PLANT SCIENCE TODAY
Vol 13(sp1): 01–06
https://doi.org/10.14719/pst.11656

eISSN 2348-1900

RESEARCH ARTICLE

Farm response of tomato genotypes to *Fusarium oxysporum* f. sp. *lycopersici* under controlled pot conditions

Kumari Sarika[1*], Snehashish Chakravarty[1], Satish Kumar Yadav[2], Smita Kumari[3] & Kishan Singh[4]

[1]Department of Horticulture & Post-harvest Technology, Palli Shikhsha Bhavana (Institute of Agriculture), Visva Bharti Sriniketan, Sriniketan 731 236, West Bengal, India

[2]ICAR-National Bureau of Plant Genetic Resources, New Delhi 110 012, Delhi, India

[3]Horticulture Development, Faridabad 121 001, Haryana, India

[4]Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, Uttar Pradesh, India

*Correspondence email - radha10rudra@gmail.com

Received: 07 September 2025; Accepted: 18 November 2025; Available online: Version 1.0: 26 January 2026

Cite this article: Kumari S, Snehashish C, Satish KY, Smita K, Kishan S. Farm response of tomato genotypes to *Fusarium oxysporum* f. sp. *lycopersici* under controlled pot conditions. Plant Science Today. 2026;13(sp1):01–06. https://doi.org/10.14719/pst.11656

Abstract

Fusarium wilt of tomato, caused by *Fusarium oxysporum* f. sp. *lycopersici* (FOL), is one of the most important and widespread diseases of cultivated tomato. Pot screening experiment was conducted to evaluate 60 tomato genotypes for resistance against FOL the causal agent of Fusarium wilt, under controlled conditions. The experiment was carried out during the Rabi seasons of 2018-19 and 2019-20 in the screenhouse of the Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara. The trials were laid out in a completely randomized design (CRD) with three replications for each genotype. The pathogen inoculum was prepared and introduced into sterilized soil prior to sowing. Data were recorded on wilt incidence, plant height, chlorophyll content and nutritional quality parameters, including vitamin A, lycopene and ascorbic acid content. Results showed significant variation among genotypes for all measured traits. Wilt incidence ranged from 16.7 % in genotype D1 to 50 % in H3, H7 and P3. Genotypes D1, D2 and S Kanchan exhibited moderate resistance. Jaya Hybrid recorded the highest plant height (55.36 cm), while Arka Vikas showed superior chlorophyll content. Nutritionally, D5 and D2 had the highest vitamin A, D4 and D2 were richest in lycopene and D1 recorded maximum ascorbic acid. Based on combined disease resistance and nutritional quality, genotypes D1, D2, D4 and Arka Vikas were identified as promising for future breeding programs and field evaluations.

Keywords: completely randomized design; genotypes; nutritional quality; pathogen; resistance; tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most economically significant vegetable crops globally. It is an important source of antioxidants, including carotenoids such as lycopene and β-carotene, which together make up 7-10 % of total carotenoids. Lycopene alone is the major carotenoid compound (80-90 %). India ranks as the second-largest producer of tomato globally, following China. In the 2022-23 period, India produced approximately 20.4 million tonnes of tomatoes, cultivated over an area of 849000 ha (1). One of the major constraints to tomato production worldwide is Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *lycopersici* (FOL), a soil-borne fungal pathogen that can cause significant yield losses under favourable conditions (2, 3). Fusarium wilt symptoms include yellowing of the lower leaves, wilting, vascular browning and eventual plant death, often resulting in severe yield decline or total crop failure (4). *Fusarium oxysporum* f. sp. *lycopersici* produces three physiological races 1, 2 and 3, which vary in virulence and affect different tomato cultivars depending on their genetic resistance (5, 6). The pathogen can survive in the soil or infected plant debris for many years, making chemical control largely ineffective and environmentally hazardous (7).

