(0.68)
T ₆	0.00	0.00	0.00	0.42	0.18	0.00	1.30	0.31	0.08	3.43	0.88	0.20
	(0.71)	(0.71)	(0.71)	(0.85)	(0.77)	(0.71)	(1.14)	(0.77)	(0.67)	(1.75)	(0.80)	(0.56)
T ₇	0.43	0.06	0.00	0.85	0.12	0.00	2.59	0.63	0.23	5.27	1.51	0.43
	(0.85)	(0.71)	(0.71)	(0.99)	(0.71)	(0.71)	(1.52)	(0.86)	(0.58)	(2.17)	(1.07)	(0.64)
Sem±	0.054	0.000	0.000	0.085	0.023	0.000	0.116	0.051	0.021	0.170	0.037	0.034
CD (p=0.05)	0.161	0.001	0.000	0.252	0.069	0.000	0.344*	0.151	0.064*	0.506*	0.111*	0.102
CV	2.125	0.019	0.000	3.142	0.919	0.000	3.520	1.911	0.895	4.061	1.362	1.496

^a Value in parentheses are square root transformed, ^b Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.143: Effect of spray on leaf curl disease and vector population (Second spray at 20 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	0.87 (0.92)	0.37 (0.84)	0.43 (0.64)	1.74 (1.24)	1.12 (1.09)	0.23 (0.58)	1.74 (1.24)	1.25 (1.12)	0.28 (0.62)	2.59 (1.52)	1.37 (1.11)	0.78 (0.87)
T ₂	0.84 (0.94)	0.48 (0.87)	0.23 (0.64)	0.84 (0.94)	0.60 (0.89)	0.20 (0.51)	0.84 (0.94)	0.60 (0.89)	0.30 (0.58)	0.84 (0.94)	0.60 (0.89)	0.65 (0.78)
T ₃	1.25 (1.08)	0.42 (0.83)	0.20 (0.51)	1.67 (1.16)	0.48 (0.85)	0.15 (0.62)	1.67 (1.16)	0.72 (0.91)	0.30 (0.63)	2.12 (1.30)	0.91 (0.97)	0.50 (0.70)
T ₄	0.84 (0.99)	0.36 (0.83)	0.23 (0.66)	1.25 (1.13)	0.78 (0.98)	0.18 (0.59)	1.25 (1.13)	0.90 (1.02)	0.18 (0.48)	1.67 (1.22)	1.19 (1.10)	0.70 (0.80)
T ₅	2.10 (1.37)	1.13 (1.07)	0.13 (0.55)	2.93 (1.58)	1.73 (1.24)	0.13 (0.61)	2.93 (1.58)	1.73 (1.24)	0.28 (0.53)	3.35 (1.67)	2.03 (1.29)	0.53 (0.70)
T ₆	4.29 (1.99)	1.12 (1.02)	0.68 (0.80)	4.71 (2.09)	1.29 (1.10)	1.03 (0.99)	5.17 (2.17)	1.48 (1.16)	1.45 (1.18)	5.61 (2.31)	1.66 (1.19)	1.60 (1.26)
T ₇	8.41 (2.85)	4.37 (2.06)	1.00 (0.99)	8.44 (2.86)	5.27 (2.25)	1.60 (1.26)	12.43 (3.50)	6.58 (2.53)	2.18 (1.47)	13.32 (3.62)	7.61 (2.73)	2.43 (1.55)
Sem±	0.198	0.126	0.047	0.216	0.129	0.058	0.200	0.147	0.053	0.206	0.150	0.051
CD (p=0.05)	0.589*	0.374*	0.140*	0.641*	0.385*	0.171*	0.595*	0.437*	0.157*	0.613*	0.446*	0.152*
CV	3.910	3.353	1.967	3.930	3.081	2.232	3.423	3.314	1.921	3.279	3.229	1.533

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.144: Effect of spray on leaf curl disease and vector population (Third spray at 30 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	3.01 (1.66)	2.03 (1.39)	1.03 (1.00)	3.87 (5.51)	2.39 (1.50)	0.38 (0.64)	4.29 (6.82)	2.70 (1.56)	0.58 (0.72)	4.74 (6.90)	3.14 (1.71)	0.83 (0.89)
T ₂	2.96 (1.65)	1.38 (1.12)	0.85 (0.90)	3.38 (6.20)	1.68 (1.23)	0.25 (0.55)	3.38 (6.20)	1.68 (1.23)	0.33 (0.62)	3.38 (6.20)	1.92 (1.33)	0.55 (0.77)
T ₃	2.12 (1.30)	1.27 (1.06)	0.75 (0.86)	2.12 (0.95)	1.51 (1.17)	0.20 (0.52)	2.53 (2.26)	1.57 (1.17)	0.35 (0.57)	2.53 (2.26)	1.57 (1.17)	0.50 (0.70)
T ₄	1.67 (1.22)	1.19 (1.10)	0.95 (0.93)	2.52 (2.28)	1.55 (1.16)	0.20 (0.56)	2.52 (2.28)	1.55 (1.16)	0.35 (0.58)	2.95 (3.62)	1.62 (1.16)	0.53 (0.71)
T ₅	3.35 (1.67)	2.03 (1.32)	0.80 (0.88)	3.77 (2.58)	2.21 (1.36)	0.15 (0.52)	3.77 (2.58)	2.21 (1.36)	0.35 (0.63)	3.77 (2.58)	2.33 (1.43)	0.43 (0.63)
T ₆	7.75 (2.74)	3.68 (1.90)	2.05 (1.43)	7.75 (9.75)	4.19 (2.02)	1.73 (1.29)	8.18 (10.19)	4.98 (2.20)	1.38 (1.16)	8.61 (10.57)	5.04 (2.22)	1.60 (1.26)
T ₇	20.88 (4.55)	12.12 (3.47)	2.88 (1.69)	22.67 (16.99)	13.01 (3.59)	2.95 (1.71)	24.89 (17.72)	14.34 (3.77)	3.10 (1.76)	25.78 (18.26)	15.35 (3.94)	3.20 (1.79)
Sem±	0.183	0.161	0.057	1.027	0.158	0.052	0.942	0.170	0.049	0.922	0.170	0.041
CD (p=0.05)	0.542*	0.478*	0.169*	3.050*	0.470*	0.154*	2.798*	0.506*	0.146*	2.738*	0.504*	0.122*
CV	2.466	2.828	1.480	4.640	2.631	1.797	3.920	2.733	1.632	3.658	2.618	1.213

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.145: Effect of spray on leaf curl disease and vector population (Fourth spray at 40 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	7.29 (14.41)	4.49 (2.02)	1.50 (1.21)	8.62 (16.57)	4.92 (2.10)	0.73 (0.84)	8.62 (16.57)	5.18 (2.18)	1.13 (1.04)	9.47 (17.51)	5.92 (7.41)	1.68 (1.26)
T ₂	5.48 (12.31)	2.83 (1.62)	1.18 (1.06)	5.48 (12.31)	3.06 (1.67)	0.58 (0.78)	5.90 (12.75)	3.24 (1.71)	0.98 (0.97)	6.34 (13.33)	3.67 (5.84)	1.35 (1.14)
T ₃	4.28 (10.12)	1.97 (1.28)	0.98 (0.98)	4.70 (11.44)	2.15 (1.31)	0.48 (0.68)	4.75 (11.48)	2.55 (1.48)	0.78 (0.87)	4.75 (11.48)	2.92 (5.01)	1.08 (1.01)
T ₄	3.37 (7.98)	1.91 (1.26)	1.18 (1.07)	3.42 (8.03)	2.07 (1.30)	0.58 (0.74)	3.42 (8.03)	2.07 (1.30)	0.88 (0.92)	3.84 (9.35)	2.13 (2.61)	1.28 (1.10)
T ₅	4.64 (10.31)	2.84 (1.51)	1.05 (1.01)	5.06 (11.62)	2.90 (1.51)	0.53 (0.70)	5.06 (11.62)	3.02 (1.53)	0.83 (0.89)	5.06 (11.62)	3.26 (3.54)	1.20 (1.05)
T ₆	12.95 (20.65)	7.39 (2.65)	2.18 (1.47)	14.26 (21.90)	7.72 (2.72)	2.20 (1.48)	14.26 (21.90)	8.09 (2.78)	2.43 (1.55)	15.54 (22.86)	9.37 (11.12)	2.75 (1.65)
T ₇	35.56 (36.55)	21.98 (4.68)	4.03 (2.01)	37.77 (37.86)	23.18 (4.80)	3.88 (1.97)	39.55 (38.93)	24.96 (4.99)	4.20 (2.05)	41.76 (39.46)	27.32 (18.60)	4.55 (2.13)
Sem±	1.594	0.180	0.037	1.307	0.184	0.049	1.375	0.197	0.040	1.415	0.547	0.055
CD (p=0.05)	4.735*	0.535*	0.109*	3.884*	0.547*	0.145*	4.086*	0.586*	0.118*	4.204*	1.625*	0.163*
CV	2.837	2.398	0.831	2.183	2.391	1.363	2.268	2.470	0.959	2.253	2.021	1.177

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.146: Effect of spray on leaf curl disease and vector population (Fifth spray at 50 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	11.19 (18.71)	6.77 (14.75)	2.18 (1.46)	11.19 (19.35)	6.77 (14.74)	1.40 (1.17)	11.19 (19.35)	6.89 (14.87)	1.53 (1.23)	11.62 (19.79)	7.32 (15.48)	1.78 (1.32)
T ₂	8.87 (16.32)	5.24 (12.85)	2.13 (1.44)	8.87 (16.88)	5.24 (12.85)	1.33 (1.14)	9.70 (18.00)	5.36 (13.07)	1.50 (1.21)	10.15 (18.39)	5.67 (13.49)	1.80 (1.33)
T ₃	6.00 (12.88)	3.45 (10.21)	1.58 (1.24)	6.00 (13.91)	3.45 (10.21)	0.90 (0.93)	6.85 (15.03)	3.81 (10.79)	1.10 (1.03)	6.85 (15.03)	4.05 (11.32)	1.30 (1.12)
T ₄	6.82 (14.35)	3.65 (10.66)	1.88 (1.35)	6.82 (14.83)	3.78 (10.91)	1.20 (1.07)	6.82 (14.83)	4.02 (11.18)	1.38 (1.15)	6.82 (14.83)	4.26 (11.55)	1.60 (1.25)
T ₅	6.32 (13.16)	3.67 (10.28)	1.75 (1.30)	6.32 (14.06)	3.67 (10.28)	1.13 (1.05)	6.32 (14.06)	3.67 (10.28)	1.28 (1.12)	6.74 (14.61)	3.97 (10.72)	1.50 (1.21)
T ₆	21.11 (26.59)	12.39 (20.38)	3.35 (1.82)	21.54 (27.38)	12.69 (20.62)	3.48 (1.86)	22.01 (27.69)	13.39 (21.21)	3.60 (1.90)	22.43 (27.98)	13.57 (21.63)	3.93 (1.98)
T ₇	52.93 (46.33)	34.53 (35.95)	5.28 (2.30)	55.13 (47.87)	35.59 (36.58)	5.50 (2.34)	57.79 (49.53)	37.36 (37.66)	5.93 (2.43)	59.56 (50.56)	38.88 (37.95)	6.45 (2.54)
Sem±	1.194	1.077	0.046	1.177	1.053	0.052	0.933	1.033	0.038	0.912	0.910	0.052
CD (p=0.05)	3.549*	3.200*	0.136*	3.496*	3.129*	0.155*	2.771*	3.068*	0.112*	2.710*	2.703*	0.155*
CV	1.610	1.872	0.837	1.525	1.813	1.089	1.177	1.735	0.747	1.132	1.489	0.971

^δ Value in parentheses are square root transformed, ^β Value in parentheses are arcsine / angular transformed

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.147: Effect of spray on leaf curl disease and vector population (Sixth spray at 60 DAT) 2015-16 and 2016-17

