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Cultivar-dependent physiological response of tomato to *Fusarium oxysporum* under controlled greenhouse conditions

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Abstract: Fusarium oxysporum is one of the most important soil-borne pathogens limiting tomato production under protected cultivation systems. Disease severity depends on the interaction between pathogen aggressiveness and host susceptibility, while vascular infection may also impair physiological processes related to photosynthesis and plant vigor. This study evaluated the cultivar-dependent response of six tomato cultivars to Fusarium oxysporum isolates FO23 and FOL43 under controlled greenhouse conditions and quantified physiological damage through changes in chlorophyll a, chlorophyll b, and carotenoid content. Montagano and San Marzano Nano were the most susceptible cultivars, showing the highest mortality and strongest symptom expression. Commercial cultivars declared resistant to races 0 and 1 showed effective resistance to FOL43 but only partial protection against the local isolate FO23. Pigment analysis revealed marked reductions in chlorophyll a, chlorophyll b, and carotenoids in most cultivars, whereas N507 showed the lowest physiological damage and maintained comparatively higher pigment stability. Disease severity differed markedly among cultivars and was closely associated with physiological impairment. The aggressive local isolate FO23 caused stronger reductions in photosynthetic pigments than FOL43, indicating a greater capacity to disrupt host physiological processes. The integration of visual disease assessment and pigment quantification provided a robust framework for evaluating cultivar tolerance under greenhouse conditions. These findings support cultivar screening, resistance evaluation, and integrated management strategies for greenhouse tomato production.

Keywords: Fusarium oxysporum; tomato wilt; cultivar response; chlorophyll; carotenoids; physiological stress; greenhouse production.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated under protected conditions and plays a major economic role in Mediterranean agriculture. In Albania,

greenhouse tomato production is especially important for local markets and commercial supply chains. However, intensive and repeated cultivation under protected systems has increased the pressure of soil-borne pathogens, which can reduce crop productivity and plant quality.

Among these pathogens, *Fusarium oxysporum* is particularly important because it infects tomato through the root system, colonizes vascular tissues, and induces chlorosis, wilting, growth reduction, and plant death [1, 3, 5, 9]. Its capacity to persist in soil and plant residues makes management difficult, especially in greenhouse systems where repeated cropping may increase inoculum pressure.

Tomato cultivars differ in their susceptibility and tolerance to Fusarium wilt [6, 7, 10, 11]. Although several commercial cultivars are declared resistant to specific races of *Fusarium oxysporum f. sp. lycopersici*, their performance may vary when challenged with local isolates or strains differing in virulence. Therefore, cultivar evaluation against locally aggressive isolates remains essential for understanding the practical value of resistance under production conditions.

2. Object and subject of research

The object of this research was the tomato-*Fusarium oxysporum* pathosystem under controlled greenhouse conditions. The study focused on the interaction between tomato cultivar background, pathogen aggressiveness, visible disease expression, mortality, and physiological disturbance associated with photosynthetic pigment reduction.

The subject of research consisted of six tomato cultivars, namely BRSAR, N507, Pink Rock F1, INKAS, San Marzano Nano, and Montagano, inoculated with two *Fusarium oxysporum* isolates: FO23 and FOL43. FO23 represented a highly aggressive local isolate, whereas FOL43 represented *Fusarium oxysporum f. sp. lycopersici* and was used as a comparative pathogenic reference.

The main shortcoming addressed by this study was that cultivar resistance declared against specific *Fusarium oxysporum f. sp. lycopersici* races may not fully predict plant performance against aggressive local isolates. In addition, visible disease symptoms alone may underestimate the physiological damage caused by vascular infection.

3. Target of research

The target of this research was to evaluate the cultivar-dependent response of tomato to *Fusarium oxysporum* isolates FO23 and FOL43 under controlled greenhouse conditions and to determine whether visible disease expression was associated with physiological impairment.

The specific tasks were to compare mortality and symptom severity among cultivars, assess the relative aggressiveness of FO23 and FOL43, quantify changes in chlorophyll a, chlorophyll b, and carotenoid content, and identify cultivars with greater physiological stability under pathogen pressure.