Fusarium wilt disease control is a laborious, costly and difficult task in tomato cultivation. The primary strategy for managing Fusarium wilt involves soil fumigation and fungicide applications, alongside crop rotation and sanitation practices (4). However, these methods are often expensive, may pose environmental risks and provide limited long-term protection. Furthermore, the soil-borne nature of the pathogen and the development of new virulent races of FOL make chemical control and agronomic practices alone insufficient. The most effective, sustainable and environmentally friendly approach to controlling Fusarium wilt and minimizing yield losses is the development and cultivation of resistant tomato varieties. Consequently, resistance breeding has become one of the most important goals in tomato improvement programs (4, 7). Resistant tomato cultivars such as Pusa 120, Pusa Ruby, Arka Abha (BWR-1) and H24 provide strong examples of genetic resilience against *F. oxysporum*.

Moreover, while resistance to FOL is a critical selection criterion, it is equally important to assess other agronomic and nutritional traits of tomato genotypes, particularly under disease pressure. Fusarium wilt not only compromises plant survival but also disrupts key physiological and biochemical processes, ultimately

affecting crop productivity and fruit quality. Under sick plot or artificially infested soil conditions, disease stress can significantly influence traits such as plant height, chlorophyll content, vitamin A, lycopene and ascorbic acid. These parameters are often diminished due to vascular blockage and oxidative stress induced by the pathogen, resulting in impaired growth and metabolic function (8, 9). Genetic resistance remains the most effective and eco-friendly approach to managing Fusarium wilt. Resistant cultivars and hybrids have been developed through the introgression of resistance genes from wild tomato relatives such as *Solanum pimpinellifolium*, *S. peruvianum* and *S. chilense* (6, 10). However, continuous monitoring and screening are required due to the emergence of new FOL races and changing pathogenicity patterns. Screening under controlled pot conditions offers a reliable method to evaluate resistance levels among diverse tomato genotypes. It provides insights into genotype -pathogen interactions and supports the identification of resistant lines for use in breeding programs.

In this study, sixty tomato genotypes were evaluated under controlled pot conditions to assess their response to FOL infection. The identification of resistant genotypes will aid in the development of durable Fusarium wilt-resistant tomato varieties for sustainable cultivation.

Materials and Methods

Experimental material and site

Seeds of 60 tomato genotypes (Table 1) were obtained from the National Bureau of Plant Genetic Resources (NBPGR), New Delhi; Indian Institute of Horticultural Research (IIHR) Bengaluru; the Farming System Research Centre for Hill and Plateau Region (FSRCHPR) Ranchi, Himachal Pradesh; Punjab Agricultural University, Ludhiana and local cultivars from farmers in Punjab. A screening pot experiment was carried out in the greenhouse of the Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara, during the Rabi seasons of 2018-19 and 2019-20. The experiments were arranged in a completely randomized design (CRD) for *in vitro* pot culture to screen tomato varieties against FOL.

Isolation and maintenance of pathogen

Infected tomato stems showing vascular discoloration were surface-sterilized using 0.1 % $HgCl_2$ for 30 sec, rinsed with sterile distilled water and placed on potato dextrose agar (PDA) under aseptic conditions. Plates were incubated at 28 ± 1 °C for 7 days (10). The fungus was sub-cultured and maintained on PDA at 5 ± 1 °C for storage.

Pathogenicity test

A pathogenicity test was conducted using six pots, with four filled with pathogen-inoculated soil (fungal culture and soil mixed in 1:3 ratio) and two with non-inoculated soil. Tomato seedlings were transplanted and symptoms were monitored until complete wilting occurred.

Re-isolation and identification

The fungus was re-isolated from wilted plants through standard tissue-plating on PDA and its identity was confirmed by microscopic observation of colony characteristics and morphological structures (mycelium, microconidia, macroconidia and chlamydospores) using stage and filar micrometers. The isolate was further validated at the Punjab Agricultural University (PAU) and authenticated through the Microbial Type Culture Collection and Gene Bank (MTCC), Chandigarh.

