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Evaluation of Tomato Genotypes for Tomato Leaf Curl Virus (ToLCV) Resistance

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Abstract

Tomato leaf curl virus disease (ToLCD), caused by whitefly transmitted begomo virus is a devastating disease affecting tomatoes worldwide. Twenty seven genotypes (Five breeding lines from World Vegetable Centre, Taiwan, nine commercial hybrids, eight germplasm accessions from NBPGR, one local collection from Idukki and four KAU varieties) were screened for ToLCV resistance under natural field conditions at Thrissur, Kerala during summer 2021. Among the screened genotypes, Ansal was found to be highly resistant, while, Kaustubh, EC 519806, Arka Rakshak and local collection (Idukki) were identified as resistant genotypes. Among the genotypes evaluated, four genotypes were moderately susceptible (AVTO 1726, AVTO 1727, Anagha and Akshaya), twelve were susceptible (AVTO 1707, AVTO 1706, AVTO 0922, Virang, Durg, Abhiraj, EC 528360, EC 620428, EC 521067 B, Manuprabha, Manulekshmi and EC 620486) and six were highly susceptible (Aryaman, Raymond, Pranay, EC 538153, EC 315489 and EC 567305) to ToLCV. The genotypes found to be highly resistant and resistant were found to be resistant to ToLCV even after whitefly mediated artificial inoculation. The resistant and highly resistant genotypes remained asymptomatic, whereas, the susceptible genotypes (Anagha and Manuprabha) exhibited ToLCV symptoms. The genotypes varied significantly with respect to plant height, number of primary branches/plant and days to flowering. Correlation between trichome density, and disease severity showed that glandular trichome density on abaxial and adaxial surfaces of leaf was significantly and negatively correlated with per cent disease incidence and disease severity index. However, the negative correlation between the abaxial glandular trichome density and ToLCV incidence was stronger. The glandular trichome density of the resistant genotypes identified in the field screening was found to be high. Non-glandular trichome density on abaxial and adaxial side of the leaf was significantly and positively correlated with per cent disease incidence and disease severity index. The resistant genotypes identified in the present study can be used for resistance breeding in tomato against ToLCV disease.

Key words: Disease screening, Genotypes, Resistance sources, Tomato leaf curl virus.

Introduction

Tomato (*Solanum lycopersicum* L., 2n=24) belongs to the family Solanaceae and is believed to have originated from Peru-Ecuador region. It is a warm season vegetable crop grown extensively for its fruits which is a rich source of vitamin C and lycopene. Lycopene is the principal carotenoid in tomato, having antioxidant activity, which in turn reduces the risk of several diseases. The major production constraints in tomato cultivation include poor fruit set and yield loss due to the pest and disease incidence. Gatahi (2020) reported 100 per cent crop loss in tomato due to pest and disease attack. Management practices using chemicals is not much effective and are hazardous to human health

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and environment. Lack of resistant varieties/hybrids to various diseases and pest limits tomato production worldwide.

Tomato is susceptible to many diseases like damping off, bacterial wilt, early blight, leaf curl virus disease, leaf spot etc. In tomato, viral disease accounted for 100% crop loss and 41.67 per cent severity, wilt disease showing 20 per cent severity, and phomopsis blight with 13.33 per cent severity (Tipu et al., 2021). Viral diseases of tomato are a major threat for its cultivation, and among the viral diseases, Tomato Leaf Curl Disease (ToLCD) is the major and the most dangerous disease, causing severe yield loss in tomato. The first report of ToLCD was in Australia, caused by a monopartite begomo virus (Dry et al., 1993). In India, Tomato leaf curl disease was first reported by Vasudeva and Sam Raj in 1948. ToLCV, caused by whitefly-transmitted begomo viruses are the most devastating genera affecting tomatoes, especially in tropical and subtropical regions. Severe infection can cause yield loss up to 100 per cent (Ray et al., 2017).

Tomato leaf curl virus (ToLCV) is now being controlled utilising sticky traps as a vector management strategy. Since pesticides are not effective in controlling ToLCV and can be harmful to human health, utilising plant natural defenses found in wild tomato relatives may provide a solution for ToLCV management. Although ToLCV resistance is not found in *S. lycopersicum*, different levels of resistance were observed in many wild species like *S. pimpinellifolium, S. peruvianum, S. chilense, S. habrochaites and S. cheesmaniae* (Ji et al., 2009). Identification of resistance sources will aid in virus resistance breeding and boost tomato production which is hampered by the lack of ToLCV resistant genotypes. In view of the above, the present investigation was carried out for identifying the ToLCV resistant genotypes.

Materials and methods

The experiment was conducted at Department of Plant Breeding and Genetics, College of Agriculture, Vellanikkara, Thrissur, Kerala during summer 2021.