4. Literature analysis

Fusarium oxysporum is a complex species with multiple formae speciales and pathogenic races that differ in host range, aggressiveness, and capacity for vascular colonization [3, 6, 10, 12]. In tomato, Fusarium wilt remains one of the most important soil-borne diseases because the pathogen can persist in soil and plant debris and can colonize the vascular system through the root tissues [3, 5, 9].

Previous studies have shown that resistance to *Fusarium oxysporum f. sp. lycopersici* can be race-specific and may vary depending on the cultivar-pathogen interaction [7, 10, 11]. Vascular colonization patterns, root exudate-mediated responses, and local pathogen variability are important factors that may explain differences in cultivar performance [7, 8, 12].

Physiological indicators such as chlorophyll a, chlorophyll b, and carotenoids provide useful information on stress intensity, photosynthetic impairment, and plant vigor [14, 15]. For this reason, pigment quantification can complement visual disease assessment and improve the identification of cultivars that maintain physiological stability under vascular pathogen pressure.

5. Research methods

Plant material and tomato cultivars

Six tomato cultivars were evaluated: BRSAR, N507, Pink Rock F1, INKAS, San Marzano Nano, and Montagano. The cultivar panel included commercial cultivars with declared resistance to *Fusarium oxysporum f. sp. lycopersici* races 0 and 1, together with local or non-resistant material. Seeds and seedlings used for the cultivar experiments were obtained through AGRO-ELIEK, Albania.

Fungal isolates

Two Fusarium isolates were used in the cultivar response assay: FO23 and FOL43. FO23 represented a local *Fusarium oxysporum* isolate previously identified as highly aggressive in pathogenicity tests, whereas FOL43 represented *Fusarium oxysporum f. sp. lycopersici* and was used as a comparative pathogenic reference.

Inoculum preparation and greenhouse assay

Fungal isolates were grown on potato dextrose agar (PDA) for conidia production under controlled laboratory conditions. Conidial suspensions were prepared in sterile distilled water and adjusted to the concentrations required for the experimental assay. Tomato seedlings were transplanted 15 days after germination into pots containing a 50:50 mixture of universal substrate and perlite. The substrate was artificially infested before transplanting, and plants were maintained under controlled greenhouse conditions.

Disease assessment

Cultivar response was assessed through mortality, visible symptom development, chlorosis, growth reduction, and overall plant vigor. Mortality and symptom expression were compared among cultivars inoculated with FO23 and FOL43. Visual observations were used together with pigment measurements to interpret cultivar susceptibility and physiological stability.

Quantification of photosynthetic pigments

Photosynthetic pigments were quantified from leaf tissues collected from inoculated and untreated plants. For each cultivar, 25 leaf discs of 5 mm diameter were collected from second-stage leaves and extracted in 80% acetone. Chlorophyll a, chlorophyll b, and carotenoids were measured spectrophotometrically at 663 nm, 648 nm, and 470 nm, respectively. Pigment reduction was interpreted as an indicator of physiological stress associated with vascular infection.

Statistical analysis

Experimental data were evaluated using descriptive and comparative statistical analysis. Mortality, symptom severity, and photosynthetic pigment responses were summarized as mean values, percentages, or relative reductions compared with the corresponding untreated controls. Where quantitative data from replicated treatments were suitable for comparison, mean values were evaluated by one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test at $P < 0.05$. For qualitative symptom categories and semi-quantitative cultivar responses, results were interpreted conservatively on the basis of stable and reproducible treatment patterns under controlled greenhouse conditions.

6. Research results

Cultivar response to FO23 and FOL43

The comparative inoculation of tomato cultivars with FO23 and FOL43 revealed clear differences in host response, both between cultivars and between pathogen isolates. Montagano and San Marzano Nano were the most susceptible cultivars, showing marked symptom development and high mortality after inoculation. By contrast, BRSAR, N507, Pink Rock F1, and INKAS showed lower symptom severity, especially when inoculated with FOL43.

The local isolate FO23 caused greater damage than FOL43 in the tested cultivar set. This indicates that the declared resistance profile of some commercial cultivars remained effective against FOL43, but

provided only partial protection against FO23. Therefore, cultivar performance under greenhouse conditions should be evaluated against local pathogen isolates, not only against reference strains.

The mortality patterns observed among cultivars are presented in fig. 1.