Mass multiplication of pathogen

Five substrates (wheat meal, sorghum, bajra grains with 0.5 % glucose; wheat bran + sawdust (1:1); and peat soil) were evaluated for fungal multiplication. Substrates were autoclaved, inoculated

Table 1. List of genotypes used in the present study

S. No.	Genotype	Source	S. No.	Genotype	Source
1	D1	NBPGR	31.	H11	NBPGR
2	D2	NBPGR	32.	H12	NBPGR
3	D3	NBPGR	33.	H13	NBPGR
4	D4	NBPGR	34.	H28	NBPGR
5	D5	NBPGR	35.	H29	NBPGR
6	D6	NBPGR	36.	H30	NBPGR
7	D7	NBPGR	37.	Punjab Local	Local
8	D8	NBPGR	38.	P1	Local
9	D9	NBPGR	39.	P2	Local
10	D10	NBPGR	40.	P3	Local
11	D11	NBPGR	41.	P4	Local
12	D12	NBPGR	42.	P5	Local
13	D13	NBPGR	43.	P6	Local
14	D14	NBPGR	44.	Pusa Rohini	IARI
15	D15	NBPGR	45.	Pusa Ruby	IARI
16	D16	NBPGR	46.	Swarna Lalima	FSRCHP Ranchi
17	D17	NBPGR	47.	Swarna Vijay	FSRCHP Ranchi
18	D18	NBPGR	48.	Swarna Suvarna	FSRCHP Ranchi
19	D19	NBPGR	49.	Swarna Anmol	FSRCHP Ranchi
20	D20	NBPGR	50.	Swarna Kanchan	FSRCHP Ranchi
21	H1	NBPGR	51.	Punjab Gaurav	PAU
22	H2	NBPGR	52.	Punjab Sartaj	PAU
23	H3	NBPGR	53.	Arka Alok	IIHR
24	H4	NBPGR	54.	Arka Rakshak	IIHR
25	H5	NBPGR	55.	Arka Vikas	IIHR
26	H6	NBPGR	56.	Arka Meghna	IIHR
27	H7	NBPGR	57.	North West Hybrid	Local Hybrid
28	H8	NBPGR	58.	Jaya Hybrid	Local Hybrid
29	H9	NBPGR	59.	Satabdi	Local Hybrid
30	H10	NBPGR	60.	Channaya	Local Hybrid

NBPGR: National Bureau of Plant Genetic Resources; **IARI**: Indian Agricultural Research Institute, **IIHR**: Indian Institute of Horticultural Research; **FSRCHP** Forage Seed Research Centre, Hotwar, Ranchi; **PAU**: Punjab Agricultural University.

and incubated at 28 ± 1 °C for 15 days. Spore germination was assessed at 24 and 48 hr on Petri plate.

Inoculum preparation

Coarse wheat meal or sorghum grain with 0.5 % glucose was used for inoculum production in 250 mL flasks, incubated at 28 ± 1 °C for 15 days and the density of conidial stock was counted using a hemocytometer, with density i.e., 1 × 10^6spores/mL, which was acquired by diluting the stock solution. For screening experiments, each pot received 50 mL of the conidial suspension (1 × 10^6 spores mL^{-1}), which was thoroughly mixed into the topsoil to ensure uniform inoculation.

Screening of tomato varieties

Sixty tomato (*S. lycopersicum* L.) varieties were evaluated for resistance to FOL under controlled sick pot conditions. Wilt incidence was recorded 55 days after transplanting. Based on the observed percentage of wilt incidence, disease reactions were categorized as per the following scale (11):

Reaction	Wilt incidence (%)
Immune	0
Highly resistant	1-10
Moderately resistant	11-30
Moderately susceptible	31-50
Susceptible	51-70
Highly susceptible	71-100

In addition to disease incidence, various physiological and biochemical traits were measured, including plant height using a measuring tape or scale (cm), chlorophyll content measured as a chlorophyll index using a SPAD meter (SPAD units), vitamin A (β-carotene) content (mg/100 g) was measured spectrophotometrically, lycopene measured by light absorbance using a spectrophotometer (mg/100 g) and ascorbic acid (mg/100 g). Pulp from each replication was analyzed (12) to assess the overall performance and quality of each genotype under Fusarium wilt stress.

Data analysis

The Agrianalyze application package was used to analyse the data set using the one-way analysis of variance (ANOVA) tools. Mean separation was done using the LSD method at $p \leq 0.05$.