Field screening

The material consisted of 27 tomato genotypes including eight NBPGR (National Bureau of Plant Genetic Resources) accessions, five breeding lines from World Vegetable Center, Taiwan, nine commercial hybrids, four KAU varieties and one local collection (Table 1). Thirty days old seedlings of each of these genotypes were planted in randomized block design with two replications and twenty plants per replication and screened during summer against ToLCV under natural field conditions. The cultural and agronomic practices were followed as per the Package of Practices Recommendations: Crops (KAU, 2016).

The plants were scored using the scale suggested by Banerjee and Kalloo (1987) after 30 (30 DAT) and 60 days of transplanting (60 DAT) as follows,

0: Symptoms absent
1: very mild curling up to 25% leaves
2: curling and puckering of 26-50% leaves
3: curling and puckering of 51-75% leaves
4: severe curling and puckering of >75% leaves.

Based on the score, Disease Severity Index (DSI) was calculated using the formula,

$$DSI = \frac{\text{Sum of numerical rating}}{\text{Total no. of plants observed} \times \text{Max. disease grade}} \times 100$$

Per cent Disease Incidence (PDI) was calculated using the formula,

$$PDI = \frac{\text{No. of plants infected}}{\text{Total no. of plants observed}} \times 100$$

Based on the Disease Severity Index (DSI) and Per cent Disease Incidence (PDI), the Coefficient of Infection (CI) was calculated using the formula,

$$CI = \frac{\text{Per cent disease severity} \times \text{Per cent disease incidence}}{100}$$

Based on the coefficient of infection the genotypes were categorized into six groups.

0-4: Highly resistant (HR)
4.1-9: Resistant (R)
9.1-19: Moderately Resistant (MR)

Figure 1. Artificial inoculation of selected genotypes with ToLCV. a) Whitefly rearing in cage, b) Acquisition feeding of whiteflies on infected tomato plant, c) Inoculation feeding of whiteflies on healthy tomato plant

19.1-39: Moderately Susceptible (MS)
39.1-69: Susceptible (S)
69.1-100: Highly Susceptible (HS)

Artificial inoculation

Genotypes resistant under the natural conditions were subjected to whitefly mediated artificial inoculation. For rearing whiteflies, thirty days old brinjal seedlings were planted in growbags and covered with insect proof net cage. Whiteflies were released when brinjal seedlings were 50 days old and allowed to multiply. Tomato genotypes identified as resistant to ToLCV were raised in pots (15 seedlings/genotype). Twenty days old tomato seedlings were kept in separate cages for inoculation. White flies were collected from the rearing cage using test tubes and plugged with cotton. They were allowed to feed on the infected tomato plants for 24 h (acquisition access period). The viruliferous whiteflies were collected and released onto the healthy seedlings (30-50 whiteflies/ seedling) and plants were kept in separate cages for 48 h (inoculation access period). The inoculated plants were sprayed with insecticide,

Figure 2. Response of genotypes to ToLCV infection under field screening. a) Highly resistant genotype Ansal, b) Resistant genotypes 1. EC 519806, 2. Local Collection (Idukki), 3. Kaustubh, 4. Arka Rakshak, c. Moderately susceptible genotype-Anagha, d. Susceptible genotype-Manuprabha

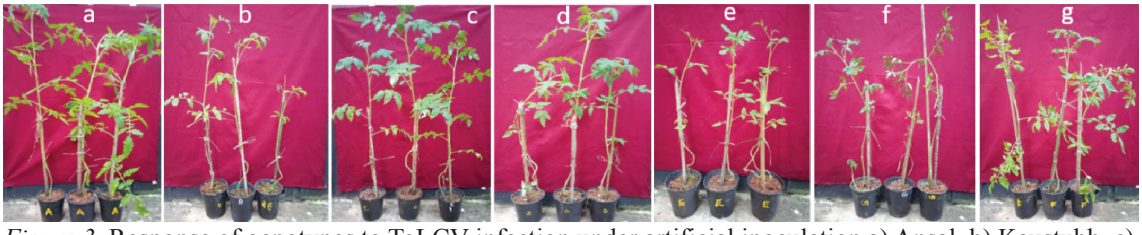

Figure 3. Response of genotypes to ToLCV infection under artificial inoculation a) Ansal, b) Kaustubh, c) EC 519806, d) Local Collection (Idukki), e) Arka Rakshak, f) Manuprabha, g) Anagha

dimethoate (30 EC) to kill the whiteflies. Cages were removed and kept for symptom development. Symptoms were observed at regular intervals after artificial inoculation.