Treatment	1 Day before spray			1 Day after spray			3 Days after spray			5 Days after spray			9 Days after spray		
	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly	Incidence	PDI	Whitefly
T ₁	14.19 (21.30)	8.31 (16.55)	2.60 (1.60)	14.19 (21.97)	8.31 (16.55)	1.75 (1.31)	14.19 (21.97)	8.80 (17.09)	1.90 (1.36)	14.19 (21.97)	8.92 (17.28)	2.03 (1.41)	14.19 (21.97)	9.42 (17.74)	1.93 (1.38)
T ₂	11.86 (19.60)	7.02 (15.08)	2.60 (1.60)	11.86 (19.97)	7.02 (15.08)	1.60 (1.25)	12.28 (20.34)	7.20 (15.26)	1.85 (1.35)	12.69 (20.77)	7.74 (15.93)	2.00 (1.40)	12.69 (20.77)	8.09 (16.35)	2.05 (1.42)
T ₃	8.10 (15.87)	4.94 (12.57)	2.05 (1.42)	8.10 (16.27)	4.94 (12.57)	1.25 (1.10)	8.10 (16.27)	4.94 (12.57)	1.45 (1.19)	8.10 (16.27)	5.18 (12.89)	1.65 (1.27)	8.53 (16.31)	5.60 (13.48)	1.55 (1.23)
T ₄	8.54 (16.30)	5.24 (13.01)	2.33 (1.51)	8.97 (17.18)	5.42 (13.26)	1.45 (1.19)	8.97 (17.18)	5.67 (13.60)	1.65 (1.28)	9.40 (17.62)	6.09 (14.11)	1.75 (1.31)	9.83 (18.00)	6.40 (14.45)	1.78 (1.31)
T ₅	8.41 (16.19)	4.70 (12.18)	2.35 (1.52)	8.41 (16.59)	4.70 (12.18)	1.50 (1.21)	8.41 (16.59)	4.81 (12.47)	1.63 (1.26)	8.41 (16.59)	4.93 (12.53)	1.83 (1.33)	8.84 (17.93)	5.35 (13.02)	1.78 (1.31)
T ₆	26.71 (30.33)	16.39 (23.68)	4.50 (2.12)	27.17 (31.24)	17.09 (24.20)	4.35 (2.08)	28.05 (31.82)	17.84 (24.79)	4.08 (2.02)	28.47 (32.11)	18.39 (25.21)	4.05 (2.01)	30.15 (33.24)	20.47 (26.79)	3.93 (1.98)
T ₇	70.29 (57.16)	46.79 (43.22)	6.78 (2.60)	72.95 (58.85)	49.08 (44.57)	6.55 (2.56)	74.27 (59.64)	50.54 (45.31)	6.28 (2.51)	77.83 (62.13)	53.09 (46.77)	5.98 (2.44)	81.42 (64.80)	56.77 (48.91)	5.75 (2.40)
Sem±	0.835	0.728	0.041	0.888	0.734	0.042	0.886	0.718	0.057	0.911	0.737	0.046	0.890	0.737	0.040
CD (p=0.05)	2.480*	2.164*	0.122*	2.640*	2.181*	0.125*	2.633*	2.133*	0.168*	2.708*	2.189*	0.136*	2.646*	2.191*	0.118*
CV	0.944	1.069	0.664	0.976	1.060	0.786	0.964	1.018	1.036	0.972	1.018	0.818	0.923	0.978	0.721

^a Value in parentheses are square root transformed, ^b Value in parentheses are arcsine / angular transformedT₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

Table 4.148: Effect of spray on leaf curl incidence (2015-16 and 2016-17)

Treatment	Average percent disease incidence of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	1.74	3.98	8.50	11.30	14.19	6.62
T ₂	0.42	0.84	3.28	5.80	9.40	12.28	5.33
T ₃	0.11	1.68	2.33	4.62	6.43	8.19	3.89
T ₄	0.21	1.25	2.42	3.51	6.82	9.14	3.89
T ₅	0.31	2.83	3.67	4.96	6.43	8.50	4.45
T ₆	1.29	4.95	8.07	14.25	21.77	28.11	13.07
T ₇	2.29	10.65	23.56	38.66	56.35	75.35	34.48

Table 4.149: Effect of spray on percent disease index of leaf curl (2015-16 and 2016-17)

Treatment	Average percent disease index of leaf curl						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.00	1.03	2.57	5.13	6.94	8.75	4.07
T ₂	0.12	0.57	1.67	3.20	6.82	7.41	3.30
T ₃	0.02	0.63	1.48	2.40	3.69	5.12	2.22
T ₄	0.09	0.81	1.48	2.05	3.93	5.76	2.35
T ₅	0.11	1.66	2.20	3.01	3.75	4.90	2.60
T ₆	0.34	1.39	4.47	8.14	13.01	18.04	7.57
T ₇	0.58	5.96	13.71	24.36	36.59	51.25	22.07

Table 4.150: Effect of spray on population of whitefly (2015-16 and 2016-17)

Treatment	Average whitefly population						
	First	Second	Third	Fourth	Fifth	Sixth	Average
T ₁	0.03	0.43	0.71	1.26	1.72	2.04	1.03
T ₂	0.01	0.35	0.50	1.02	1.69	2.02	0.93
T ₃	0.00	0.29	0.45	0.83	1.22	1.59	0.73
T ₄	0.00	0.32	0.51	0.98	1.52	1.79	0.85
T ₅	0.01	0.27	0.43	0.90	1.42	1.82	0.81
T ₆	0.07	1.19	1.69	2.39	3.59	4.18	2.19
T ₇	0.17	1.80	3.03	4.17	5.79	6.27	3.54

Table 4.151: Efficacy of insecticide spray on incidence of leaf curl (2015-16 and 2016-17)

Treatment	Percent disease incidence (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	6.09	6.60	6.67	7.10	14.19
T ₂	5.00	5.07	5.49	5.71	12.69
T ₃	3.63	3.77	3.98	4.13	8.53
T ₄	3.54	3.83	3.90	4.18	9.83
T ₅	4.14	4.42	4.42	4.76	8.84
T ₆	12.14	12.64	13.16	14.02	30.15
T ₇	31.42	32.97	35.25	37.25	81.42

Table 4.152: Efficacy of insecticide spray on percent disease index of leaf curl (2015-16 and 2016-17)

Treatment	Percent disease index (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	3.66	3.92	4.14	4.45	9.42
T ₂	3.78	2.93	3.05	3.31	8.09
T ₃	2.01	2.09	2.27	2.45	5.60
T ₄	2.06	2.27	2.40	2.58	6.40
T ₅	2.40	2.54	2.57	2.82	5.35
T ₆	6.83	7.19	7.68	8.15	20.47
T ₇	19.98	21.04	22.40	23.96	56.77

Table 4.153: Efficacy of insecticide spray on population of whitefly (2015-16 and 2016-17)

Treatment	Population of whitefly (days before / after spray)				
	1 DBA	1 DAA	3 DAA	5 DAA	9 DAA
T ₁	1.29	0.75	0.90	1.20	1.93
T ₂	1.17	0.66	0.83	1.06	2.05
T ₃	0.93	0.50	0.66	0.84	1.55
T ₄	1.10	0.60	0.74	0.98	1.78
T ₅	1.01	0.57	0.73	0.92	1.78
T ₆	2.13	2.13	2.17	2.36	3.93
T ₇	3.33	3.41	3.65	3.84	5.75

were very low in T₃, T₄ and T₅ than the other treated plots as the infestation of whitefly was also low in these plots.

4.5.4 Effect of treatments or management strategies on yield

The data presented in Table 4.155 displayed that in both the years (2015-16 and 2016-17) all the treated plots provided highly significant superior marketable yield (q ha⁻¹) than the untreated control plots. In both years (2015-16 and 2016-17) the significant highest marketable yield (327.22 and 305.87 q ha⁻¹) was obtained when the crop was treated with T₅. This was followed by T₄ (284.59 q ha⁻¹) and T₃ (253.03 q ha⁻¹) in 2015-16 and T₃ (278.39 q ha⁻¹) and T₄ (266.25 q ha⁻¹) in 2016-17. The pooled data also expressed that the crop in the T₅ plots produced highest (316.55 q ha⁻¹) marketable yield which was followed by T₄ (275.42 q ha⁻¹) and T₃ (265.71 q ha⁻¹). In both the experimental years the significant lowest marketable yield (106.85 and 105.71 q ha⁻¹) was recorded in untreated control plots with pooled mean of 106.28 q ha⁻¹.

In both years all the treated plots gave significantly low unmarketable yield in comparison to the control (Table 4.155). In 2015-16 the numerically minimum unmarketable yield was noted in T₅ (6.39 q ha⁻¹) followed by T₄ (8.45 q ha⁻¹) and T₃ (9.94 q ha⁻¹). However in 2016-17 the significant lowest unmarketable yield was collected in T₃ (5.14 q ha⁻¹) followed by T₅ (11.70 q ha⁻¹) and T₄ (12.07 q ha⁻¹). It was revealed from the pooled data that the T₃ plots recorded least unmarketable yield (7.54 q ha⁻¹) which was followed by T₅ (9.04 q ha⁻¹) and T₄ (10.26 q ha⁻¹). In both years the significant highest unmarketable yield (16.25 and 30.11 q ha⁻¹) was noted in untreated control plots with pooled mean of 23.18 q ha⁻¹.

The data presented in Table 4.155 displayed that in both the years (2015-16 and 2016-17) all the treated plots provided highly significant superior total yield (q ha⁻¹) than the untreated control plots. In both years (2015-16 and 2016-17) the significant highest total yield (333.61 and 317.57 q ha⁻¹) was harvested when the crop was treated with T₅. This was followed by T₄ (293.03 q ha⁻¹) and T₃ (262.97 q ha⁻¹) in 2015-16 and T₃ (283.53 q ha⁻¹) and T₄ (278.32 q ha⁻¹) in 2016-17. The pooled data also expressed that the crop in the T₅ plots produced highest (325.59 q ha⁻¹) total yield which was followed by T₄ (285.67 q ha⁻¹) and T₃ (273.25 q ha⁻¹).

Table 4.154: Performance of different treatments on management of leaf curl disease through vector control

Treatment	Percent incidence			Percent Disease Index			Whitefly population		
	2015-16	2016-17	Avg	2015-16	2016-17	Avg	2015-16	2016-17	Avg
T ₁	6.32	6.91	6.62	3.54	4.59	4.07	0.92	1.13	1.03
T ₂	5.18	5.45	5.33	2.74	3.82	3.30	0.84	1.01	0.93
T ₃	3.35	4.42	3.89	1.66	2.78	2.22	0.73	0.73	0.73
T ₄	2.89	4.83	3.89	1.43	3.22	2.35	0.69	1.01	0.85
T ₅	2.67	6.19	4.45	1.10	4.07	2.60	0.58	1.03	0.81
T ₆	14.72	11.28	13.07	8.57	6.42	7.57	2.15	2.23	2.19
T ₇	36.14	32.58	34.48	22.79	21.10	22.07	3.57	3.53	3.54

Table 4.155: Performance of different treatments on tomato yield (2015-16 and 2016-17)

Treatment	Yield q ha ⁻¹							
	Marketable				Unmarketable			
	2015-16	2016-17	Pooled	Average	2015-16	2016-17	Average	Total
T ₁	198.82	201.18	200.00	15.11	20.83	17.97	213.93	222.01
T ₂	226.35	208.02	217.18	10.89	19.45	15.17	237.24	227.46
T ₃	253.03	278.39	265.71	9.94	5.14	7.54	262.97	283.53
T ₄	284.59	266.25	275.42	8.45	12.07	10.26	293.03	278.32
T ₅	327.22	305.87	316.55	6.39	11.70	9.04	333.61	317.57
T ₆	182.78	199.69	191.24	12.70	23.89	18.29	195.47	223.58
T ₇	106.85	105.71	106.28	16.25	30.11	23.18	123.10	135.82
Sem±	4.485	2.608	2.468	2.088	2.716	1.811	4.748	4.353
CD (p=0.05)	13.326*	7.750*	7.333*	6.203*	8.070*	5.381*	14.107*	12.934*
CV	0.568	0.333	0.314	5.238	4.410	3.570	0.572	0.516
Average	217.97	232.35	273.25	325.59	209.53	129.46	3.484	10.352*

In both the experimental years the significant lowest total yield (123.10 and 135.82 q ha⁻¹) was recorded in untreated control plots with pooled mean of 129.46 q ha⁻¹.

4.5.5 Economics of different management practices 2015-16

The economics of different management practices have been worked out to find out the best cost effective strategy for the management of tomato leaf curl disease. The economics of different management practices was shown in Table 4.156. The average rate of produce throughout the season was Rs 5 kg⁻¹ (Rs 500 q⁻¹). In 2015-16 the value of produce (gross return) ranged from Rs 163610 in T₅ to Rs 53425 in untreated control. The maximum gross return (Rs 163610) earned from T₅ followed by T₄ (Rs 142295) and T₃ (Rs 126515) whereas the minimum return (Rs 53425) was earned from control.