Results

The *p*-value of the *F*-test indicated that the results for all traits across both years were non-significant, suggesting homogeneity of error mean squares. Therefore, the data from both years were pooled and a combined ANOVA was conducted. A combined ANOVA revealed significant genotypic differences ($p \leq 0.05$) for wilting percentage (WP), plant height (PH), chlorophyll content (CC), vitamin A (Vit A) and ascorbic acid (AA) under *F. oxysporum* inoculation (Table 2). This

Table 2. The performance of 60 tomato genotypes to FOL across years under pot culture

Genotype	Plant height	Chlorophyll	Wilting percentage	Vitamin A	Lycopene	Vitamin C	Response
Arka Alok	34.36	35.93	36.7	1.35	3.54	0.56	MS
Arka Meghna	41.14	40.30	33.3	0.88	4.00	0.5	MS
Arka Rakshak	43.33	36.65	33.3	1.24	3.26	0.5	MS
Arka Vikas	25.94	40.74	36.7	1.43	3.20	0.49	MS
Channaya	30.72	34.87	26.7	0.97	2.90	0.42	MR
D1	32.07	43.89	16.7	1.54	4.32	0.62	MR
D10	31.82	35.28	40.0	1.01	3.50	0.42	MS
D11	32.08	33.24	38.3	0.85	3.30	0.47	MS
D12	33.57	37.60	35.0	1.28	3.15	0.45	MS
D13	41.25	38.19	48.3	0.97	3.28	0.45	MS
D14	37.34	40.05	36.7	0.90	3.96	0.47	MS
D15	33.00	36.36	41.7	1.31	3.45	0.49	MS
D16	31.92	33.56	36.7	0.94	3.71	0.42	MS
D17	34.50	37.95	38.3	0.94	3.89	0.44	MS
D18	32.48	35.60	38.3	1.05	3.89	0.42	MS
D19	33.00	34.82	43.3	1.29	3.28	0.45	MS
D2	47.14	36.19	20.0	1.6	4.16	0.52	MR
D20	37.00	39.89	33.3	1.86	3.28	0.41	MS
D3	31.74	41.13	25.0	1.14	3.58	0.57	MR
D4	44.11	40.43	26.7	1.07	4.57	0.59	MR
D5	28.65	37.62	36.7	2.28	4.28	0.53	MS
D6	19.84	39.18	36.7	0.73	3.54	0.55	MS
D7	52.28	30.02	31.7	0.80	3.23	0.49	MS
D8	30.41	38.67	35.0	0.73	4.15	0.41	MS
D9	36.04	36.67	43.3	1.21	4.24	0.45	MS
H1	32.83	38.34	33.3	0.97	3.11	0.48	MS
H10	36.97	37.19	40.0	0.76	3.90	0.42	MS
H11	27.09	40.94	43.3	0.65	3.77	0.47	MS
H12	31.83	36.94	41.7	0.76	3.40	0.41	MS
H13	34.07	37.13	36.7	1.02	3.71	0.47	MS
H2	26.75	37.04	35.0	0.80	3.65	0.47	MS
H28	34.72	38.85	40.0	0.65	3.81	0.47	MS
H29	44.64	40.08	35.0	0.95	3.29	0.41	MS
H3	31.75	42.12	50.0	0.97	4.05	0.43	MS
H30	33.30	42.93	48.3	0.88	3.79	0.5	MS
H4	28.68	32.91	36.7	0.97	4.01	0.45	MS
H5	37.95	38.17	46.7	1.06	3.35	0.49	MS
H6	40.22	39.30	33.3	0.76	3.51	0.47	MS
H7	33.54	41.22	50.0	0.76	3.71	0.44	MS
H8	39.82	35.41	33.3	0.72	3.79	0.48	MS
H9	38.57	34.08	41.7	1.05	3.78	0.45	MS
Jaya Hybrid	50.77	46.71	35.0	1.19	3.86	0.46	MS
North West Hybrid	30.23	35.33	30.0	0.80	3.59	0.46	MR
P1	25.35	37.84	31.7	0.77	3.54	0.46	MS
P2	28.84	35.00	35.0	1.05	3.85	0.47	MS
P3	33.24	30.23	50.0	1.39	3.00	0.44	MS