Morphological growth characters

The morphological features were recorded at 60 days after transplanting on all plants and the observations on growth characters of the genotypes evaluated includes growth habit, plant height, number of primary branches per plant, spread of the plant and days to flowering. Trichome density (Number of trichomes/cm^2) of both glandular and non-glandular trichomes on abaxial as well as adaxial surface of leaf was recorded using stereo microscope Leica EZ4E with image analyser. The area of the leaf was measured using Leica Application Suite (LAZ) and the total number of hairs per cm^2 was counted.

Results and discussion

Based on the score assigned to each genotype as per the scale suggested by Banerjee and Kalloo (1987), PDI, DSI and CI were calculated for each genotype and reaction to ToLCV infection was analysed at 30 DAT and 60 DAT. The response of the genotypes evaluated displayed wide variability ranging from highly resistant response to highly susceptible response (Table 1& 2).

Reaction of tomato genotypes to ToLCV under natural conditions at 30 DAT

The disease severity index ranged from 10 to 91.25%. Ansal recorded the minimum disease severity (10%) and Pranay recorded the highest (91.25%). The per cent disease incidence ranged from 35 to 95%. Arka Rakshak recorded minimum per cent disease incidence (35%), and AVTO 1706, Raymond, Pranay and Anagha recorded the highest (95%). Coefficient of infection ranged from 4 to 86.68. The minimum coefficient of infection was recorded in Ansal (4) and maximum in Pranay (86.68).

*Table 1:*Response of tomato genotypes toToLCV under natural conditions (30 DAT)

Sl. No.	Genotype	PDI (%)	DSI	CI	Category
1	AVTO 1726	90	35.00	31.50	MS
2	AVTO 1727	85	41.25	35.06	MS
3	AVTO 1707	85	46.25	39.30	S
4	AVTO 1706	95	67.50	64.12	S
5	AVTO 0922	90	72.50	65.25	S
6	Ansal	40	10.00	4.00	HR
7	Virang	85	80.00	68.00	S
8	Kaustubh	45	16.25	7.31	R
9	Aryaman	90	78.75	70.87	HS
10	Durg	85	75.00	63.75	S
11	Raymond	95	86.25	81.93	HS
12	Abhiraj	90	65.00	58.50	S
13	Pranay	95	91.25	86.68	HS
14	EC 519806	50	12.50	6.25	R
15	EC 528360	85	76.25	64.80	S
16	EC 620428	80	76.25	61.00	S
17	EC 521067 B	85	73.75	62.68	S
18	EC 538153	90	87.50	78.75	HS
19	Local collection (Idukki)	45	11.25	5.06	R
20	Manuprabha	85	78.75	66.90	S
21	Manulekshmi	90	75.00	67.50	S
22	Anagha	95	37.50	35.62	MS
23	Akshaya	85	33.75	28.68	MS
24	EC 620486	90	76.25	68.62	S
25	EC 315489	90	82.50	74.25	HS
26	EC 567305	90	85.00	76.50	HS
27	Arka Rakshak	35	13.75	4.81	R

DSI - Disease Severity Index, PDI - Percent Disease Incidence, CI - Coefficient of Infection, HR- Highly Resistant, R- Resistant, MR- Moderately Resistant, MS-Moderately Susceptible, S- Susceptible, HS- Highly Susceptible.

Among the 27 genotypes, one genotype was found to be highly resistant (Ansal), four were resistant (Kaustubh, EC 519806, Local collection (Idukki), Arka Rakshak), four were moderately susceptible (AVTO 1726, AVTO 1727, Anagha, Akshaya), twelve were susceptible (AVTO 1707, AVTO 1706. AVTO 0922, Virang, Durg, Abhiraj, EC 528360, EC 620428, EC 521067 B, Manuprabha, Manulekshmi, EC 620486) and six were highly susceptible (Aryaman, Raymond, Pranay, EC 538153, EC 315489, EC 567305) based on CI.

Reaction of tomato genotypes to ToLCV under natural conditions at 60 DAT

The disease severity index ranged from 15 to 93.75%. Ansal recorded the minimum disease

Table 2. Response of tomato genotypes to ToLCV under natural conditions (60 DAT)

Sl. No.	Genotype	PDI (%)	DSI (%)	CI	Category
1	AVTO 1726	93.75	30.00	28.13	MS
2	AVTO 1727	89.47	45.00	40.26	MS
3	AVTO 1707	95.00	48.75	46.31	S
4	AVTO 1706	95.00	72.50	68.87	S
5	AVTO 0922	88.89	75.00	66.67	S
6	Ansal	55.00	15.00	8.25	R
7	Virang	94.44	82.50	77.91	HS
8	Kaustubh	47.36	18.75	8.88	R
9	Aryaman	95.00	85.00	80.75	HS
10	Durg	94.44	73.75	69.64	HS
11	Raymond	100.00	91.25	91.25	HS
12	Abhiraj	84.20	75.00	63.15	S
13	Pranay	94.73	83.75	79.33	HS
14	EC 519806	55.00	16.25	8.93	R
15	EC 528360	84.20	77.50	65.25	S
16	EC 620428	85.00	81.25	69.00	S
17	EC 521067 B	84.20	78.75	66.30	S
18	EC 538153	95.00	93.75	89.06	HS
19	Local collection (Idukki)	55.00	16.25	8.93	R
20	Manuprabha	84.21	75.00	63.15	S
21	Manulekshmi	80.00	78.75	63.00	S
22	Anagha	84.21	62.50	52.63	S
23	Akshaya	83.33	56.94	47.45	S
24	EC 620486	94.11	80.88	76.11	HS
25	EC 315489	87.50	68.75	60.18	S
26	EC 567305	93.33	80.00	74.66	HS
27	Arka Rakshak	56.25	15.62	8.78	R