The total cost for the management practices ranged from Rs 109583.00 in T₂ to Rs 55565.90 in control (Table 4.156). Maximum cost was invested in T₂ (Rs 109583.00) followed by T₃ (Rs 104718.00) and T₁ (Rs 96087.20). Among the treated plots the least cost was invested in T₆ (Rs 89113.00) which was followed by T₅ (Rs 94341.70) and T₄ (Rs 95451.70).

In 2015-16 the cost benefit ratio was ranged from 1:1.11 in T₂ to 1:2.84 in T₅. The data presented in Table 4.156 explained that the best cost benefit ratio (1:2.84) was achieved by T₅ which was followed by T₄ (1:2.23) and T₃ (1:1.49). The least cost benefit ratio was gained by T₂ (1:1.11).

2016-17

The economics of different management practices was presented in Table 4.157. The average rate of produce throughout the season was Rs 5 kg⁻¹ (Rs 500 q⁻¹). In 2016-17 the value of produce (gross return) was ranged from Rs 152935 in T₅ to Rs 52855 in untreated control. The maximum gross return (Rs 152935) earned from T₅ followed by T₃ (Rs 139195) and T₄ (Rs 133125) whereas the minimum return (Rs 52855) was earned from control.

The total cost for the management practices ranged from Rs 120135.00 in T₂ to Rs 63412.90 in control (Table 4.157). Maximum cost was invested in T₂ (Rs

120135.00) followed by T₃ (Rs 115270.00) and T₁ (Rs 106639.20). Among the treated plots the least cost was invested in T₆ (Rs 98713.70) which was followed by T₅ (Rs 104894.00) and T₄ (Rs 106004.00).

In 2015-16 the cost benefit ratio was ranged from 1:0.90 in T₂ to 1:2.41 in T₅. The data summarised in Table 4.157 explained that the best cost benefit ratio (1:2.41) was achieved by T₅ which was followed by T₄ (1:1.88) and T₃ (1:1.66). The least cost benefit ratio was gained by T₂ (1:0.90).

Mean (2015-17)

The average economics of different management practices have been also computed from 2015-16 and 2016-17 data and presented in Table 4.158. It was revealed from the average economics of different management practices that the average rate of produce was Rs 5 kg⁻¹ (Rs 500 q⁻¹) throughout the experimental period (2015-16 and 2016-17). During both years the average value of produce (gross return) was ranged from Rs 158275 in T₅ to Rs 53140 in untreated control. The maximum gross return (Rs 158275) earned from T₅ followed by T₄ (Rs 137710) and T₃ (Rs 132855) whereas the minimum return (Rs 53140) was earned from control.

The total average cost for the management practices ranged from Rs 114858.95 in T₂ to Rs 59489.38 in control (Table 4.158). Maximum cost was invested in T₂ (Rs 114858.95) followed by T₃ (Rs 109994.41) and T₁ (Rs 101363.27). Among the treated plots the least cost was invested in T₆ (Rs 93913.34) which was followed by T₅ (Rs 99617.75) and T₄ (Rs 100727.75).

The average cost benefit ratio was ranged from 1:1.00 in T₂ to 1:2.62 in T₅. The data presented in Table 4.158 explained that the best cost benefit ratio (1:2.62) was achieved by T₅ which was followed by T₄ (1:2.05) and T₃ (1:1.58). The least cost benefit ratio was gained by T₂ (1:1.00).

4.5.6 Overall performance of treatments/ management strategies 2015-16

The overall performance of all the treatments has been worked out to find out best strategy for the management of ToLCD with high yield and economic return. It is visible from the data presented in Table 4.159 that in 2015-16 all the

Table 4.156: Economics of different treatments (2015-16)

1	2	3	4	5	6	7	8
Treatment	Marketable yield (q/ha)	Rate of produce (Rs/q)	Value of produce (Rs)	Total cost (Rs)	Value of produce in treatment - Value of produce in control (Rs)	Per Re value (6/5)	B:C ratio
T ₁	198.82	500	99410	96087.20	45985	1.13	01:1.13
T ₂	226.35	500	113175	109583.00	59750	1.11	01:1.11
T ₃	253.03	500	126515	104718.00	73090	1.49	01:1.49
T ₄	284.59	500	142295	95451.70	88870	2.23	01:2.23
T ₅	327.22	500	163610	94341.70	110185	2.84	01:2.84
T ₆	182.78	500	91390	89113.00	37965	1.13	01:1.13
T ₇	106.85	500	53425	55565.90			

Table 4.157: Economics of different treatments (2016-17)

1	2	3	4	5	6	7	8
Treatment	Marketable yield (q ha ⁻¹)	Rate of produce (Rs/q)	Value of produce (Rs)	Total cost (Rs)	Value of produce in treatment - Value of produce in control (Rs)	Per Re value (6/5)	B:C ratio
T ₁	201.18	500	100590	106639.00	47735	1.10	01:1.10
T ₂	208.02	500	104010	120135.00	51155	0.90	01:0.90
T ₃	278.39	500	139195	115270.00	86340	1.66	01:1.66
T ₄	266.25	500	133125	106004.00	80270	1.88	01:1.88
T ₅	305.87	500	152935	104894.00	100080	2.41	01:2.41
T ₆	199.69	500	99845	98713.70	46990	1.33	01:1.33
T ₇	105.71	500	52855	63412.90			

Table 4.158: Economics of different treatments (2015-16 and 2016-17)

1	2	3	4	5	6	7	8
Treatment	Marketable yield (q ha ⁻¹)	Rate of produce (Rs/q)	Value of produce (Rs)	Total cost (Rs)	Value of produce in treatment - Value of produce in control (Rs)	Per Re value (6/5)	B:C ratio
T ₁	200.00	500.00	100000	101363.27	46860	1.12	01:1.12
T ₂	217.18	500.00	108590	114858.95	55450	1.00	01:1.00
T ₃	265.71	500.00	132855	109994.41	79715	1.58	01:1.58
T ₄	275.42	500.00	137710	100727.75	84570	2.05	01:2.05
T ₅	316.55	500.00	158275	99617.75	105135	2.62	01:2.62
T ₆	191.24	500.00	95620	93913.34	42480	1.23	01:1.23
T ₇	106.28	500.00	53140	59489.38			

T₁: Imidacloprid, T₂: Fipronil, T₃: Cyantraniliprole, T₄: Buprofezin, T₅: Thiamethoxam, T₆: Silver polythene mulch only and T₇: Control

treated plots provided superior overall performance than the control and among the treated plots best performance was given by T₅ that showed lowest disease incidence (7.56 %), PDI (3.96 %) and vector population (1.20 per ten leaves) at last observation along with highest marketable yield (327.22 q ha⁻¹) and economic returns *i.e.* best cost benefit ratio (1:2.84). Throughout the experimental period (2015-16) the lowest average disease incidence (2.67 %), PDI (1.10 %) and vector population (0.58) were also recorded in T₅. This was followed by T₄ and T₃.

The plots treated with T₄ exhibited low disease incidence (8.56 %), PDI (5.13 %) and vector population (1.40 per ten leaves) at last observation and gave good marketable yield (284.59 q ha⁻¹) and cost benefit ratio (1:2.23). In T₄ plots the average disease incidence and PDI were recorded 2.89 and 1.43 percent respectively with vector population of 0.69 per ten leaves. Whereas T₃ provided pertinent control against ToLCD with marketable yield of 253.03 q ha⁻¹ and cost benefit ratio of 1:1.49. In these plots the disease incidence and PDI were noted as 10.09 and 6.23 percent respectively with vector population of 1.50 per ten leaves (Table 4.159).

The overall performance of T₂ was inferior in comparison to other treated plots because it gave lowest cost benefit ratio (1:1.11). However the disease incidence (12.88 and 5.18 %), PDI (7.73 and 2.74%) and vector population (1.70 and 0.84) were lower and marketable yield (226.35 q ha⁻¹) was higher in T₂ than the T₁ and T₆ (Table 4.159).

2016-17

The data presented in Table 4.160 displayed that in 2016-17 all the treated plots were superior over control for overall performance and among the treated plots best performance was given by T₅ because the highest marketable yield (305.87 q ha⁻¹) and cost benefit ratio (1:2.41) was observed from these plots which was followed by T₄ and T₃. Though at last observation the disease incidence (10.11 %) and PDI (6.74 %) were slightly higher in T₅ than T₃ (6.96 and 4.97 %) and the vector population (2.35 per ten leaves) was also higher than the T₃ (1.60), T₁ (2.00) and T₄ (2.15). However throughout the experimental period (2016-17) the lowest

average disease incidence (4.42 %), PDI (2.78 %) and vector population (0.73) were recorded in T₃.

The plots treated with T₄ exhibited low disease incidence (11.09 %), PDI (7.67 %) and vector population (2.15 per ten leaves) at last observation and gave good marketable yield (266.25 q ha⁻¹) and cost benefit ratio (1:1.88). In T₄ plots the average disease incidence and PDI were recorded 4.83 and 3.22 percent respectively with vector population of 1.01 per ten leaves. T₃ provided best control against ToLCD with marketable yield of 278.39 q ha⁻¹ and cost benefit ratio of 1:1.66 whereas the lowest disease incidence (6.96 %), PDI (4.97 %) and vector population (1.60 per ten leaves) were noted in T₃ (Table 4.160).

The overall performance of T₂ was inferior to the other treated plots because it gave lowest cost benefit ratio (1:0.90). However the disease incidence (12.50 and 5.45 %), PDI (8.45 and 3.82 %) and vector population (2.40 and 1.01) were lower and marketable yield (208.02 q ha⁻¹) was higher in T₂ than the T₁ and T₆ (Table 4.160).

Mean (2015-16 and 2016-17)

It was depicted from the data presented in Table 4.161 that in both years (2015-16 and 2016-17) all the treated plots provided superior overall performance than the control and among the treated plots best performance was given by T₅ that showed lowest disease incidence (8.84 %), PDI (5.35 %) and vector population (1.78 per ten leaves) at last observation along with highest marketable yield (316.55 q ha⁻¹) and best cost benefit ratio (1:2.62). Throughout the experimental period (2015-17) the lowest average disease incidence (4.45 %), PDI (2.60 %) and vector population (0.81) were also recorded in T₅. This was followed by T₄ and T₃.

The plots treated with T₄ exhibited low disease incidence (9.83 %), PDI (6.40 %) and vector population (1.78 per ten leaves) at last observation and gave good marketable yield (275.42 q ha⁻¹) and cost benefit ratio (1:2.05). In T₄ plots the average disease incidence and PDI were recorded 3.89 and 2.35 percent respectively with vector population of 0.85 per ten leaves. Whereas T₃ provided best control against ToLCD with marketable yield of 265.71 q ha⁻¹ and cost benefit ratio of 1:1.58. In these plots the disease incidence and PDI were noted as 8.53 and

Table 4.159: Overall performance of treatments (2015-16)

Treatment	Incidence (%)		PDI		Population of whitefly		Marketable yield (q ha ⁻¹)	B:C ratio
	Max	Mean	Max	Mean	Max	Mean		
T ₁	15.09 (22.71) ^β	6.32	9.59 (17.88) ^β	3.54	1.85 (1.35) ^δ	0.92	198.82	01:1.13
T ₂	12.88 (20.88)	5.18	7.73 (15.92)	2.74	1.70 (1.30)	0.84	226.35	01:1.11
T ₃	10.09 (17.59)	3.35	6.23 (14.32)	1.66	1.50 (1.22)	0.73	253.03	01:1.49
T ₄	8.56 (16.93)	2.89	5.13 (13.04)	1.43	1.40 (1.18)	0.69	284.59	01:2.23
T ₅	7.56 (15.10)	2.67	3.96 (11.42)	1.10	1.20 (1.10)	0.58	327.22	01:2.84
T ₆	31.67 (34.20)	14.72	21.40 (27.51)	8.57	3.90 (1.98)	2.15	182.78	01:1.13
T ₇	86.48 (68.59)	36.14	58.46 (49.89)	22.79	5.90 (2.43)	3.57	106.85	
Sem±	1.193		0.953		0.051		4.485	
CD (p=0.05)	3.546*		2.831*		0.151*		13.326*	
CV	1.218		1.271		0.966		0.568	

Table 4.160: Overall performance of treatments (2016-17)