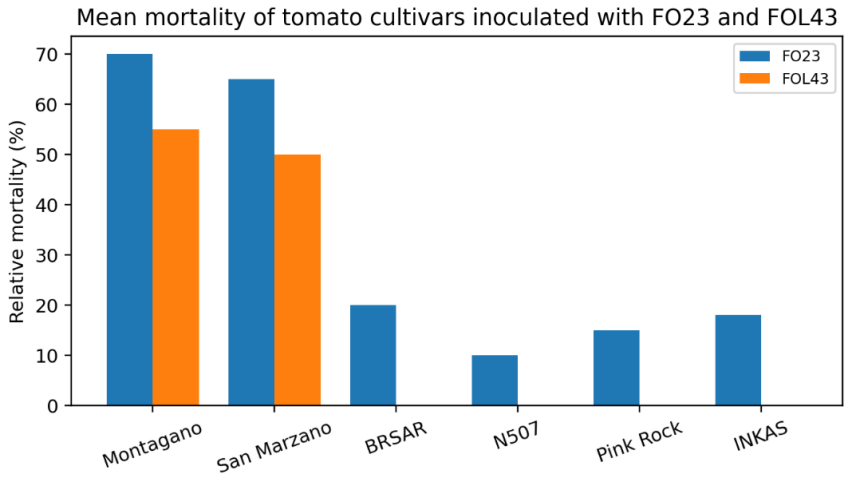

Figure 1. Mean mortality (%) of tomato cultivars inoculated with *Fusarium oxysporum* isolates FO23 and FOL43 under controlled greenhouse conditions.

Table 1. Tomato cultivars included in the study, seed source, and declared resistance profile.

Cultivar	Seed company	Declared resistance	Production type	Notes
BRSAR	BASF	Va, Vd; Fol 0-1	Industrial	Commercial resistant line
N507	BASF	Va, Vd; Fol 0-1	Industrial	Lowest pigment damage
Pink Rock F1	Yuksel Seeds	Vd, Va; Fol 0-1	Fresh market	Commercial resistant hybrid
INKAS	BASF	Vd; Fol 0-1	Industrial	Commercial resistant line
San Marzano Nano	Semiorto Sementi	Non-resistant	Fresh market	Highly susceptible
Montagano	Local variety	Undetermined	Industrial	Highly susceptible local material

Table 2. Comparative response of tomato cultivars to inoculation with FO23 and FOL43.

Cultivar	FO23 response	FOL43 response	Symptom severity	Interpretation
Montagano	Highly susceptible	Susceptible	Severe	Very vulnerable local cultivar
San Marzano Nano	Highly susceptible	Susceptible	Severe	Non-resistant and highly vulnerable
BRSAR	Partial susceptibility	No mortality under tested conditions	Mild to moderate	Resistance effective mainly against FOL43

Continuation of Table 2

N507	Partial susceptibility with low physiological damage	No mortality under tested conditions	Mild	Most stable commercial cultivar
Pink Rock F1	Partial susceptibility	No mortality under tested conditions	Mild to moderate	Better response to FOL43 than FO23
INKAS	Partial susceptibility	No mortality under tested conditions	Mild to moderate	Commercial resistance not fully effective against FO23

Representative symptom expression observed 30 days after inoculation is shown in fig. 2.