DSI - Disease Severity Index, PDI - Percent Disease Incidence, CI - Coefficient of Infection, HR- Highly Resistant, R- Resistant, MR- Moderately Resistant, MS-Moderately Susceptible, S- Susceptible, HS- Highly Susceptible.

severity (15%) and EC 538153 recorded the highest (93.75%). The per cent disease incidence ranged from 47.36 to 100%. Kaustubh recorded minimum per cent disease incidence (47.36%) and Raymond recorded the highest (100%). Coefficient of infection ranged from 8.25 to 89.06. The minimum coefficient of infection was recorded in Ansal (8.25) and maximum in EC 538153 (89.06).

Among the 27 genotypes screened, five genotypes (Ansal, Kaustubh, EC 519806, Local collection (Idukki) and Arka Rakshak) were resistant after 60 days of transplanting. The genotypes AVTO 1726 and AVTO 1727 were moderately susceptible to ToLCV. The genotypes AVTO 1706, AVTO 1707, AVTO 0922, Abhiraj, EC 528360, EC 620428, EC 521067 B, EC 315489, Manuprabha, Manulekshmi, Anagha and Akshaya were susceptible to ToLCV. The highly susceptible genotypes after 60 days of transplanting are Virang, Aryaman, Durg, Raymond, Pranay, EC 538153, EC 620486 and EC 567305.

The genotypes AVTO 1726, AVTO 1727, AVTO 1707, AVTO 1706, AVTO 0922, Kaustubh, Aryaman, Raymond, Abhiraj, Pranay, EC 519806, EC 528360, EC 620428, EC 521067 B, EC 538153, local collection (Idukki), Manuprabha, Manulekshmi, EC 567305 and Arka Rakshak did not display any change in the disease response category at 60 DAT compared to 30 DAT. However, the hybrid Ansal which was in the highly resistant category at 30 DAT moved to the resistant category at 60 DAT. The genotypes Virang, Durg and EC 620486 which were in the susceptible category at 30 DAT shifted to highly susceptible category at 60 DAT. Moderately susceptible varieties Anagha and Akshaya at 30 DAT became susceptible at 60 DAT. The genotype EC 315489 which was highly susceptible at 30 DAT was in susceptible category at 60 DAT.

Arka Rakshak was found to be resistant to ToLCV both under 30 and 60 DAT. Arka Rakshak is the first triple resistant (bacterial wilt, tomato leaf curl virus disease and early blight) hybrid released from IIHR (Mishra et al., 2019). Anagha was observed to be moderately susceptible to ToLCV at 30 DAT and susceptible at 60 DAT in the present study. The result was in agreement with observations by Yadav (2011), where, Anagha was reported to be highly susceptible with a disease severity of 66.7 per cent. On the contrary, Divakaran (2008) reported Anagha as a highly resistant genotype with 10 per cent disease severity both under natural condition as well as in pot culture at Vellanikkara, Kerala.

Manuprabha and Manulekshmi were found to be susceptible to ToLCV both at 30 and 60 DAT. The result was in accordance with the observations by Nadkarni et al. (2017), where, Manuprabha was reported to be susceptible to ToLCV in Kerala with

41.67 per cent disease severity. They also reported that the variety Manulekshmi is moderately susceptible to ToLCV with 37.50 per cent disease severity. EC 528360 and EC 521067 B were found to be susceptible in the present study. Ponselvakumari et al. (2020) reported moderate susceptibility of EC 528360 and moderate resistance in EC 521067 B under field conditions. Our study indicated that EC 538153 was highly susceptible under the prevailing field conditions. Similar response was reported by Ponselvakumari et al. (2020), where they reported susceptibility of EC 538153 in Madurai, Tamil Nadu.

Reaction of genotypes to artificial inoculation

Whitefly mediated inoculation ensures infection in susceptible genotypes, allowing reliable screening of tomato germplasm (Yadav, 2011). Gomez (1994) and Paul (2014) also used whitefly transmission for screening against ToLCV in tomato.