Treatment	Incidence (%)		PDI		Population of whitefly		Marketable yield (q ha ⁻¹)	B:C ratio
	Max	Mean	Max	Mean	Max	Mean		
T ₁	13.28	6.91	9.24	4.59	2.00	1.13	201.18	01:1.10
	(21.24) ^β		(17.60) ^β		(1.41) ^δ			
T ₂	12.50	5.45	8.45	3.82	2.40	1.01	208.02	01:0.90
	(20.67)		(16.79)		(1.54)			
T ₃	6.96	4.42	4.97	2.78	1.60	0.73	278.39	01:1.66
	(15.03)		(12.65)		(1.24)			
T ₄	11.09	4.83	7.67	3.22	2.15	1.01	266.25	01:1.88
	(19.07)		(15.86)		(1.45)			
T ₅	10.11	6.19	6.74	4.07	2.35	1.03	305.87	01:2.41
	(20.77)		(14.62)		(1.53)			
T ₆	28.63	11.28	19.54	6.42	3.95	2.23	199.69	01:1.33
	(32.28)		(26.07)		(1.98)			
T ₇	76.36	32.58	55.08	21.10	5.60	3.53	105.71	01:1.10
	(61.02)		(47.93)		(2.37)			
Sem±	1.556		1.439		0.074		2.608	
CD (p=0.05)	4.622*		4.275*		0.219*		7.750*	
CV	1.637		1.9		1.283		0.333	

Table 4.161: Overall performance of treatments (2015-16 and 2016-17)

Treatment	Incidence (%)		PDI		Population of whitefly		Marketable yield (q ha ⁻¹)	B:C ratio
	Max	Mean	Max	Mean	Max	Mean		
T ₁	14.19 (21.97)	6.62	9.42 (17.74)	4.07	1.93 (1.38)	1.03	200.00	01:1.12
T ₂	12.69 (20.77)	5.33	8.09 (16.35)	3.30	2.05 (1.42)	0.93	217.18	01:1.00
T ₃	8.53 (16.31)	3.89	5.60 (13.48)	2.22	1.55 (1.23)	0.73	265.71	01:1.58
T ₄	9.83 (18.00)	3.89	6.40 (14.45)	2.35	1.78 (1.31)	0.85	275.42	01:2.05
T ₅	8.84 (17.93)	4.45	5.35 (13.02)	2.60	1.78 (1.31)	0.81	316.55	01:2.62
T ₆	30.15 (33.24)	13.07	20.47 (26.79)	7.57	3.93 (1.98)	2.19	191.24	01:1.23
T ₇	81.42 (64.80)	34.48	56.77 (48.91)	22.07	5.75 (2.40)	3.54	106.28	
Sem±	0.890		0.737		0.040		2.468	
CD (p=0.05)	2.646*		2.191*		0.118*		7.333*	
CV	0.923		0.978		0.721		0.314	



A. Treated plots



B. Control plots (T₇)

Fig 4.39: Experimental plots of management of leaf curl disease



Fig 4.40: Tomato plant with leaf curl symptoms



Fig 4.41: Whitefly in tomato plant

5.60 percent respectively with vector population of 1.55 per ten leaves (Table 4.161).

The overall performance of T₂ was inferior in comparison to other treated plots because it gave lowest cost benefit ratio (1:1.00). However the disease incidence (12.69 and 5.33 %) and PDI (8.09 and 3.30 %) were lower whereas vector population (2.05 and 0.93) and marketable yield (217.18 q ha⁻¹) was higher in T₂ than the T₁ and T₆ (Table 4.161).

The early infection of ToLCV virus can cause up to 95 percent yield loss but if we could delay this infection then we can reduce the yield loss up to about 10 percent (Saikia and Muniyappa, 1989 and Singh *et al.*, 2014). Since the virus is transmitted by sweet potato whitefly (*Bemisia tabaci*). Thus the management of the disease is possible only through vector control.

Some management practices such as polythene/ plastic mulch and border crop are reported to lower the vector population. However, the application of insecticides gives significantly control the ToLCD by reducing vector population (Legg *et al.*, 2014). Therefore five insecticides were tested in combination with silver polythene mulch and maize as border crop to find out best and cost effective strategy for management of tomato leaf curl disease.

The present results indicated that in both years the disease pressure was low in all the treated plots than the control plots because the vector population was also low in treated plots than control. There may be three possible reasons for the reduction of vector population: (i) since the majority of adult whitefly normally fly <2 m from the ground thus the placement of tall border crop around the crop field may obstruct or delay the movement of vector (Gerling and Horowitz, 1984 and Hilje *et al.*, 2001), (ii) the mulch may interfere with visual host identification by vector or suicidal attraction to the sun-heated mulch (Cohen and Berlinger, 1986, Smith *et al.*, 2000 and Rajasri *et al.*, 2011) and (iii) the application/ spraying of insecticides directly kill the whitefly (Kodandaram *et al.*, 2010).

This experiment shows that up to 5 days after spraying insecticide, a minor increase was noted in the disease pressure (percent incidence and PDI) because the population of whitefly was reduced due to spray but over time, the effect of insecticide gradually decreased and as the vector population increased, the disease

pressure continued to increase. It was also seen that until the 3rd spray, the disease pressure and vector population increased gradually, whereas with the 4th spray it got a little faster and after the 6th spray, the maximum was recorded (Barrania and Abou-Taleb, 2014 and Meena and Raju, 2014).

On the basis of pooled data we can say that among all the treatments three treatments (T₃, T₅ and T₄) were found to be most effective to control ToLCD than the others (Jane and Lapidot, 2007, Selby *et al.*, 2008, Kodandaram *et al.*, 2010 and El-Sayed, 2013). In these treatments the maximum incidence, PDI and vector population ranged 8.53 to 9.83 percent, 5.35 to 6.40 percent and 1.55 to 1.78 per ten leaves, respectively. The average incidence, PDI and vector population ranged 3.89 to 4.45 percent, 2.22 to 2.60 percent and 0.73 to 0.85, respectively. Out of these three treatments the crop treated with T₅ produced highest marketable yield (316.55 q ha⁻¹) and provided best B:C ratio (1:2.62). Whereas T₄ and T₃ gave marketable yield of 275.42 and 265.71 q ha⁻¹ and B:C ratio of 01:2.05 and 01:1.58, respectively. Among the treated plots T₆ showed highest disease pressure with maximum and average incidence of 30.15 and 13.07 percent, PDI of 20.47 and 7.57 percent and vector population of 3.93 and 2.19 per ten leaves and provided lowest marketable yield (191.24). However the least benefit cost ratio was obtained from T₂. Our results are partially supported with the findings of Ahmed (2006) who conducted a study to evaluate the effect of twelve treatments on the control of TLCV disease. He found that covering of the tomato seedlings in combination with Actara (thiamethoxam), Confider insecticides application have significantly decreased whitefly population by 22.4 per cent and 44.3 per cent, respectively. Palumbo *et al.* (2001) suggested that the imidacloprid and thiamethoxam are the most effective insecticide for the control of *B. tabaci*. Ali *et al.* (2005) proved that Buprofezin is the most effective insecticide against nymphs and imidacloprid against the whitefly adults during the year 2003 and 2004. Govindappa *et al.* (2013) recorded that among the different concentrations of new molecule, cyantraniliprole 10 OD at 60 and 75 g a.i ha⁻¹ have knockdown effect and caused 100 per cent mortality at 48 hrs after treatments and also recorded least virus transmission (10 and 5 % respectively).

Disease pressure (percent incidence and PDI), vector population, yields and B:C ratio are the important criteria for the selection of any management strategy. The B:C ratio describes that after investing one unit of money on management how much unit we get in return. Thus on the basis of these criteria we can say that T_5 was the best and cost effective management strategy for ToLCD which was followed by T_4 and T_3 . Thus we can say that these three strategies could be promising method for the management of ToLCD through vector control.

CHAPTER-V

SUMMARY AND CONCLUSIONS

Tomato (*Solanum lycopersicum* L.) is one of the most popular and extensively grown vegetables in tropical and subtropical countries. Many diseases are known to infect tomato crop throughout its life. Among them leaf curl caused by *Tomato leaf curl virus* is one of the most important disease that causes severe crop loss.

In field condition the occurrence of prevalent diseases were recorded for two seasons in three consecutive years i.e. *rabi* (2014-15, 2015-16 and 2016-17) and *Kharif* (2015, 2016 and 2017). Five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were observed in the crop during both the seasons. In *Rabi* the first occurrence of leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were observed in November, December - January, January - February, January and December respectively. The infection pattern of the diseases was leaf curl > early blight > mosaic > collar rot > tomato spotted wilt. In *Kharif* the first occurrence of leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were observed in August, September – October, October, September – October and August September respectively. The infection pattern of the diseases was leaf curl > early blight > collar rot > mosaic > tomato spotted wilt.

In poly house or protected condition the occurrence of prevalent diseases were recorded for two years from first fortnight of November to end of April in 2015-16 and first fortnight of August to end of January in 2016-17. Four diseases viz. leaf curl, mosaic, early blight and collar rot were appeared in the crop during both the years. In first season (2015-16) the first appearance of leaf curl, mosaic, early blight and collar rot were observed in December, January, February and January respectively. In second season (2016-17) the first symptoms of leaf curl, mosaic, early blight and collar rot were seen between first fortnight of September to first fortnight of October.

The presence of *Tomato leaf curl virus* was confirmed in two samples (Raipur and Rasni) by PCR amplification with two primers viz., AV1 and ToLCV MP which provided amplified DNA fragments of approximately 800 bp and 200

bp respectively. The nucleotide sequences of coat protein and movement protein of sample virus confirms the presence of *Tomato leaf New Delhi virus* in Raipur.

In *Rabi*, the first count of adult whitefly was recorded at about 7 days after transplanting (DAT). The population of adult whitefly ranged from 0.06 at 7 DAT to 6.51 at 91 DAT. The first appearance of tomato leaf curl disease (ToLCD) was noted at 7 days after transplanting. The percent incidence and index of leaf curl ranged from 0.89 to 85.55 percent and 0.32 to 65.29 percent, respectively.

The whitefly showed highly significant positive correlation with maximum temperature ($r = 0.623$, $p = 0.001$) and wind speed ($r = 0.791$, $p = 0.001$) but negative with maximum relative humidity ($r = -0.802$, $p = 0.001$). However, it (whitefly) also exhibited a significant positive correlation with minimum temperature ($r = 0.540$, $p = 0.005$) and negative with relative humidity gradient ($r = -0.546$, $p = 0.005$).

The percent incidence of leaf curl indicated highly significant positive correlation with whitefly population ($r = 0.981$, $p = 0.001$), maximum temperature ($r = 0.649$, $p = 0.001$), and wind speed ($r = 0.853$, $p = 0.001$) but negative with maximum relative humidity ($r = -0.875$, $p = 0.001$). It also showed significant positive correlation with minimum temperature ($r = 0.600$, $p = 0.005$) and negative with relative humidity gradient ($r = -0.593$, $p = 0.005$).

The percent disease index of leaf curl displayed highly significant positive correlation with incidence ($r = 0.998$, $p = 0.001$), adult whitefly population ($r = 0.975$, $p = 0.001$), maximum temperature ($r = 0.693$, $p = 0.001$), minimum temperature ($r = 0.640$, $p = 0.001$), wind speed ($r = 0.858$, $p = 0.001$) and negative with maximum relative humidity ($r = -0.888$, $p = 0.001$). A significant negative correlation was also observed between PDI and relative humidity gradient ($r = -0.586$, $p = 0.005$).

None of the weather parameters independently significantly influenced the population of whitefly but together they contributed around 88.80 percent ($R^2 = 0.888$).

Population of whitefly and weather parameters together were responsible for 92.60 percent ($R^2 = 0.926$) of total change in percent leaf curl incidence.

Regression also expressed that with every unit increase in population of whitefly there was significant positive increase of ($b = 9.200$) percent leaf curl incidence.

Percent incidence of leaf curl, population of whitefly and weather parameters were found to contribute 94.0 percent ($R^2 = 0.940$) effect on PDI of leaf curl. Regression also expressed that with every unit increase in percent leaf curl incidence there was significant positive increase of ($b = 0.719$) leaf curl PDI.

During *Kharif* 2015 to 2017 the first trace of adult whitefly was recorded 14 days after transplanting (DAT). The population of adult whitefly ranged from 0.0 at 14 DAT to 4.33 at 91 DAT. The first appearance of tomato leaf curl disease (ToLCD) was noted at 14 days after transplanting. The percent incidence and index of leaf curl ranged from 0.64 to 68.09 percent and 0.14 to 49.91 percent, respectively.