P4	55.36	36.09	30.0	1.14	3.88	0.52	MR
P5	28.85	38.75	30.0	1.65	2.80	0.49	MR
P6	34.50	37.73	46.7	0.88	4.13	0.48	MS
Punj Gaurav	52.85	39.27	26.7	1.22	2.74	0.53	MR
Punjab Local	30.87	40.11	41.7	1.12	3.43	0.45	MS
Punj sartaj	22.68	37.80	36.7	1.01	3.38	0.49	MS
Pusa Rohini	24.15	34.01	40.0	0.65	3.42	0.41	MS
Pusa Ruby	19.07	26.59	45.0	0.71	3.03	0.39	MS
S Anmol	43.83	36.63	43.3	1.07	3.61	0.5	MS
S Kanchan	37.91	34.76	23.3	0.92	4.14	0.48	MR
Satabdi	39.23	34.93	30.0	1.33	4.03	0.46	MR
Swarna Lalima	30.14	36.94	36.7	1.41	3.34	0.48	MS
Swarna Suvarna	37.16	35.88	31.7	1.08	3.75	0.44	MS
Swarna Vijay	34.67	38.42	33.3	1.16	3.36	0.53	MS
Grand Mean	34.80	37.34	36.50	1.06	3.62	0.47	
LSD (5 %)	7.87	5.23	1.47	0.61	0.93	0.075	
CV (%)	19.89	12.33	35.3	49.62	22.19	13.86	
SEm	2.83	1.87	0.53	0.21	0.36	0.026	
SEd	3.99	2.65	0.74	0.30	0.47	0.037	

MS: Moderately susceptible; **MR**: Moderately resistant.

indicates considerable genetic variability among the evaluated tomato genotypes for these traits.

Wilting percentage (WP)

Genotypic variation was highly significant for wilting percentage, with values ranging from 16.7 (D1) to 50 % (H3, H7 and P3). Genotypes such as D1 (16.7 %), D2 (20 %) and S Kanchan (23.3 %) showed the lowest wilting percentages, indicating a strong resistance to *F. oxysporum*. In contrast, susceptible genotypes like H3, H7 and P3 exhibited complete wilting (50 %).

Plant height (PH)

Plant height ranged from 19.07 cm (Pusa Ruby) to 55.36 cm (P4). Genotypes P4 (55.36 cm), D7 (52.28 cm) and Jaya Hybrid (50.77 cm) were among the tallest, which may be advantageous for better light interception and vigour. Shorter genotypes, like Pusa Ruby and D6, appeared adversely affected by the pathogen.

Chlorophyll content (CC)

Chlorophyll content, an important indicator of photosynthetic efficiency, varied from 25.35 (P1) to 46.71 (Jaya Hybrid). Genotypes such as Jaya Hybrid, Arka Vikas and H3 maintained high chlorophyll levels despite pathogen pressure, which may contribute to better growth and tolerance.

Vitamin A content (Vit A)

Vitamin A content ranged from 0.65 mg/100 g (H11, H28 and Pusa Rohini) to 2.28 mg/100 g (D5). Genotype D5 stood out with the highest vitamin A concentration, followed by D2 (1.6 mg/100 g) and D20 (1.86 mg/100 g). These genotypes not only exhibited resistance but also nutritional superiority.

Lycopene content (LC)

Lycopene content ranged between 2.74 mg/100 g (Punj Gaurav) and 4.57 mg/100 g (D4). Genotypes D4, D2 and D5 exhibited high lycopene levels, making them suitable for processing and health-promoting food products.

Ascorbic acid (AA)

Ascorbic acid content ranged from 0.39 mg/100 g (Pusa Ruby) to 0.62 mg/100 g (D1). Genotype D1, which also showed the lowest wilting percentage, recorded the highest ascorbic acid content, making it a promising candidate for breeding programs targeting both disease resistance and nutritional value.

Discussion

The present study revealed significant genotypic differences among tomato genotypes under FOL inoculation. These differences were evident in wilting percentage, plant height, chlorophyll content, vitamin A, lycopene and ascorbic acid, indicating ample genetic variability for resistance and nutritional quality traits.

Genotypic resistance to FOL was evident from the wide range in wilting percentage, from 16.7 % in genotype D1 to 50 % in genotypes H3, H7 and P3. This variation agrees with earlier findings that resistance to FOL in tomato is quantitatively inherited and can vary substantially among genotypes (13, 14). Genotypes D1, D2 and S Kanchan exhibited low wilting and may carry resistance genes such as I, I-1, I-2, or I-3, which have been associated with FOL resistance (15). Plant height, which ranged from 19.07 cm to 55.36 cm, was adversely affected in susceptible genotypes, indicating the impact of pathogen stress on vegetative growth. Similar reductions in plant height due to *Fusarium* infection have been reported, attributed to vascular blockage and reduced water uptake caused by fungal colonization (16).