The susceptible varieties Anagha and Manuprabha in the present study were found to be symptomatic after artificial inoculation. Symptoms were observed at weekly intervals and mild curling and upward cupping symptoms appeared in them at four weeks after artificial inoculation. The genotypes found to be resistant under the field screening (Ansal, Kaustubh, EC 519806, Local collection (Idukki) and Arka Rakshak) were found to be resistant after artificial inoculation also, whereas, mild curling was observed in Arka Rakshak, which was resistant during the field screening.

Growth habit

Among the genotypes evaluated, EC 528360, EC 538153 and Akshaya were found to be indeterminate. All the other genotypes *viz.,* AVTO 1726, AVTO 1727, AVTO 1707, AVTO 1706, AVTO 0922, Ansal, Virang, Kaustubh, Aryaman, Durg, Raymond, Abhiraj, Pranay, EC 519806, EC 620428, EC 521067 B, Local collection (Idukki), Manuprabha, Manulekshmi, Anagha, EC 620486, EC 315489, EC 567305 and Arka Rakshak had determinate growth habit.

Table 3. Growth characters of the tomato genotypes

Sl. No.	Genotype	Plant height (cm)	Number of primary branches per plant	Spread of the plant (cm)	Days to flowering
1	AVTO 1726	53.60^{abcd}	1.91^{efghij}	36.97	37.67^{fgh}
2	AVTO 1727	33.31^{ef}	1.39^{ij}	22.91	51.46^{a}
3	AVTO 1707	33.48^{ef}	1.50^{hij}	22.95	39.78^{ef}
4	AVTO 1706	39.77^{def}	1.84^{efghij}	32.85	34.36^{ijk}
5	AVTO 0922	60.02^{a}	2.59^{bcdefg}	36.40	33.27^{jkl}
6	Ansal	44.49^{abcdef}	1.18^{j}	22.43	42.53^{cd}
7	Virang	57.09^{abc}	1.49^{hij}	29.24	50.63^{a}
8	Kaustubh	50.69^{abcd}	1.19^{j}	26.63	47.36^{b}
9	Aryaman	53.33^{abcd}	1.30^{ij}	31.59	40.59^{de}
10	Durg	59.09^{abc}	$2.11^{defghij}$	36.67	32.43^{klm}
11	Raymond	56.93^{abc}	1.55^{ghij}	33.36	28.68^{op}
12	Abhiraj	48.59^{abcde}	1.62^{fghij}	30.08	43.86^{c}
13	Pranay	53.63^{abcd}	1.92^{efghij}	31.35	36.03^{ghi}
14	EC 519806	53.72^{abcd}	4.45^{a}	39.61	30.74^{mno}
15	EC 528360	59.46^{ab}	$2.31^{cdefghi}$	38.41	30.57^{mno}
16	EC 620428	45.13^{abcde}	1.41^{hij}	28.01	42.69^{cd}
17	EC 521067 B	50.19^{abcd}	3.07^{bcd}	36.72	29.76^{nop}
18	EC 538153	58.80^{abc}	$2.03^{defghij}$	30.64	33.62^{jk}
19	Local collection (Idukki)	28.88^{f}	2.57^{bcdefg}	17.75	39.27^{ef}
20	Manuprabha	51.11^{abcd}	2.81^{bcde}	35.95	38.13^{fg}
21	Manulekshmi	59.12^{abc}	2.62^{bcdef}	38.14	30.34^{mno}
22	Anagha	46.34^{abcde}	$2.45^{bcdefgh}$	32.42	35.06^{ij}
23	Akshaya	58.22^{abc}	2.71^{bcde}	34.65	32.29^{klm}
24	EC 620486	53.00^{abcd}	$2.04^{defghij}$	27.29	35.40^{hij}
25	EC 315489	44.31^{bcdef}	3.21^{bc}	28.09	27.81^{p}
26	EC 567305	43.77^{cdef}	3.46^{ab}	31.52	36.16^{ghi}
27	Arka Rakshak	50.77^{abcd}	3.06^{bcd}	31.70	31.28^{lmn}
	CD ($p \leq 0.05$)	15.632	1.042	NS	2.299
	CV (%)	15.25	22.92	25.11	3.05

Morphological growth characters

The genotypes varied significantly with respect to plant height, number of primary branches/plant and days to flowering. But there was no significant difference between the genotypes in case of spread of the plant (Table 3).

The plant height was highest in AVTO 0922 (60.02 cm) followed by EC 528360 (59.46 cm) and lowest in local collection (Idukki) (28.88 cm). For plant height, all the genotypes evaluated, except local collection (Idukki), were on par with Anagha, the determinate tomato variety released by Kerala Agricultural University.