The whitefly population showed highly significant negative correlation with minimum temperature ($r = -0.873$, $p = 0.001$), rainfall ($r = -0.746$, $p = 0.001$) minimum relative humidity ($r = -0.930$, $p = 0.001$) and wind velocity ($r = -0.790$, $p = 0.001$) It also exhibited highly significant positive correlation with temperature gradient ($r = 0.933$, $p = 0.001$), relative humidity gradient ($r = 0.931$, $p = 0.001$) and sun shine hour ($r = 0.838$, $p = 0.001$).

The percent incidence of leaf curl had highly significant negative correlation with minimum temperature ($r = -0.967$, $p = 0.001$), rainfall ($r = -0.700$, $p = 0.001$), minimum relative humidity ($r = -0.928$, $p = 0.001$) and wind velocity ($r = -0.722$, $p = 0.001$). However, whitefly population ($r = 0.963$, $p = 0.001$), temperature gradient ($r = 0.973$, $p = 0.001$) relative humidity gradient ($r = 0.916$, $p = 0.001$) and sun shine hour (0.768, $p = 0.001$) showed highly significant positive correlation with percent leaf curl incidence. A significant negative correlation was observed between percent leaf curl incidence and maximum relative humidity (-0.523 , $p = 0.005$).

The PDI exhibited highly significant positive correlation with incidence ($r = 0.997$, $p = 0.001$), whitefly population ($r = 0.948$, $p = 0.001$), temperature gradient ($r = 0.966$, $p = 0.001$), relative humidity gradient ($r = 0.895$, $p = 0.001$) and sun shine hour ($r = 0.739$, $p = 0.001$). It also displayed highly significant negative correlation with minimum temperature ($r = -0.977$, $p = 0.001$), rainfall (r

= -0.691, $p = 0.001$), minimum relative humidity ($r = -0.916$, $p = 0.001$) and wind velocity ($r = -0.677$, $p = 0.001$).

None of the weather parameters independently caused significant influence on population of whitefly but found to contribute around 89.50 percent ($R^2 = 0.895$) impact on population of whitefly (*B. tabaci*) when acted together.

Percent incidence of leaf curl and weather parameters conjointly were found to contribute around 94.90 percent ($R^2 = 0.949$) impact on percent incidence of leaf curl. The unit change in whitefly population significantly affect the incidence of leaf curl ($b = 8.064$).

The percent leaf curl incidence, population of whitefly and weather parameters were found to contribute 95.30 percent ($R^2 = 0.953$) effect on PDI of leaf curl and with every unit increase in percent leaf curl incidence showed significant positive increase ($b = 0.805$) of PDI.

Among the nineteen ToLCVRES entries/ varieties evaluated none of them showed consistent resistant reaction, but only one entry (2016/ToLCVRES-1) was moderately resistant against ToLCD. The higher total fruit yield (ha^{-1}) was recorded in 2015/ToLCVRES-5 (636.04 q), 2016/ToLCVRES-1 (631.81 q), 2014/ToLCVRES-5 (565.35 q), 2015/ToLCVRES-1 (551.59 q) and 2015/ToLCVRES-2 (550.01 q).

Out of 23 commercial varieties the performance of 17 varieties was consistent in both the evaluation years. Of them 10 varieties viz. Bharani, Bhagyanwan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham and NS 962 showed resistant reaction, 4 varieties viz. MHTM 256, Anvitha, Nun 7610 and Kundan were moderately resistant and one (Red Ruby) was moderately susceptible against ToLCD. The maximum (471.22 q) total yield (ha^{-1}) was recorded in Arka Rakshak followed by Bharani (419.49 q), Abhilash (412.43 q), Bhagyanwan (386.11 q) and Priya-6636 (327.35 q).

Among the determinate tomato, two entries viz. 2016/ToDVAR-5 and 2016/ToDVAR-12 expressed resistant and one (2014/ToDVAR-5) showed moderately resistant reaction against ToLCD. The higher fruit yield was recorded from 2016/ToDVAR-12 (344.08 q), H-86 (337.34 q), 2016/ToDVAR-5 (332.07

q) and 2016/TODVAR-12 (295.37 q) entries. In cherry tomato group, two entries (2015/TOCVAR-4 and 2015/TOCVAR-5) showed moderately resistant reaction and other two entries viz. 2015/TOCVAR-1 and 2015/TOCVAR-3 were moderately susceptible against the disease. The maximum fruit total yield ha^{-1} (301.64 and 331.09 q) was noted in Swarna Ratan followed by 2015/TOCVAR-4 (309.72 q) and 2015/TOCVAR-5 (290.65 q). Two entries (2015/TOINDVAR-4 and 2015/TOINDVAR-5) of indeterminate tomato showed moderately resistant reaction in both the years. The maximum total fruit yield ha^{-1} (384.41 q) was obtained from 2015/TOINDVAR-5 followed by 2015/TOINDVAR-4 (321.65 q).

Disease pressure (incidence and PDI) and vector population were low in all the treated plots than the control. The crop sprayed with Thiamethoxam along with mulching had lowest leaf curl incidence (8.84 %), PDI (5.35 %) and vector population (1.78 per ten leaves), produced highest marketable yield (316.55 q ha^{-1}) with best B:C ratio (1:2.62) followed by T_4 (Buprofezin) and T_3 (Cyantraniliprole / Cyazypyr). The plots treated with T_4 (Buprofezin) exhibited low disease incidence (9.83 %), PDI (6.40 %) and vector population (1.78 per ten leaves) and gave good marketable yield (275.42 q ha^{-1}) with B:C ratio of 1:2.05. In the plots sprayed with Cyantraniliprole / Cyazypyr (T_3) the disease incidence and PDI were recorded 8.53 and 5.60 percent respectively, vector population of 1.55 per ten leaves with marketable yield of 265.71 q ha^{-1} and cost benefit ratio of 1:1.58.

CONCLUSION

In field condition the tomato crop was infected with five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot in both the seasons (*Rabi* and *Kharif*). In poly house or protected condition four diseases leaf curl, mosaic, early blight and collar rot infected the tomato crop.

Two samples (Raipur and Rasni) of leaf curl disease were found positive for virus and this was identified as *Tomato leaf curl virus* by PCR amplification with two primers viz., AV1 and ToLCV MP which provided amplified DNA fragments of approximately 800 bp and 200 bp, respectively. This was the first report from Raipur, Chhattisgarh.

The activity of adult whitefly and occurrence of disease was observed at 7 and 14 days after transplanting in *Rabi* and *Kharif*, respectively. In *Rabi* the relationship of leaf curl was significantly positive with whitefly population, T max, wind speed and T min and negative with RH max and RH gr. The weather parameters jointly contributed around 88.80 percent ($R^2 = 0.888$) impact on population of whitefly (*B. tabaci*). The change in whitefly population significantly influenced the percent incidence of leaf curl ($b = 9.200$). The impact of percent incidence was significantly positive ($b = 0.719$) with PDI of leaf curl. In *Kharif* the correlation of leaf curl was significantly positive with whitefly population, T gr, RH gr and sun shine hours and negative with T min, rainfall, RH min and wind velocity. The weather parameters were found to contribute around 89.50 percent ($R^2 = 0.895$) impact on population of whitefly (*B. tabaci*) when acted together. The unit change in whitefly population significantly affected the incidence of leaf curl ($b = 8.064$). The percent leaf curl incidence, population of whitefly and weather parameters conjointly contributed 95.30 percent ($R^2 = 0.953$) effect on PDI of leaf curl. The unit increase in percent leaf curl incidence showed significant positive increase ($b = 0.805$) of percent disease index.

Among the 74 entries/ varieties evaluated the performance of 12 viz. Bharani, Bhagyawan, Abhilash, Karan, Kareena, Karishma, VNR-3357, Lakshmi, Saksham, NS 962, 2016/ToDVAR-5 and 2016/ToDVAR-12 were constant with resistant reaction. Ten entries/ varieties (2016/ToLCVRES-1, MHTM 256, Anvitha, Nun 7610, Kundan, 2014/TODVAR-5, 2015/TOCVAR-4, 2015/TOCVAR-5, 2015/TOINDVAR-4 and 2015/TOINDVAR-5) showed consistent moderately resistant reaction. However, 3 entries/ varieties viz. Red Ruby, 2015/TOINDVAR-3 and Arka Vikash were constant with moderately susceptible reaction. The maximum total yield ha^{-1} was recorded in 2015/ToLCVRES-5 (636.04 q) followed by 2016/ToLCVRES-1 (631.81 q), 2014/ToLCVRES-5 (565.35 q), 2015/ToLCVRES-1 (551.59 q) and 2016/ToLCVRES-4 (462.66 q).

Among the five insecticides evaluated the lowest disease incidence (8.84 %), PDI (5.35 %) and vector population (1.78 / 10 leaves) and highest marketable fruit yield (316.55 q ha^{-1}) and B:C ratio (1:2.62) was recorded in T₅

(Thiamethoxam) followed by T₄ (Buprofezin) and T₃ (Cyantraniliprole / Cyazypyr).

SUGGESTION FOR FUTURE RESEARCH WORK

The following suggestions may be given after the completion of the investigation-

- There is need to conduct extensive surveys in different parts of Chhattisgarh and the distribution pattern of different virus species of *Tomato leaf curl virus* is need to be worked out.
- There is need to investigate the effect of plant biochemical substances and physiological structures on *Tomato leaf curl virus*.
- There is need to understand the nature of resistance in the resistant genotypes and identification of molecular markers linked to ToLCV resistance.
- There is need to develop varieties with broad spectrum resistance to overcome with possible emergence of new begomovirus complexes.

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APPENDIX - A

Weekly meteorological data *Rabi* 2014-15

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
42	31.5	22.5	9.0	1.2	91.0	56.0	35.0	2.6	8.4
43	29.1	19.4	9.7	5.4	92.0	52.0	40.0	2.0	5.9
44	30.1	16.9	13.2	0.0	94.0	37.0	57.0	1.9	8.0
45	30.7	17.6	13.1	0.0	88.0	44.0	44.0	3.0	7.8
46	31.4	19.3	12.1	0.0	84.0	35.0	49.0	2.8	6.8
47	29.3	11.9	17.4	0.0	91.0	28.0	63.0	1.9	8.5
48	30.2	12.5	17.7	0.0	90.0	26.0	64.0	1.9	8.6
49	28.9	10.8	18.1	0.0	90.0	28.0	62.0	2.2	9.0
50	28.6	15.8	12.8	0.0	89.0	49.0	40.0	2.3	3.0
51	25.0	8.3	16.7	0.0	89.0	31.0	58.0	2.2	7.8
52	26.0	9.9	16.1	0.0	86.0	34.0	52.0	2.2	8.3
1	25.0	14.8	10.2	1.3	94.7	52.4	42.3	4.4	4.5
2	25.8	8.0	17.8	0.0	89.9	28.6	61.3	2.2	9.2
3	26.0	8.3	17.7	0.0	89.7	29.0	60.7	2.2	8.3
4	28.9	13.5	15.3	0.0	88.4	37.4	51.0	2.1	7.4
5	28.3	11.7	16.7	0.0	88.3	28.9	59.4	2.6	7.6
6	29.7	14.3	15.3	0.0	84.4	38.7	45.7	2.6	6.4
7	29.3	13.6	15.7	0.3	88.1	39.3	48.9	3.2	8.2
8	33.5	15.7	17.8	0.0	84.0	27.6	56.4	2.7	9.8
9	30.8	18.5	12.3	2.7	82.6	48.9	33.7	4.2	6.7
10	31.3	16.6	14.7	0.0	81.3	34.1	47.1	3.0	8.1
11	34.1	19.9	14.1	0.0	76.1	33.3	42.9	4.1	7.6
12	35.1	18.7	16.4	0.0	65.7	22.0	43.7	3.4	9.0
13	37.3	21.5	15.8	0.0	66.0	30.7	35.3	4.7	7.2
14	39.1	22.8	16.3	0.0	64.6	26.1	38.4	6.6	8.2
15	33.7	20.8	12.9	3.1	83.3	49.4	33.9	6.7	5.4
16	38.0	24.6	13.4	2.0	71.3	33.4	37.9	7.0	9.4

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX - B

Weekly meteorological data *Kharif* 2015

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
26	33.5	25.0	8.5	3.7	87.0	59.3	27.7	9.3	4.3
27	33.6	25.2	8.4	6.0	82.0	61.1	20.9	9.1	5.9
28	31.2	25.2	6.0	10.4	89.3	79.1	10.1	7.9	1.7
29	31.8	25.6	6.2	1.1	90.7	70.9	19.9	8.0	2.4
30	30.7	25.1	5.6	6.2	89.9	70.3	19.6	7.9	3.4
31	31.2	25.2	6.0	7.0	86.0	69.1	16.9	10.4	4.6
32	30.8	24.7	6.1	0.7	94.3	73.4	20.9	4.8	2.5
33	31.7	25.3	6.3	18.1	93.6	72.7	20.9	7.5	4.1
34	32.3	25.9	6.4	3.4	86.7	64.6	22.1	8.1	6.5
35	30.8	25.0	5.8	5.4	94.3	79.6	14.7	4.9	1.2
36	33.0	25.5	7.4	1.4	93.1	63.6	29.6	4.7	6.9
37	33.5	25.4	8.1	9.8	92.6	61.7	30.9	3.8	6.8
38	30.1	25.1	5.0	19.3	94.0	77.6	16.4	5.8	3.1
39	32.5	24.6	7.9	0.0	92.1	56.7	35.4	3.0	7.2
40	33.7	24.4	9.3	0.0	92.0	51.4	40.6	2.4	7.8
41	33.9	22.2	11.7	0.0	89.4	46.6	42.9	3.0	8.7
42	33.4	22.8	10.6	0.0	91.4	44.9	46.6	2.4	8.7
43	33.7	21.3	12.4	0.0	90.3	36.9	53.4	2.1	8.2
44	30.0	19.4	10.7	0.0	90.3	54.7	35.6	4.1	6.7
45	31.7	18.8	13.0	0.0	90.9	37.4	53.4	2.6	7.8
46	31.7	16.3	15.4	0.0	88.9	32.9	56.0	2.4	7.5
47	30.6	15.5	15.1	0.0	88.1	36.1	52.0	2.8	8.3

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX - C

Weekly weather data *Rabi* 2015-16.