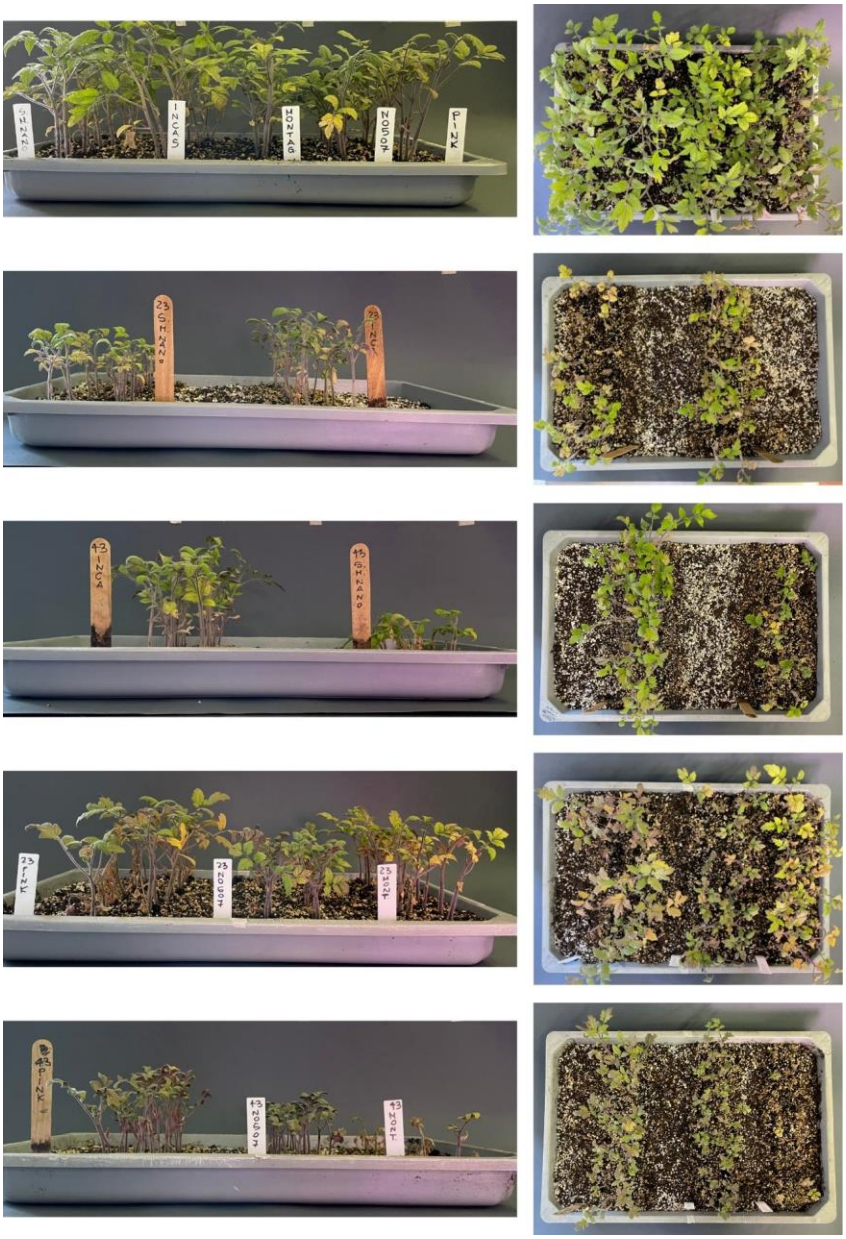

Figure 2. Symptom expression in tomato cultivars 30 days after inoculation with FO23 and FOL43. Reduction of chlorophyll a, chlorophyll b, and carotenoids

Inoculation with FO23 caused a clear reduction in chlorophyll a, chlorophyll b, and carotenoids in infected plants compared with untreated controls. The reduction of photosynthetic pigments was strongest in Montagano and San Marzano Nano, which also showed the highest symptom severity. This indicates that visible disease development was associated with marked physiological disturbance.

N507 showed the lowest pigment reduction and maintained the greatest physiological stability under FO23 pressure. This result suggests that cultivar tolerance may involve not only lower visible disease expression, but also a greater capacity to maintain photosynthetic pigment content during infection.

The reduction of photosynthetic pigments is summarized in fig. 3.