The number of primary branches/plant was the highest in EC 519806 (4.45) followed by EC 567305 (3.46) and EC 315489 (3.21). The lowest number of primary branches/plant was recorded in Ansal (1.18). The genotypes AVTO 1727, Ansal, Kaustubh and Aryaman were inferior to Anagha in terms of number of primary branches/plant. But the genotype EC 519806 was superior to Anagha. All other genotypes were on par with Anagha.

Days to flowering was the highest in AVTO 1727 (51.46) followed by Virang (50.63). The lowest days to flowering was recorded in EC 315489 (27.81). The genotypes AVTO 1727, AVTO 1726, AVTO 1707, Ansal, Kaustubh, Virang, Abhiraj, Aryaman, EC 620428, local collection (Idukki) and Manuprabha took more number of days to flower compared to Anagha. The genotypes Durg, Raymond, EC 519806, EC 528360, EC 521067 B, Manulekshmi, Akshaya, EC 315489 and Arka Rakshak had lower days to flowering than Anagha.

Trichome density on the abaxial and adaxial leaf surfaces

Glandular trichome density on the adaxial leaf surface was high in Arka Rakshak (344/cm^2) followed by Kaustubh, EC 519806, Akshaya and Anagha (Table 4). Glandular trichome density on the abaxial leaf surface was high in Ansal (472/cm^2) and Kaustubh (472/cm^2) followed by EC 519806, Arka Rakshak and local collection (Idukki). Among these genotypes, Arka Rakshak, Kaustubh, Ansal, local collection (Idukki) and EC 519806 were resistant under field screening and artificial inoculation.

Table 4. Trichome density on the abaxial and adaxial leaf surfaces

Sl.No.	Genotype	Density on adaxial surface (Number/ cm^2)		Density on abaxial surface (Number/ cm^2)	
		GT	NGT	GT	NGT
1	AVTO 1726	6.33^{fghi}(40)	9.78^{h}(96)	10.92^{cde}(120)	22.28^{o}(496)
2	AVTO 1727	7.49^{efghi}(56)	9.82^{h}(96)	10.95^{cde}(128)	23.67^{n}(560)
3	AVTO 1707	4.88^{hi}(24)	7.49^{i}(56)	10.60^{cde}(136)	24.99^{m}(624)
4	AVTO 1706	4.06^{i}(16)	10.2^{h}(104)	7.33^{efg}(56)	32.01^{ghij}(1024)
5	AVTO 0922	4.06^{i}(16)	17.67^{a}(312)	4.88^{fg}(24)	32.25^{fghi}(1040)
6	Ansal	11.94^{bcde}(144)	7.49^{i}(56)	21.73^{a}(472)	28.28^{l}(800)
7	Virang	10.60^{cdef}(136)	9.78^{h}(96)	10.70^{cde}(128)	32.98^{ef}(1088)
8	Kaustubh	18.08^{a}(328)	7.52^{i}(56)	21.73^{a}(472)	21.17^{p}(448)
9	Aryaman	4.88 ^{hi}(24)	10.2^{h}(104)	8.92^{defg}(80)	33.47^{e}(1120)
10	Durg	6.94^{fghi}(56)	10.22^{h}(104)	8.51^{defg}(80)	31.75^{hij}(1008)
11	Raymond	5.51^{ghi}(32)	15.76^{bc}(248)	6.33^{efg}(40)	36.00^{b}(1296)
12	Abhiraj	4.06^{i}(16)	13.27^{ef}(176)	4.88^{fg}(24)	30.47^{k}(928)
13	Pranay	4.06^{i}(16)	14.71^{cd}(216)	4.88^{fg}(24)	37.10^{a}(1376)
14	EC 519806	16.24^{ab}(272)	12.98^{efg}(168)	21.00^{a}(448)	24.00^{n}(576)
15	EC 528360	9.49^{cdefgh}(96)	16.70^{ab}(280)	9.68^{cdef}(96)	32.01^{ghij}(1024)
16	EC 620428	4.88^{hi}(24)	7.49^{i}(56)	4.88^{fg}(24)	31.24^{jk}(976)
17	EC 521067 B	15.42^{ab}(240)	15.49^{c}(240)	14.15^{bc}(200)	31.50^{ij}(992)
18	EC 538153	15.66^{ab}(248)	15.76^{bc}(248)	9.68^{cdef}(96)	35.56^{bc}(1264)
19	Local collection (Idukki)	4.06^{i}(16)	7.49^{i}(56)	16.95^{ab}(288)	23.67^{n}(560)
20	Manuprabha	9.31^{defgh}(88)	9.39^{h}(88)	4.06^{g}(16)	32.50^{fgh}(1056)
21	Manulekshmi	12.00^{bcde}(144)	12.02^{g}(144)	6.33^{efg}(40)	32.74^{efg}(1072)
22	Anagha	15.88^{ab}(256)	10.2^{h}(104)	10.21^{cde}(104)	24.00^{n}(576)
23	Akshaya	16.25^{ab}(264)	12.34^{fg}(152)	9.68^{cdef}(96)	21.17^{p}(448)
24	EC 620486	9.68^{cdefg}(96)	9.82^{h}(96)	8.92^{defg}(80)	32.99^{ef}(1088)
25	EC 315489	12.34^{bcd}(152)	12.35^{fg}(152)	12.97^{bcd}(168)	34.41^{d}(1184)
26	EC 567305	14.15^{abc}(200)	14.15^{de}(200)	6.86^{efg}(48)	34.87^{cd}(1216)
27	Arka Rakshak	18.54^{a}(344)	9.82^{h}(96)	17.42^{ab}(304)	32.01^{ghij}(1024)
	CD ($p \leq 0.05$)	4.74	1.18	5.12	0.801

