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The Protection of Tomatoes Against the Fruit Blight and the Sustainability of Cultivars to the Pathogen (*Phytophthora infestans*)

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ABSTRACT

This two-year research aimed to evaluate the efficacy of chemical preparations and the resistance of tomato cultivars (Amati and Bella) against the *Phytophthora infestans* pathogen causing fruit blight. Fungicides, including Metalaxyl, Azoxystrobin, Mancozeb, and Copper, were tested in seven combinations, and disease assessments were conducted using the McKinney Index. Results from 2021 and 2022 consistently demonstrated that the combination of Azoxystrobin and Metalaxyl exhibited the highest efficiency in protecting both cultivars against *Phytophthora infestans*, with infection rates as low as 5.30% and 4.43%, respectively. In addition to fungicide effectiveness, cultivar resistance analysis revealed that Bella consistently displayed higher sustainability to the pathogen compared to Amati, with infection rates ranging from 4.43% to 6.30% for Bella, compared to 5.30% to 7.03% for Amati. This enhanced resistance in Bella was attributed to its smaller vegetative mass. The study underscores the importance of meticulous systemic fungicide use to prevent the development of pathogen resistance. Furthermore, the research recommends adjusting the frequency of sprayings based on climatic conditions to optimize blight management strategies. This research provides valuable insights into effective blight management strategies, highlighting specific fungicide combinations, and emphasizing the resistance characteristics of tomato cultivars. These findings contribute to the development of sustainable practices for protecting tomatoes against *Phytophthora infestans*, ultimately aiding in the cultivation of more resilient and disease-resistant tomato crops.

Keywords: cultivar resistance, sustainability, disease management, McKinney Index, pathogen resistance, climatic conditions, tomato cultivars.

INTRODUCTION

Tomatoes (*Solanum lycopersicum*) are a crucial staple in global agriculture, contributing significantly to both economic and nutritional spheres. However, the susceptibility of tomato crops to various pathogens, particularly *Phytophthora infestans*, has been a persistent challenge for growers worldwide. *Phytophthora infestans* is notorious for causing tomato fruit blight, leading to substantial yield losses and economic repercussions. As the need for sustainable and resilient agricultural practices intensifies, it becomes imperative to develop effective strategies for protecting tomatoes against this formidable pathogen. The primary purpose of this two-year research is to address the dual goals of enhancing the protection of tomatoes against *Phytophthora infestans*-induced fruit blight and evaluating the sustainability of different tomato cultivars in the context of this pathogenic threat. By focusing on the effectiveness of specific chemical preparations and assessing the resistance characteristics of two prominent tomato cultivars, Amati and Bella, this study aims to provide actionable insights for developing practical and sustainable solutions in tomato cultivation.

Previous studies have extensively documented the impact of *Phytophthora infestans* on tomato crops, emphasizing the need for comprehensive disease management strategies. Recent publications highlight the evolving nature of *Phytophthora infestans* strains, underlining the importance of staying abreast of the latest developments in the field [Childers et al., 2015; Modesto et al., 2016; Cohen et al., 2018]. These emerging strains pose a significant challenge to traditional control methods, necessitating a continuous reassessment of existing practices and the exploration of novel approaches [González-Tobón et al., 2020; McLeod et al., 2023].

In the realm of chemical control, the efficacy of various fungicides against *Phytophthora infestans* has been a subject of ongoing research. Notably, recent studies have reported promising results with fungicides such as Azoxystrobin and Metalaxyl, indicating the potential for improved disease management (FRAC, 2024; PCPB, 2024). The dynamic nature of pathogen resistance necessitates a nuanced understanding of the interactions between different fungicides and *Phytophthora infestans* strains, emphasizing the importance of tailored and sustainable fungicide use [Ivanov et al., 2021; Nuwamanya et al., 2023].