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
40	33.7	24.4	9.3	0.0	92.0	51.4	40.6	2.4	7.8
41	33.9	22.2	11.7	0.0	89.4	46.6	42.9	3.0	8.7
42	33.4	22.8	10.6	0.0	91.4	44.9	46.6	2.4	8.7
43	33.7	21.3	12.4	0.0	90.3	36.9	53.4	2.1	8.2
44	30.0	19.4	10.7	0.0	90.3	54.7	35.6	4.1	6.7
45	31.7	18.8	13.0	0.0	90.9	37.4	53.4	2.6	7.8
46	31.7	16.3	15.4	0.0	88.9	32.9	56.0	2.4	7.5
47	30.6	15.5	15.1	0.0	88.1	36.1	52.0	2.8	8.3
48	31.9	16.7	15.2	0.0	87.1	34.3	52.9	2.4	7.5
49	31.2	14.8	16.5	0.0	88.1	31.0	57.1	2.3	8.0
50	30.1	17.3	12.8	0.6	77.4	46.0	31.4	2.9	4.3
51	27.7	16.6	11.1	1.3	85.0	51.9	33.1	3.1	2.0
52	26.3	10.7	15.6	0.0	86.4	29.7	56.7	2.5	5.8
1	30.5	12.0	18.5	0.0	81.9	26.9	55.0	2.0	8.0
2	29.5	11.1	18.4	0.0	87.1	26.6	60.6	2.4	7.5
3	28.0	14.6	13.4	0.3	87.6	47.7	39.9	3.3	4.2
4	26.4	8.6	17.8	0.0	89.9	34.1	55.7	2.7	8.8
5	31.5	14.0	17.5	0.0	85.6	31.9	53.7	2.7	8.5
6	31.0	13.2	17.7	0.0	78.0	30.0	48.0	3.1	9.0
7	32.3	19.5	12.8	0.0	79.4	41.1	38.3	3.2	5.3
8	34.9	18.9	16.0	0.0	71.3	29.0	42.3	3.0	7.2
9	33.1	20.8	12.3	0.0	82.1	40.1	42.0	3.5	3.0
10	35.1	20.5	14.7	0.1	73.3	26.7	46.6	3.8	7.7
11	33.7	20.7	13.0	0.4	75.7	36.3	39.4	4.9	6.7
12	37.0	21.1	15.9	0.0	61.3	19.9	41.4	4.5	8.9
13	38.3	20.1	18.2	0.0	65.7	21.0	44.7	3.6	8.8
14	40.4	23.8	16.6	0.8	62.6	23.3	39.3	5.1	8.8

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX - D

Weekly meteorological dataKharif 2016

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
26	34.1	26.2	7.9	4.6	88.3	58.9	29.4	5.7	6.9
27	32.0	25.2	6.9	11.9	93.4	76.4	17.0	9.9	2.9
28	28.7	24.7	4.0	11.9	93.3	79.7	13.6	8.9	0.6
29	30.9	24.6	6.4	15.4	94.7	79.9	14.9	6.9	1.7
30	31.6	25.2	6.4	22.2	93.0	69.4	23.6	3.6	4.4
31	31.2	25.6	5.6	1.1	90.4	77.4	13.0	6.1	4.4
32	28.6	24.6	4.0	18.7	92.9	81.1	11.7	9.1	1.6
33	29.0	24.7	4.3	1.3	89.1	76.7	12.4	9.2	1.3
34	31.0	25.4	5.6	0.5	88.7	66.0	22.7	5.8	4.7
35	32.4	25.9	6.5	3.8	90.9	71.1	19.7	3.2	5.2
36	30.8	25.3	5.5	7.9	86.6	67.0	19.6	6.5	1.5
37	30.9	24.3	6.6	20.1	96.0	78.4	17.6	2.6	2.0
38	32.2	24.9	7.3	12.9	93.9	69.0	24.9	2.5	6.6
39	30.1	24.7	5.4	15.7	97.3	83.6	13.7	3.2	3.9
40	30.4	24.8	5.7	9.7	95.4	73.4	22.0	2.8	4.3
41	31.3	23.3	8.0	2.2	95.3	57.7	37.6	1.6	4.7
42	31.8	19.4	12.4	0.0	89.1	32.6	56.6	1.1	10.0
43	31.6	18.0	13.6	0.0	90.1	33.6	56.6	1.3	9.5
44	30.5	19.6	10.9	0.0	83.1	51.0	32.1	2.0	8.2
45	30.5	16.7	13.7	0.0	87.1	32.0	55.1	2.2	8.7
46	29.2	14.5	14.7	0.0	90.1	36.3	53.9	1.3	7.6
47	29.7	11.5	18.1	0.0	88.4	25.1	63.3	1.1	8.6
48	31.0	12.4	18.6	0.0	87.0	25.4	61.6	1.0	9.0

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX - E

Weekly weather data *Rabi*2016-17

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
40	30.4	24.8	5.7	9.7	95.4	73.4	22.0	2.8	4.3
41	31.3	23.3	8.0	2.2	95.3	57.7	37.6	1.6	4.7
42	31.8	19.4	12.4	0.0	89.1	32.6	56.6	1.1	10.0
43	31.6	18.0	13.6	0.0	90.1	33.6	56.6	1.3	9.5
44	30.5	19.6	10.9	0.0	83.1	51.0	32.1	2.0	8.2
45	30.5	16.7	13.7	0.0	87.1	32.0	55.1	2.2	8.7
46	29.2	14.5	14.7	0.0	90.1	36.3	53.9	1.3	7.6
47	29.7	11.5	18.1	0.0	88.4	25.1	63.3	1.1	8.6
48	31.0	12.4	18.6	0.0	87.0	25.4	61.6	1.0	9.0
49	29.0	14.6	14.3	0.0	89.4	39.9	49.6	1.7	7.3
50	28.7	12.1	16.6	0.0	84.6	30.1	54.4	1.8	7.9
51	27.7	8.9	18.8	0.0	87.1	23.9	63.3	1.5	8.4
52	27.8	9.5	18.4	0.0	85.4	26.3	59.1	1.2	7.6
1	29.0	12.1	16.9	0.0	89.7	33.9	55.9	1.6	6.4
2	28.2	12.7	15.6	0.8	86.1	33.7	52.4	1.6	6.7
3	27.7	10.5	17.3	0.0	83.1	26.0	57.1	1.2	8.2
4	29.8	13.2	16.6	0.0	84.3	28.3	56.0	2.0	8.7
5	29.9	13.3	16.6	0.0	79.0	27.7	51.3	1.5	8.0
6	31.6	12.9	18.7	0.0	83.9	24.3	59.6	1.9	9.6
7	31.2	16.2	15.0	0.8	79.6	34.3	45.3	2.6	6.4
8	33.9	15.3	18.6	0.0	75.0	18.1	56.9	2.5	10.2
9	33.5	14.5	19.0	0.0	68.3	15.3	53.0	2.0	10.1
10	33.8	19.0	14.8	0.8	67.3	30.3	37.0	2.9	7.3
11	32.2	17.2	15.0	0.0	60.9	21.4	39.4	3.5	8.3
12	35.2	19.0	16.2	0.0	65.1	18.1	47.0	3.4	9.1
13	40.4	22.6	17.8	0.0	60.9	13.6	47.3	2.3	8.9
14	41.4	25.9	15.6	0.0	52.7	16.1	36.6	4.8	8.4

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX - F

Weekly meteorological data *Kharif* 2017.

SMW	T max	T min	T gr	Rainfall	RH max	RH min	RH gr	WS	SS
	°C	°C	°C	mm	%	%	%	kmph	hr
26	32.6	25.0	7.5	18.5	92.1	71.6	20.6	6.6	2.4
27	31.9	25.7	6.2	7.4	84.0	60.1	23.9	7.2	2.1
28	31.3	25.0	6.3	5.8	90.3	74.0	16.3	4.6	2.0
29	30.7	25.4	5.3	7.3	91.1	73.4	17.7	3.4	2.4
30	30.2	24.6	5.6	3.8	90.7	73.9	16.9	5.8	1.3
31	32.7	26.2	6.5	2.5	85.1	65.9	19.3	3.1	5.5
32	30.8	24.9	5.9	6.4	89.0	72.3	16.7	3.4	1.8
33	32.1	25.1	6.9	6.3	91.9	69.4	22.4	2.0	2.4
34	31.8	25.1	6.7	5.1	91.4	69.1	22.3	1.4	5.5
35	31.7	25.3	6.4	4.5	92.1	70.6	21.6	0.8	4.0
36	33.4	26.2	7.2	0.0	90.1	63.3	26.9	2.4	6.5
37	32.2	24.8	7.4	6.6	94.0	74.7	19.3	3.0	3.8
38	30.7	24.5	6.2	16.5	94.0	75.4	18.6	4.4	3.5
39	32.9	25.2	7.7	3.1	89.3	60.7	28.6	2.7	7.5
40	31.8	24.7	7.1	4.9	92.7	71.6	21.1	3.0	5.2
41	31.9	24.9	7.0	1.4	95.0	70.4	24.6	2.3	4.8
42	33.5	23.1	10.4	0.9	89.1	44.9	44.3	2.5	7.7
43	33.2	22.7	10.4	0.0	86.4	44.4	42.0	2.4	7.9
44	31.2	18.5	12.7	0.0	86.9	39.0	47.9	2.3	7.8
45	30.3	16.3	14.0	0.0	89.7	34.0	55.7	2.6	9.0
46	28.5	18.3	10.2	0.1	88.4	55.4	33.0	3.7	5.2
47	30.3	17.5	12.8	0.0	82.1	38.3	43.9	2.2	6.9
48	29.7	12.0	17.7	0.0	84.4	25.6	58.9	1.7	8.8

SMW = Standard meteorological week, T = Temperature, RH = Relative humidity,
WS = Wind speed, SS = Sun shine.