GT- Glandular Trichome NGT- Non-glandular Trichome. Original values in paranthesis

Table 5. Correlation of trichome density with PDI and DSI

Trichome density	PDI	DSI
Glandular abaxial trichome density	-0.884**	-0.795**
Non-glandular abaxial trichome density	0.420*	0.824**
Glandular adaxial trichome density	-0.444*	-0.393*
Non-glandular adaxial trichome density	0.404*	0.496**

*Correlation is significant at the 0.05 level (2 tailed) **Correlation is significant at the 0.01 level (2 tailed)

Non-glandular trichome density on adaxial leaf surface was high in AVTO 0922 (312/ cm^2) followed by EC 528360 and Raymond and these were susceptible to ToLCV under field screening. Kaustubh, AVTO 1707, EC 620428, Ansal and local collection (Idukki) had lower non-glandular trichome density than Anagha, among which, Kaustubh, Ansal and local collection (Idukki) were resistant in field screening and artificial inoculation. Non-glandular trichome density on abaxial leaf surface was high in Pranay (1376/cm^2) followed by Raymond, EC 538153 and EC 567305 and were highly susceptible under field screening (Table 4).

Correlation of trichome density with PDI and DSI

Correlation analysis showed that glandular trichome density on abaxial and adaxial surfaces of leaf was significantly and negatively correlated with per cent disease incidence and disease severity index (Table 5). However, the negative correlation was stronger between the abaxial glandular trichome density and ToLCV resistance. This has been attributed to the production of terpenes (Fridman et al., 2005; Bleeker et al., 2009) and acyl sugars which operates as glue trap (Burke et al., 1987), thus interfering with the landing and oviposition of whiteflies. Non-glandular trichome density on abaxial and adaxial surfaces of the leaf was significantly and positively correlated with per cent disease incidence and disease severity index. Whiteflies prefer to lay eggs on tomato leaves with a high density of non-