In terms of cultivar resistance, recent research has shed light on the genetic factors influencing tomato resistance to *Phytophthora infestans*. The choice of these particular varieties, Amati and Bella, was based on their prevalence in tomato cultivation and their susceptibility to the pathogen. These varieties represent different genetic backgrounds, allowing us to explore potential differences in resistance and treatment efficacy. Advances in molecular biology and genomics have enabled the identification of key genes associated with resistance, offering opportunities for targeted breeding programs [Fry et al., 2015; Saville et al., 2015]. Understanding the genetic basis of resistance is crucial for selecting cultivars with enduring protection against *Phytophthora infestans*, contributing to the overall sustainability of tomato production [Martin et al., 2016; Ristaino et al., 2021].

In the context of tomato cultivation, particularly in the municipality of Peja, Broliq village, Kosovo, the threat of *Phytophthora infestans*-induced fruit blight poses significant challenges to growers. Our research endeavors to address this gap by focusing on the efficacy of chemical treatments and the resistance levels of two prominent tomato cultivars, Amati and Bella, in the local context. By systematically evaluating these factors over a two-year period, our study aims to provide specific insights and practical recommendations for sustainable tomato blight management practices tailored to the unique challenges faced by growers in Kosovo. The research focused on two specific tomato cultivars, Amati and Bella, for several reasons. Firstly, these varieties are widely cultivated in our region, reflecting their importance in local agriculture. Secondly, it's crucial to compare infection levels between different varieties to understand their resistance traits and effectiveness against Phytophthora infestans. Importantly, these cultivars are not genetically modified, ensuring that our findings are relevant to conventional farming practices. Additionally, they have not been previously infected, as they were planted for the first time in soil previously uncultivated with tomatoes. However, infection can still occur from neighboring fields planted with the same crop. We have also taken environmental factors into account, such as rainfall and temperature, which can influence disease development. Overall, our choice of these cultivars allows us to provide insights into blight management strategies tailored to our local context while considering both genetic and environmental factors.

Through this research, we seek to empower local farmers with evidence-based strategies to protect their tomato crops from Phytophthora infestans while enhancing the resilience of tomato cultivation.

MATERIAL AND METHODS

The research conducted in the years 2021-2022 in the municipality of Peja, Broliq village, Kosovo, focused on the management of tomato blight using two cultivars: Amati and Bella. The environmental factors were consistent for both tomato varieties, Amati and Bella. The experiments were conducted in the same location, with identical growing conditions, including soil type, climate, and cultivation practices. The chemical preparations involved the use of Metalaxyl with a local systemic action at a concentration of 0.35%. The experimental design employed a randomized block design with each variant replicated in two blocks.

The experiment consisted of seven variants (B_1 to B_7), representing different combinations of the chemical preparations. The testing fields had dimensions of 4 × 5 meters (20 m^2), and each variant was assigned to these fields. The spraying process was carried out using a 10-litre pump tank, with a total of seven sprayings conducted. Two sprayings were done before blooming, and five were conducted after blooming, with intervals of 8-10 days between each application. The interval of 8-10 days between sprayings was chosen based on several factors to ensure effective disease management while minimizing potential adverse effects. Firstly, this interval aligns with the typical growth and development stages of tomato plants, particularly during the critical pre-blooming and post-blooming phases when they are most susceptible to *Phytophthora infestans* infection. By conducting sprayings before blooming, we aimed to establish an initial protective barrier against the pathogen, thus reducing the likelihood of infection during this vulnerable period. Subsequent sprayings after blooming were scheduled to coincide with the emergence of new foliage and fruits, which represent additional targets for infection. Additionally, the 8-10 day interval allows for adequate coverage and penetration of the fungicides throughout the plant canopy, ensuring thorough protection against potential infection sites. Overall, this spraying interval was carefully chosen to optimize the efficacy of chemical treatments while minimizing the risk of resistance development and phytotoxicity. The infection evaluation utilized a five-class categorization system, as detailed in Table 1.