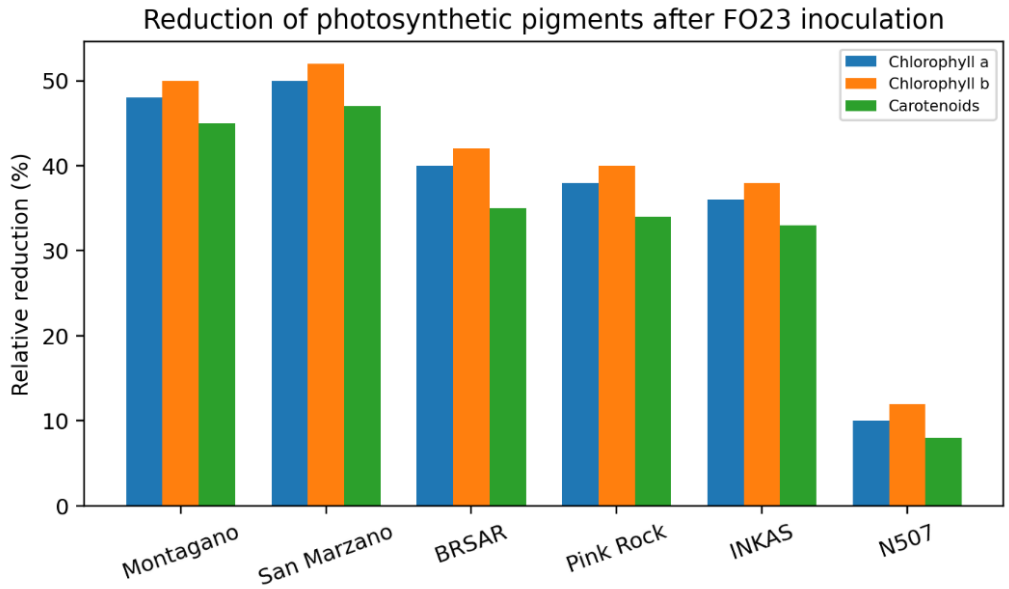

Figure 3. Quantification of chlorophyll a, chlorophyll b, and carotenoids in tomato cultivars after inoculation with FO23.

Table 3. Relative reduction of chlorophyll a, chlorophyll b, and carotenoids in tomato cultivars inoculated with FO23.

Cultivar	Chlorophyll a	Chlorophyll b	Carotenoids	Overall pigment impact
Montagano	Strong reduction	Strong reduction	Strong reduction	Severe physiological stress
San Marzano Nano	Strong reduction	Strong reduction	Strong reduction	Severe physiological stress
BRSAR	Moderate to strong reduction	Moderate to strong reduction	Moderate reduction	Clear physiological impact
Pink Rock F1	Moderate to strong reduction	Moderate to strong reduction	Moderate reduction	Clear physiological impact
INKAS	Moderate to strong reduction	Moderate to strong reduction	Moderate reduction	Clear physiological impact
N507	Slight reduction	Slight reduction	Slight reduction	Lowest physiological damage

The results demonstrate that tomato response to *Fusarium oxysporum* is strongly influenced by cultivar background and pathogen aggressiveness. FO23 produced more severe disease expression than FOL43, suggesting that local pathogen isolates may represent a greater practical risk under greenhouse conditions than reference isolates alone.

The strong susceptibility of Montagano and San Marzano Nano confirms that local or non-resistant material may be highly vulnerable to vascular wilt under pathogen pressure. In contrast, the lower symptom expression and reduced physiological damage observed in N507 indicate a more stable response to infection.

The reduction of chlorophyll a, chlorophyll b, and carotenoids provides important physiological evidence of the impact of Fusarium infection [14, 15]. Pigment depletion is consistent with impaired photosynthetic capacity, chlorosis development, and reduced plant vigor. Therefore, pigment analysis can complement visual symptom scoring and improve the identification of tolerant cultivars.

7. Prospects for further research development

Future research should validate these cultivar response patterns under commercial greenhouse conditions and across a broader collection of local *Fusarium oxysporum* isolates. This would help determine whether FO23 represents a local virulence pattern that requires specific resistance screening in Albanian greenhouse tomato production.

Further development should also integrate physiological indicators, such as photosynthetic pigment stability, with molecular pathogen identification, pathogenicity testing, and agronomic performance. This approach can strengthen cultivar recommendation systems and improve integrated Fusarium wilt management under protected cultivation.

8. Conclusions

The study showed clear cultivar-dependent differences in response to *Fusarium oxysporum* under controlled greenhouse conditions. The local isolate FO23 caused stronger disease expression than FOL43 across the tested cultivar set.

Montagano and San Marzano Nano were the most susceptible cultivars, whereas N507 showed the greatest physiological stability and the lowest pigment reduction under pathogen pressure.

Photosynthetic pigment reduction closely reflected disease severity and provided a useful physiological indicator of stress caused by vascular infection.

These findings support the use of combined visual and physiological assessment for cultivar screening and resistance evaluation in greenhouse tomato production systems.

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