APPENDIX – I

Sequencing data of sample Rasni with primer AV1

>0718_067_085_PCR_K2_AV1_F_H07.ab1

AAGTACGCCGAACGTTCTCAACTTTTCGACAGCCCCTATGGAGCTCGTGC
 AGTTGTCCCCATTGCCCCGCGTCACAAAAGCAAAGGCCTGGACAAACAG
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 CGTGCCAAGGGGATGTGAAGGCCCTTGCAAGGTGCAGTCCTTTGAATC
 CAGGCATGATGTCTCTCATATTGGCAAAGTCATGTGTGTTAGTGATGTT
 ACTCGAGGAACTGGACTCACACATCGCGTAGGAAAGCGATTTTGTGTG
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 GTCCTACAGGATCCCCCAAGATTTTGGGGAAGTTTTTAACATGTTTGA
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>0718_067_086_PCR_K2_AV1_R_A08.ab1

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 ACACTTGATAACGATCACGATGCATGTTCTTCACCGTTGCTGTGCTCGG
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 GTAGGACGACGGTCACGGACCAAAAAAACATAACACTGTTAGTATGG
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 AGATTTCA

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 TCAAAGGACTGCACCTTGCAAGGGCCTTCACATCCCCTTGGCACGTCAG
 GACTTCTATACATTCTGTACATTCTGGGTTTTCTGTTTCATCGGCCTGTTT
 GTCCAGGCCTTTGCTTTTGTGACGCGGGCAATGGGGACAACGTCACGA
 GCTCCATAGGGGCTGTGCAAGTTGAGACGACGGCGTACTTTTCGATGCG
 GGAGTTGAAATGATGATATCTGCTGGTCGCTTCCGCCATAAA

APPENDIX – J

Sequencing data of sample Rasni with primer ToLCGV MP

>0718_067_089_PCR_K4_MP1_F_D08.ab1

GGTACATATTTGGCATAGGTCCGAACGAATCATGGGCAAGCAGATCGG
AGGTAGGACATTTCGTCCGTGATCAGCAGACCATATAAAAACCTAAGCG
GGTTGGACGATTTCGGCAATCGATCCAGGTCCGTTCGGCATCACAAGCGG
GGAGTATCACGAGGGAAGAGATTGCAGAAA

>0718_067_090_PCR_K4_MP1_R_E08.ab1

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TGGTCTGCTGATCACGGACGAATGTCCTACCTCCGATCTGCTTGCCCAT
GATTCGTTTCGGACCTATTGCCAAATATGGTACACGTAACGATCTTGAAC
TATGTCCCATTAACCGTGAACCATCCAAA

APPENDIX – K

Percent identities (nucleotide) of isolated ToLCV CP gene with the most closely related Genebank viruses [Sample: Rasni, Primer: AV1]

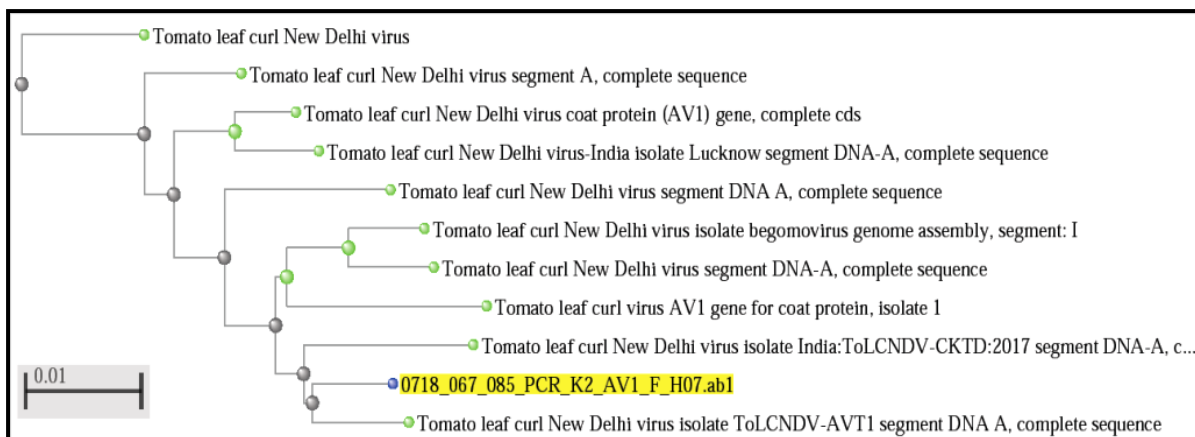
S.N.	Virus	E value		NCBI Accession	Query coverage: Identity	
		F	R		F	R
1.	Tomato leaf curl New Delhi virus isolate ToLCNDV-AVT1 segment DNA A, complete sequence	0	0	AY428769.1	94:98	99:98
2.	Tomato leaf curl New Delhi virus isolate India:ToLCNDV- CKTD:2017 segment DNA-A, complete sequence	0	0	MF807949.1	94:97	99:98
3.	Tomato leaf curl New Delhi virus isolate begomovirus genome assembly, segment: I	0	0	LT556071.1	93:97	99:97
4.	Tomato leaf curl New Delhi virus segment DNA- A, complete sequence	0	0	EF068246.1	93:97	99:97
5.	Tomato leaf curl New Delhi virus coat protein (AV1) gene, complete cds	0	0	HQ840736.1	93:97	99:96
6.	Tomato leaf curl New Delhi virus segment DNA A, complete sequence	0	0	EF620534.1	94:97	99:96
7.	Tomato leaf curl virus AV1 gene for coat protein, isolate 1	0	0	AJ810340.1	94:97	99:96
8.	Tomato leaf curl New Delhi virus-India isolate Lucknow segment DNA- A, complete sequence	0	0	KC513822.1	93:96	99:96
9.	Tomato leaf curl New Delhi virus segment A, complete sequence	0	0	AY939926.1	93:96	99:96
10.	Tomato leaf curl New Delhi virus	0	0	LN878118.1	94:96	99:95

APPENDIX - L

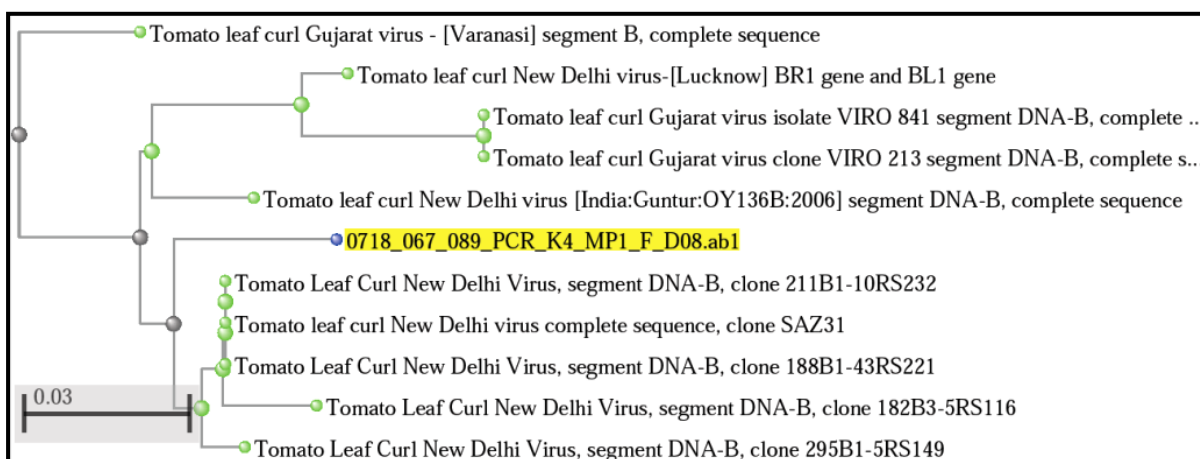
Percent identities (nucleotide) of isolated ToLCV MP gene with the most closely related Genbank viruses [Sample: Rasni, Primer: ToLCGV MP]

S.N.	Virus	E value		NCBI Accession	Query coverage: Identity	
		F	R		F	R
1.	Tomato leaf curl New Delhi virus, segment DNA-B, clone 211B1- 10RS232	9e- 69	4e- 67	LT168887.1	98:95	97:94
2.	Tomato leaf curl New Delhi virus, segment DNA-B, clone 188B1- 43RS221	9e- 69	4e- 67	LT168883.1	98:95	97:94
3.	Tomato leaf curl New Delhi virus, segment DNA-B, clone 295B1- 5RS149	9e- 69	2e- 65	LT168868.1	98:95	97:94
4.	Tomato leaf curl New Delhi virus complete sequence, clone SAZ31	3e- 68	9e- 69	LN713270.1	98:95	97:95
5.	Tomato leaf curl New Delhi virus [India:Guntur:OY136B:20 06] segment DNA-B, complete sequence	7e- 65	2e- 71	GU112087.1	98:94	98:95
6.	Tomato leaf curl New Delhi virus, segment DNA-B, clone 182B3- 5RS116	2e- 65	4e- 62	LT168853.1	98:94	97:93
7.	Tomato leaf curl New Delhi virus-[Lucknow] BR1 gene and BL1 gene	7e- 60	7e- 65	X89653.1	98:92	98:93
8.	Tomato leaf curl Gujarat virus - [Varanasi] segment B, complete sequence	3e- 58	3e- 59	AY190291.1	98:91	98:91
9.	Tomato leaf curl Gujarat virus isolate VIRO 841 segment DNA-B, complete sequence	9e- 54	2e- 56	KU196751.1	98:90	98:90
10.	Tomato leaf curl Gujarat virus clone VIRO 213 segment DNA-B, complete sequence	9e- 54	2e- 56	KP235538.1	98:90	98:90

APPENDIX - M



a. Phylogenetic tree of coat protein (CP) gene sequence of the sample and selected *Tomato leaf curl viruses* [Sample: Rasni, Primer: AV1].



b. Phylogenetic tree of movement protein (MP) gene sequence of the sample and selected *Tomato leaf curl viruses* [Sample: Rasni, Primer: ToLCGV MP].

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Seasonal occurrence of prevalent diseases of tomato under field conditions

KN Koshale and CP Khare**Abstract**

Tomato is one of the most popular and extensively grown vegetables in India as well as in Chhattisgarh. The tomato plant is infected with number of diseases in its life span but they do not occur simultaneously and their development varies with location and season. Therefore a study was undertaken in *Kharif* season of three consecutive years (2015, 2016 and 2017) at Horticulture Instruction cum Research Farm, College of Agriculture, Raipur (Chhattisgarh) to know the prevalent diseases of tomato, their occurrence pattern and extent of infection. Five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were observed to infect the crop during the investigation. Under Raipur situations the first occurrence of leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were observed in August, September – October, October, September – October and August - September respectively. Leaf curl and early blight were most serious diseases of the crop out of five commonly occurring diseases.

Keywords: disease, collar rot, leaf curl, mosaic, tomato**1. Introduction**

Tomato, *Solanum lycopersicum* L. a member of the family Solanaceae (Singh, 2014) [41] is one of the most popular and extensively grown vegetables (Chaudhary *et al.* 2010 and Singh *et al.* 2015) [15, 42] of both tropics and subtropics of the world (Govindappa *et al.* 2013) [18]. In the world, tomato is cultivated over an area of 5.7 million ha with an annual production of 211.80 million metric tonnes and productivity of 37.16 metric tonnes ha⁻¹ (Anonymous, 2016) [7]. In India, it occupies an area of about 0.80 million ha producing over 19.54 million metric tonnes with the productivity of 21.2 metric tonnes ha⁻¹ (Anonymous, 2017) [8]. There are many constraints that come in the way of tomato cultivation but diseases are one of the important factors for low productivity of the crop (Kakati and Nath, 2014) [20]. Tomato is known to susceptible for more than 200 diseases (Shelat *et al.* 2014) [40]. Among them buckeye rot (fruit rot); *Phytophthora nicotianae* var. *parasitica* (Sharma and Dohroó, 2004) [39], collar rot or Sclerotium wilt; *Sclerotium rolfsii* (Mahato *et al.* 2017) [22], damping off; *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii* (Prasad *et al.* 2017) [32], early blight; *Alternaria solani* (Roopa, 2012) [35], *Fusarium* wilt; *Fusarium oxysporum* f.sp. *lycopersici* (Manikandan and Raguchander, 2014) [23], late blight (Olanya *et al.* 2015) [28], powdery mildew (Park *et al.* 2010 and Cerkauskas and Brown, 2015) [29, 14], *Rhizoctonia* root rot; *Rhizoctonia solani* (Sumalatha *et al.* 2017) [44], *Septoria* leaf spot (Parker *et al.* 1997 and Blum, 2000) [30, 11], bacterial fruit canker; *Clavibacter michiganensis* subsp. *michiganensis* (Ftayeh *et al.* 2010 and Sharabani *et al.* 2013) [17, 38], bacterial spot; *Xanthomonas campestris* pv. *vesicatoria* (Kavitha and Umesha, 2007) [21], bacterial wilt; *Ralstonia solanacearum* (Ayana and Fininsa, 2016) [9], bud blight; *Groundnut bud necrosis virus* (Manjunatha *et al.* 2010) [24], leaf curl disease; *Tomato leaf curl virus* (Shelat *et al.* 2014 and Yadav *et al.* 2014) [40, 46], tomato mosaic; *Tomato mosaic virus* (Alishiri *et al.* 2013) [4], tomato spotted wilt; *Tomato spotted wilt virus* (Sevik and Arli-Sokmen, 2012) [37], Root knot; *Meloidogyne* spp (Naz *et al.* 2012) [26], little leaf; *Candidatus Phytoplasma trifolii* (Santos-Cervantes *et al.* 2008 and Rathnamma, 2014) [36, 34] are major diseases of tomato (Mahato *et al.* 2017) [22]. But it is not necessary that all these diseases come together with great extent in one crop season, climatic conditions and location because the climatic conditions of a particular area favours some specific pathogens and this is the important consideration for the management of disease. Therefore a study was undertaken to know the prevalent diseases of tomato, their occurrence pattern and extent of infection in *Kharif* season under Raipur conditions.