Table 1. The rate of the evaluation of infection

Type	The infected part in %	Infection evaluation
0	0%	Without infection
1	Up to 10%	Low
2	11–20%	Average
3	21–50%	High
4	Over 50%	Very high

The stages of evaluation considered the percentage of the infected part and categorized the infection level accordingly. The research aimed to assess the effectiveness of different combinations of Metalaxyl and evaluate their impact on managing tomato blight in the specified region and conditions.

Experimental diagram

The experimental design is summarized in Table 2, outlining different experimental variants with corresponding combination symbols and chemical preparations used in the study. The purpose of these variants was to assess the effectiveness of various chemical combinations in managing tomato blight.

The symbols B_1 to B_7 represent different experimental variants for clarity throughout the text. This experimental setup allowed for the assessment of the interactions between fungicides and cultivar resistance, providing valuable insights into the efficacy of various chemical preparations and their combinations in controlling tomato blight. To compare the effectiveness of various methods for protecting tomatoes against *Phytophthora infestans*, the pathogen causing fruit blight, and to evaluate the sustainability of cultivars to this pathogen across two years (2021 and 2022), we employed a comprehensive statistical analysis approach. This involved utilizing descriptive statistics, conducting statistical tests, analyzing tables, and employing other relevant methodologies.

Table 2. Different experimental variants used

Variant	Combination	Chemical preparations
B_1	Metalaxyl + Mancozeb (changeable application)	Metalaxyl, Mancozeb
B_2	Azoxystrobin for the first two treatments, then Mancozeb	Azoxystrobin, Mancozeb
B_3	Metalaxyl + Copper (changeable application)	Metalaxyl, Copper
B_4	Azoxystrobin for the first two treatments, then Copper	Azoxystrobin, Copper
B_5	Azoxystrobin for the first two treatments, then Metalaxyl	Azoxystrobin, Metalaxyl
B_6	Mancozeb + Copper (changeable application)	Mancozeb, Copper
B_7	Checking and control	No fungicide application (Control)

Note: the symbols B_1 to B_7 represent different experimental variants used in the text for clarity.

RESULTS

The two-year research conducted in the municipality of Peja, Broliq village, Kosovo, aimed to assess the protection of tomatoes against *Phytophthora infestans*-induced fruit blight and evaluate the sustainability of two tomato cultivars, Amati and Bella. The results of the experiment revealed varying degrees of blight management efficacy among the different chemical combinations. Notably, the combination of Azoxystrobin and Metalaxyl consistently demonstrated the highest efficiency in protecting both Amati and Bella cultivars throughout the two-year period. This combination exhibited superior control over *Phytophthora infestans*, as evidenced by reduced disease incidence and severity. In the following, the results for the years 2021 and 2022 are presented.

Results for the year 2021

According to the results obtained during the evaluation of the disease in 2021, it appears that the seven variants used to protect the fruits from blight in cultivar Amati, on the B_5 variant the average percentage of the disease has been lower, about (7.93%) where have been used Azoxystrobin, and Metalaxyl, and therefore these preparations have shown very high efficacy against the disease. Then, regarding efficiency, after the B_5 variant, it is ranked the combination of preparations Metalaxyl and Mancozeb with the percentage infection (10.40%) to the B_1 variant. Whereas, less efficient have been shown the combinations of preparations on variant B_2 (12.76%) which used Azoxystrobin and Mancozeb, then variant B_3 (16.66%) which used Metalaxyl and Copper, then the B_4 variant (17.86%) with the preparation Azoxystrobin and Copper and the variant B_6 (20.76%), where have been combined Mancozeb and Copper. While, during the controlling process the average percentage of infection was B_7 (34.36%).

Meanwhile, in terms of cultivar Bella, the highest efficacy of the chemical preparations against the pathogen was in the B_5 variant with an average percentage of the disease (5.46%), there has been used the combination of the preparations Azoxystrobin and Metalaxyl. High efficacy has shown also in the combination of Metalaxyl and Mancozeb in the B_1 variant where the percentage of the infection was (8.56%). An average efficacy has been shown in the preparations of Azoxystrobin and Mancozeb in the B_2 variant (9.63%). Whereas, less efficient were the combinations of Metalaxyl and Copper used in the B_3 variant (13.03%), then the B_4 variant (14.96%) where has been used the combination of Azoxystrobin and Copper, and also the B_6 variant with very low efficacy, the average percentage of infection was (17.33%) where the combination of Mancozeb and Copper has been used. In the controlling process, the average percentage of infection was in B_7 (30.16%).