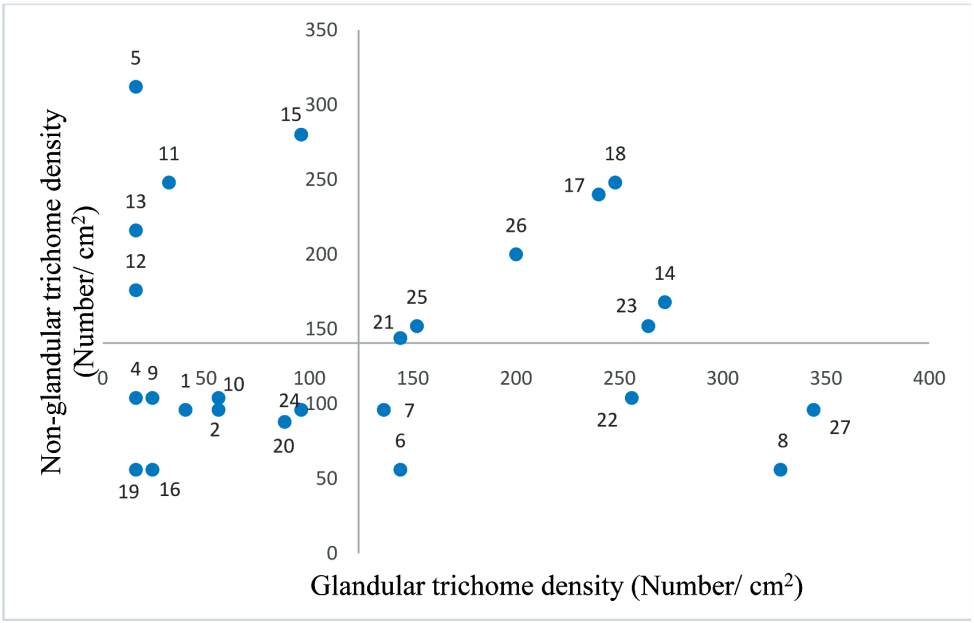

Figure 4. Scatter plot showing trichome density on adaxial leaf surface of genotypes. 1-AVTO 1726, 2-AVTO 1727, 3- AVTO 1707, 4- AVTO 1706, 5- AVTO 0922, 6- Ansal, 7-Virang, 8- Kaustubh, 9- Aryaman, 10- Durg, 11- Raymond, 12- Abhiraj, 13- Pranay, 14- EC 519806, 15- EC 528360, 16- EC 620428, 17-EC 521067 B, 18- EC 538153, 19-Local collection (Idukki), 20- Manuprabha, 21- Manulekshmi, 22- Anagha, 23- Akshaya, 24- EC 620486, 25- EC 315489, 26- EC 567305,27- Arka Rakshak

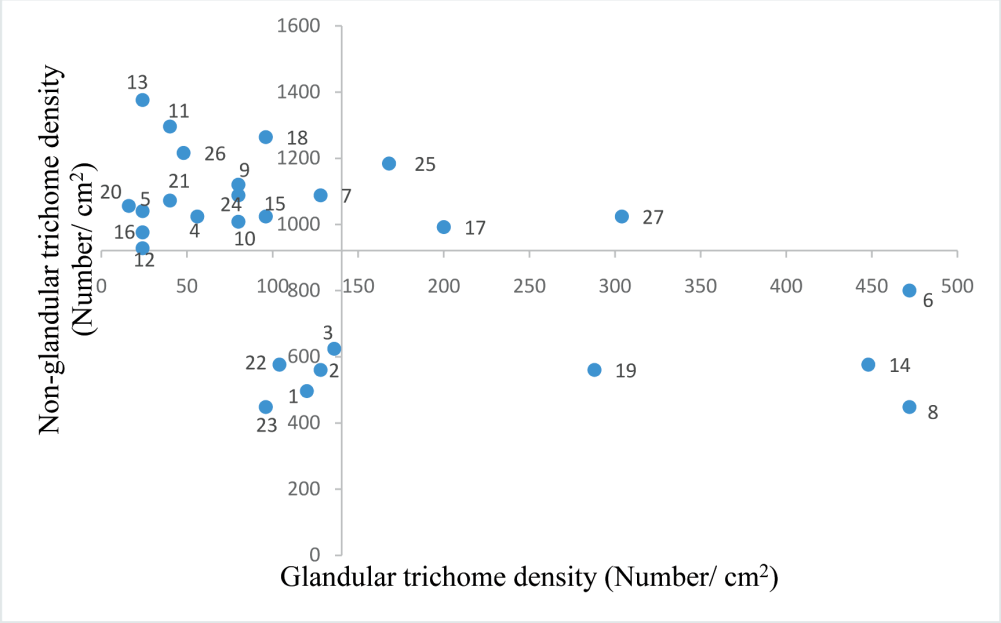

Figure 5. Scatter plot showing trichome density on abaxial leaf surface of genotypes. 1-AVTO 1726, 2-AVTO 1727, 3- AVTO 1707, 4- AVTO 1706, 5- AVTO 0922, 6- Ansal, 7-Virang, 8- Kaustubh, 9- Aryaman, 10- Durg, 11- Raymond, 12- Abhiraj, 13- Pranay, 14- EC 519806, 15- EC 528360, 16- EC 620428, 17-EC 521067 B, 18- EC 538153, 19-Local collection (Idukki), 20- Manuprabha, 21- Manulekshmi, 22- Anagha, 23- Akshaya, 24- EC 620486, 25- EC 315489, 26- EC 567305,27- Arka Rakshak

glandular trichomes (Heinz and Zalom 1995). The non-glandular trichomes provide suitable microclimate and shelter and thereby making the plants are more susceptible to whitefly infestation .

Genotypes having high density of glandular trichomes, especially on the abaxial leaf surface, and low density of non-glandular trichomes will have better ToLCD resistance. Ansal, Kaustubh, EC 519806, local collection (Idukki) and Arka Rakshak, had lower non-glandular trichome density and higher glandular trichome density than the mean value, especially on the abaxial surface, and is better equipped to have ToLCD resistance (Fig. 4 & 5). This was evident from the fact that Ansal, Kaustubh, EC 519806, local collection (Idukki) and Arka Rakshak genotypes exhibited resistance to ToLCV infection under field screening as well as artificial infection.

Conclusion

From the present study, we identified Ansal, Kaustubh, EC 519806, Local collection (Idukki) and Arka Rakshak as resistant genotypes under field conditions prevailing at Vellanikkara, Kerala in summer.Trichome density was found to be a reliable morphological marker for ToLCV resistance. The resistant genotypes identified in the study can be utilized as parents in resistance breeding programmes in tomato for developing ToLCV resistant genotypes.

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