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Raipur, Chhattisgarh, India

2. Material and Methods

A study was undertaken in *Kharif* season of three consecutive years (2015, 2016 and 2017) at Horticulture Instruction cum Research Farm, College of Agriculture, Raipur (Chhattisgarh) to know the prevalent diseases of tomato, their occurrence pattern and extent of infection. The observations on percent disease incidence and percent disease index (PDI) of each disease were recorded at fortnight interval from ten untreated plots of tomato (cv. Pusa Ruby). Percent disease incidence was calculated by following formula suggested by Nene (1972) ^[27]:

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

However the disease rating was recorded for each plant of every plot by following rating scales as described in below thereafter percent disease index (PDI) was calculated for each plot by implying formulae suggested by Wheeler (1969) ^[45].

$$\text{PDI} = \frac{\text{Sum of numerical disease ratings}}{\text{Number of plants observed} \times \text{maximum disease rating}} \times 100$$

2.1 Leaf curl

Disease rating of individual plants was recorded by using a slightly modified visual scale of 0-7, where: 0 = No visible disease symptom; 1 = Top leaves curled only; 3 = Top leaves curled and slight stunting of plant or All leaves curled without stunting; 5 = All leaves curled and slight stunting of plant and 7 = Severe curling of leaves, stunting of plant and proliferation of auxiliary branches (Alegbejo, 1995 and Alegbejo and Banwo, 2006) ^[3, 2].

2.2 Mosaic

Disease symptoms of mosaic were rated on a scale of 0-5, where: 0 = No symptoms; 1 = Light or dark green mottling or mosaic; 2 = Light or dark green mottling or mosaic with distortion or reduction of younger leaves; 3 = Dark green areas of the mottle often appear thicker and somewhat elevated giving the leaves a blister like appearance with no stunting; 4 = Dark green areas of the mottle often appear thicker and somewhat elevated giving the leaves a blister like appearance with stunting and sometimes yellow mottling of leaves and 5 = Severe stunting of plant with leaves look fern like and sharply pointed and sometimes dark necrotic streaks in stems, petioles, leaves or fruit (Cerkaskas, 2004 and Anonymous, 2012) ^[13, 5].

2.3 Tomato spotted wilt

A visual disease rating of 1-5 was used, where: 1 = No visible symptoms; 2 = Mild purpling, chlorosis, and limited leaf distortion; 3 = Moderate purpling, chlorosis, and leaf distortion with some plant stunting; 4 = Severe purpling, chlorosis, leaf distortion and plant stunting; 5 = Severe purpling, chlorosis, leaf distortion and extreme stunting (Canady *et al.* 2001 and Sivparsad and Gubba, 2011) ^[12, 43].

2.4 Early blight

The percent disease index (PDI) of the early blight was recorded according to following scale of 0-9 given by Mayee and Datar, 1986 ^[25]. Where: 0 = No symptoms; 1 = Small circular, scattered, brown spots, covering 1 per cent or less of the leaf area; 3 = Spots enlarging, dark brown in colour covering 1 to 10 per cent of leaf area and infection on the lower most leaves of the plant; 5 = Spots enlarging, dark brown in colour covering 11 to 25 per cent of leaf area and

infection on the lower most leaves of the plant; 7 = Spots dark brown in colour covering 26 to 50 per cent of leaf area and covering one third of the plant and 9 = Spots uniformly dark brown, coalescing, covering 50 per cent or more leaf area and severe infection on all leaves (Abdussamee *et al.* 2014) ^[1].

3. Results and Discussions

In field condition the occurrence of prevalent diseases were recorded for *Kharif* seasons of three consecutive years (2015, 2016 and 2017). It was recorded from last week of July to first fortnight of November (Table 1, 2 and 3). Five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were appeared during the course of investigation.

3.1 Leaf curl

In *kharif* season the first appearance of leaf curl was observed in first fortnight of August in 2015 and 2017 while in 2016 first symptom of the disease was observed in second fortnight of August and appeared up to first fortnight of November. Initially the occurrence of the disease started with very low disease incidence (1.00, 3.70, and 2.66,) and percent disease index (0.24, 1.49 and 1.14) which increased with increase in age of the plant and reached maximum in first fortnight of November (68.48, 49.58; 62.36, 45.56 and 69.64, 51.30) (Table 1, 2 and 3).

The average incidence of leaf curl was recorded from October 2013 to March 2014 in *kharif* with increasing trend and average maximum disease incidence of 12.24 percent (March 2014) was recorded under open field condition (Anonymous, 2013-14) ^[6]. Ehsanullah (2014) ^[16] recorded 10.8 to 91.3 percent disease incidence in major tomato growing districts of Karnataka with highest disease incidence of 70.81 percent in Kolar and least incidence of 21.00 percent in Ramanagara district.

3.2 Mosaic

The first occurrence of mosaic was observed in second fortnight of September in 2015 whereas in 2016 and 2017 first symptoms of the disease was noticed in first fortnight of October and appeared up to first fortnight of November. The disease incidence (0.59, 0.96 and 0.67) and percent disease index of the disease were very low (0.24, 0.48 and 0.15) during the early growth stage which gradually increased as plant developed and reached maximum in first fortnight of November (2.75, 1.63; 4.38, 4.10 and 2.69, 1.78) (Table 1, 2 and 3).

Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *Kharif* 2013. The average incidence of mosaic was recorded from October 2013 to March 2014 with increasing trend and average maximum disease incidence of 17.03 percent was recorded in February 2014 in open field condition (Anonymous, 2013-14) ^[6]. Jalender *et al.* (2017) ^[19] conducted survey in tomato growing areas of Ranga Reddy district during *kharif* 2013 and in Guntur district during *rabi* 2013-14 and recorded natural occurrence of disease incidence with a percent ranged from 6.9 to 15.7 among different Mandals.

3.3 Tomato spotted wilt

The disease was not occurred in *Kharif* 2015 but the first occurrence of tomato spotted wilt disease was appeared in first and second fortnight of October in 2016 and 2017 respectively. The infection was started with 0.96 and 0.38 percent incidence and 0.53 and 0.35 percent disease index in 2016 and 2017 respectively. The disease was appeared up to first fortnight of November with maximum disease incidence

(2.36 and 1.34) and percent disease index (1.42 and 0.70) (Table 1, 2 and 3).

Pattaiya, (2006) ^[31] carried out survey and surveillance of tomato spotted wilt virus disease at open fields of three locations viz. Panagar, Jabalpur and Indrana to determine the incidence of virus. A total of five thousand and sixty tomato plant samples from five varieties viz. Pusa early dwarf, JT 99, Pusa ruby, Sourabh and Abhisek were observed for tomato spotted wilt virus. Overall 18 to 34, 15 to 30 and 16 to 24 percent infection was observed in Panagar, Jabalpur and Indrana respectively in different varieties.

3.4 Early blight

In three consecutive *Kharif* seasons (2015, 2016 and 2017) the first appearance of early blight was observed in first fortnight of October in 2015 whereas in 2016 and 2017 first symptom of the disease was recorded in second fortnight of September and appeared up to first fortnight of November. Initially the disease incidence (4.03, 2.91 and 0.95 percent) and percent disease index of the disease were very low (0.32, 0.11 and 0.03) which rapidly increased and reached maximum in the first fortnight of November (52.79, 19.91; 54.57, 26.45 and 56.89 and 29.11) (Table 1, 2 and 3).

Prasad, (2002) ^[33] recorded 28.60 to 65.36 percent disease severity of early blight in northern districts of Karnataka during 2001. Roopa (2012) ^[35] undertook a roving survey

during 2011 to assess the disease severity of early blight of tomato in major tomato growing areas of Dharwad, Belgaum, Haveri, Gadag and Bagalkot districts. The severity was ranged from 17.30 to 37.25 percent, highest disease severity was recorded in Haveri (31.03%) and least in Dharwad (20.16%) districts. Ten fields of Raipur (Chhattisgarh) were selected for the pest surveillance of tomato in *Kharif* 2013-14. The average severity of early blight was recorded from October 2013 to March 2014 with increasing trend and average maximum disease severity of 23.33 percent was recorded in March under open field condition (Anonymous, 2013-14) ^[6].

3.5 Collar rot

In *kharif* season (2015, 2016 and 2017) the first appearance of collar rot was recorded in first fortnight of September in 2015 and 2017 whereas in 2016 the first symptoms of the disease were observed in second fortnight of August. Initially percent incidence of the disease was low (2.05, 3.36 and 1.67) which steadily increased and reached maximum in first fortnight of October (2.72, 5.40 and 4.72) (Table 1, 2 and 3).

In field condition the incidence of collar rot was recorded 5 to 10 percent in Raipur, Chhattisgarh (Anonymous, 2013-14) ^[6], 10-45 percent in Himachal Pradesh (Banyal, *et al.* 2008) ^[10] and 7.61 to 21.79 percent in undulating red and lateritic zone of West Bengal (Mahato *et al.* 2017) ^[22].

Table 1: Seasonal occurrence of prevalent diseases of tomato under field conditions (*Kharif* 2015)

Disease	Incidence and PDI	At 15 days interval (Days after transplanting)						
		Aug		Sep		Oct		Nov
		I	II	I	II	I	II	I
Leaf curl	Incidence	1.00	3.71	9.66	16.05	34.77	58.29	68.48
	PDI	0.24	1.50	4.66	7.87	20.32	42.25	49.58
Mosaic	Incidence	-	-	-	0.59	0.69	0.28	2.75
	PDI	-	-	-	0.24	0.28	1.11	1.63
Spotted Wilt	Incidence	-	-	-	-	-	-	-
	PDI	-	-	-	-	-	-	-
Early blight	Incidence	-	-	-	-	4.03	21.13	52.79
	PDI	-	-	-	-	0.32	4.98	19.91
Collar rot	Incidence	-	-	2.05	2.39	2.72	2.72	2.72

Table 2: Seasonal occurrence of prevalent diseases of tomato under field conditions (*Kharif* 2016)

Disease	Incidence and PDI	At 15 days interval (Days after transplanting)						
		Aug	Sep		Oct		Nov	
		II	I	II	I	II	I	
Leaf curl	Incidence	3.70	5.74	8.14	20.26	47.92	62.36	
	PDI	1.49	2.76	4.11	11.75	26.48	45.56	
Mosaic	Incidence	-	-	-	0.96	3.57	4.38	
	PDI	-	-	-	0.48	2.37	4.10	
Spotted Wilt	Incidence	-	-	-	0.96	1.83	2.36	
	PDI	-	-	-	0.53	0.93	1.42	
Early blight	Incidence	-	-	2.91	6.26	23.00	54.57	
	PDI	-	-	0.11	0.39	5.78	26.45	
Collar rot	Incidence	3.36	4.05	4.05	5.40	5.40	5.40	

Table 3: Seasonal occurrence of prevalent diseases of tomato under field conditions (*Kharif* 2017)

Disease	Incidence and PDI	At 15 days interval (Days after transplanting)						
		Aug		Sep		Oct		Nov
		I	II	I	II	I	II	I
Leaf curl	Incidence	2.66	7.33	13.28	17.70	29.67	54.91	69.64
	PDI	1.14	4.00	7.70	10.70	18.74	40.56	51.30
Mosaic	Incidence	-	-	-	-	0.67	1.64	2.69
	PDI	-	-	-	-	0.15	0.71	1.78
Spotted Wilt	Incidence	-	-	-	-	-	0.38	1.34
	PDI	-	-	-	-	-	0.35	0.70
Early blight	Incidence	-	-	-	0.95	8.62	33.51	56.89
	PDI	-	-	-	0.03	0.75	9.17	29.11
Collar rot	Incidence	-	-	1.67	4.14	4.72	4.72	4.72

4. Conclusion

From the present investigation it can be concluded that in Raipur, five diseases viz. leaf curl, mosaic, tomato spotted wilt, early blight and collar rot were prevalent in tomato crop under field conditions. The severity pattern of the diseases was leaf curl > early blight > collar rot > mosaic > tomato spotted wilt.

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