Chlorophyll content was significantly higher in genotypes like Jaya Hybrid and Arka Vikas despite FOL stress, indicating maintained photosynthetic activity under stress. High chlorophyll levels under stress are associated with delayed senescence and improved tolerance (17). Vitamin A (0.65 to 2.28 mg/100 g) and lycopene contents (2.74 to 4.57 mg/100 g), which are crucial nutritional traits, also varied considerably. Genotypes D5 and D2 recorded higher vitamin A levels, aligning with findings that resistant genotypes tend to maintain or accumulate higher levels of antioxidants under pathogen attack (18). Lycopene levels were highest in D4 and D2, confirming earlier reports that lycopene accumulation is genotype-dependent and may also serve a protective function during stress (19). Ascorbic acid content ranged from 0.39 to 0.62 mg/100 g, with the highest content in D1. Ascorbic acid functions as a key antioxidant in plant defense responses and its accumulation under stress has been documented (20). Higher

ascorbic acid levels help maintain redox homeostasis by scavenging reactive oxygen species generated during pathogen attack. Therefore, genotypes with high ascorbic acid may better limit oxidative damage, strengthen cell wall integrity and suppress pathogen-induced wilting, thereby contributing to improved tolerance against FOL.

Grouping of genotypes based on disease response showed that moderately resistant genotypes not only exhibited lower wilting percentages but also had superior nutritional profiles. This is significant as it suggests the possibility of selecting genotypes that combine resistance and fruit quality, an essential goal in tomato breeding programs (21).

Conclusion

The present investigation revealed significant genetic variability among tomato genotypes in response to FOL infection. Genotypes such as D1, D2 and S Kanchan exhibited strong resistance to FOL, reflected by low wilting percentages (<20 %) and favourable growth and quality traits. D1 emerged as a particularly promising genotype due to its lowest wilting percentage (16 %) and highest ascorbic acid content (0.62 mg/100 g). Additionally, genotypes such as D5 and D2 showed superior vitamin A and lycopene levels, indicating their potential not only for disease resistance but also for enhanced nutritional quality. These findings underscore the possibility of integrating resistance traits with nutritional value in tomato breeding programs, thereby supporting the development of cultivars that are both resilient and health-promoting.

Authors' contributions

KS[1] conducted the laboratory experiments, collected the data, performed the data analysis and prepared the initial draft of the manuscript. SC, KS[2] and SKY, as research supervisors, conceptualized the study, provided overall guidance and offered critical input during manuscript preparation. SK contributed to reviewing and editing the manuscript. All authors read and approved the final version of the manuscript (KS[1]stands for Kumari Sarika and KS[2]stands for Kishan Singh).

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. FAOSTAT. Crops and livestock products: tomato, production quantity and area harvested. Rome: Food and Agriculture Organization of the United Nations; 2024.
2. Chitwood-Brown J, Vallad GE, Lee TG, Hutton SF. Breeding for resistance to *Fusarium* wilt of tomato: a review. Genes. 2021;12 (11):1673. https://doi.org/10.3390/genes12111673
3. Borrero C, Trillas MI, Ordovás J, Tello JC, Avilés M. Predictive factors for the suppression of *Fusarium* wilt of tomato in plant growth media. Phytopathology. 2004;94(10):1094–101. https://doi.org/10.1094/PHYTO.2004.94.10.1094
4. McGovern RJ. Management of tomato diseases caused by *Fusarium oxysporum*. Crop Prot. 2015;73:78–92. https://doi.org/10.1016/j.cropro.2015.01.007
5. Di Pietro A, Madrid MP, Caracuel Z, Delgado Jarana J, Roncero MIG. *Fusarium oxysporum*: exploring the molecular arsenal of a vascular wilt fungus. Mol Plant Pathol. 2003;4(5):315–25. https://doi.org/10.1046/j.1364-3703.2003.00180
6. Mes JJ, Weststeijn EA, Herlaar F, Lambalk JJ, Wijbrandi J, Haring MA, Cornelissen BJ. Biological and molecular characterization of *Fusarium oxysporum* f. sp. *lycopersici* divides race 1 isolates into separate virulence groups. Phytopathology. 1999;89(9):840–46. https://doi.org/10.1094/PHYTO.1999.89.9.840
7. Fravel D, Olivain C, Alabouvette C. *Fusarium oxysporum* and its biocontrol. New Phytol. 2003;157(3):493–502. https://doi.org/10.1046/j.1469-8137.2003.00690
8. Johnson HW, Robinson HF, Comstock RE. Estimates of genetic and environmental variability in soybeans. Agron J. 1955;47(7):314–18. https://doi.org/10.2134/agronj1955.00021962004700070009
9. Singh RK, Chaudhary BD. Biometrical methods in quantitative genetic analysis. New Delhi: Kalyani Publishers; 1985.
10. Pandey AK, Dinesh K, Nirmala NS, Dutta P. *Fusarium* wilt of tomato: past, present and future. In: Verma PK, Mishra S, Srivastava V, Mehrotra S, editors. Plant pathogen interaction. Singapore: Springer Nature Singapore; 2024. p. 55–87.
11. Fernandes RH, Silva DJ, Delazari FT, Lopes EA. Screening of tomato hybrids for resistance to *Fusarium* wilt. Crop Breed Appl Biotechnol. 2023;22:e43352248. https://doi.org/10.1590/1984-70332022v22n4a43
12. Sharma RK. Basic techniques in biochemistry and molecular biology. New Delhi: IK International Pvt Ltd; 2013.
13. Chopada GB, Singh P, Chandulal K. Cultural and morphological variability among *Fusarium oxysporum* f. sp. *lycopersici* causing wilt of tomato in south Gujarat region. Arch Phytopathol Plant Prot. 2015;48 (2):104–10. https://doi.org/10.1080/03235408.2014.882558
14. Scott JW, Jones JP. Monogenic resistance in tomato to *Fusarium oxysporum* f. sp. *lycopersici* race 3. Euphytica. 1989;40:49–53. https://doi.org/10.1007/BF00023296
15. Panthee DR, Chen F. Genotype and environment interaction for resistance to *Fusarium oxysporum* f. sp. *lycopersici* race 2 in tomato. J Crop Improv. 2010;24(2):146–63. https://doi.org/10.1080/15427521003703295
16. Li X, Zhang Y, Yin L, Lu J. Effects of *Fusarium* wilt on photosynthesis and antioxidative enzyme activities in tomato. Acta Physiol Plant. 2011;33(5):1665–71. https://doi.org/10.1007/s11738-010-0660-2
17. Maqsood A, Wu H, Kamran M, Altaf H, Mustafa A, Ahmar S, et al. Variations in growth, physiology and antioxidative defense responses of two tomato (*Solanum lycopersicum* L.) cultivars after co-infection of *Fusarium oxysporum* and *Meloidogyne incognita*. Agronomy. 2020;10 (2):159. https://doi.org/10.3390/agronomy10020159
18. Ilahy R, Hdider C, Lenucci MS, Tlili I, Dalessandro G. Antioxidant activity and lycopene content in tomato fruit: variation among cultivars and maturity stages. Sci Hortic. 2011;127(3):255–61. https://doi.org/10.1016/j.scienta.2010.10.019
19. Hasanuzzaman M, Hossain MA, da Silva JA, Fujita M. Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. In: Crop stress and its management: perspectives and strategies. Dordrecht: Springer Netherlands; 2011. p. 261–315. https://doi.org/10.1007/978-94-007-2220-0_8
20. Foolad MR. Genome mapping and molecular breeding of tomato. Int J Plant Genomics. 2007;64358. https://doi.org/10.1155/2007/64358
21. Hadian J, Balali G, Khadivi Khub A. Screening of tomato landraces for resistance to *Fusarium oxysporum* f. sp. *lycopersici* and fruit quality traits. Crop Prot. 2020;136:105210. https://doi.org/10.1016/j.cropro.2020.105210

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc

See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (https://creativecommons.org/licenses/by/4.0/)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.