In terms of resistance of the tomato cultivars against the blight pathogen, the cultivar Bella was more resistant compared with cultivar Amati based on the results obtained in the first year of the research. This sustainability can be seen in all combinations of chemical preparations including the control, where on cultivar Bella the percentage of infection was lower than in the cultivar Amati (Table 3).

Interpretation of results – 2021

The results obtained from the evaluation of tomato blight disease in 2021 reveal significant differences in the efficacy of chemical treatments and cultivar resistance. Specifically, in the Amati cultivar, the combination of Azoxystrobin and Metalaxyl (variant B_5) demonstrated the lowest average disease percentage (7.93%), indicating its high efficacy against the disease. Conversely, less efficient combinations were observed in variants B_2 to B_6, with varying degrees of infection ranging from 12.76% to 20.76%. In terms of cultivar resistance, Bella exhibited higher resistance compared to Amati, evident in consistently lower infection rates across all chemical combinations, as shown in Table 3.

Research conducted by Jung et al., [2016] yielded parallel trends regarding the efficacy of Azoxystrobin and Metalaxyl combinations against *Phytophthora infestans* in tomato crops. Similarly, Hansen et al., [2014] observed analogous levels of various tomato cultivars' effectiveness in blight management trials. These comparisons bolster the credibility of our findings and offer further affirmation of the effectiveness of specific chemical treatments and cultivar resistance traits elucidated in this study.

Results for the year 2022

During the evaluation of tomato fruit blight in 2022, it appears that from the seven variants used to cultivar Amati, in the B_5 variant, the average percentage of the disease was the lowest

Table 3. Percentage of blight infection (*Phytophthora infestans*) in tomato fruits during the year 2021

Cultivar	Chemicals factors	Evaluation of the disease factor (C)			x̄ (Mean)
Factor (A)	Factor (B)	C_1	C_2	C_3	
AMATI	B_1	9.10	12.00	10.10	10.40
	B_2	12.00	14.10	12.20	12.76
	B_3	15.90	18.30	15.80	16.66
	B_4	17.30	19.50	16.80	17.86
	B_5	6.20	9.10	8.50	7.93
	B_6	20.10	21.80	20.40	20.76
	B_7	28.10	35.00	40.00	34.36
BELLA	B_1	7.50	9.20	9.00	8.56
	B_2	9.10	10.60	9.20	9.63
	B_3	13.50	14.00	11.60	13.03
	B_4	15.00	16.10	13.80	14.96
	B_5	5.00	6.10	5.30	5.46
	B_6	17.10	18.90	16.00	17.33
	B_7	25.00	29.50	36.00	30.16

Note: factors B_1 to B_7 are variants of cultivars, and factors C_1, C_2, and C_3 presented the evolution of disease and x is the present average percentage of infection.

(5.30%) where the preparations of Azoxystrobin and Metalaxyl. Therefore, these fungicides have shown very high efficacy against the pathogen (fruit blight). Then, regarding the efficiency, after variants B_5, it is ranked the combination of Metalaxyl and Mancozeb in the B_1 variant with a percentage of infection (7.03%). The third combination is between Azoxystrobin and Mancozeb in the B_2 variant with a percentage of infection (8.43%). Meanwhile, less efficient were the combinations of Metalaxyl and Copper in the B_3 variant with a percentage of infection (12.73%), then the B_4 variant (15.43%), where the combination of Azoxystrobin and Copper was used, and also the B_6 variant (17.36%) where Mancozeb and Copper were used as a combination. While in the controlling process, the average infection was in the B_7 variant (31.06%).

Whereas, in Bella cultivar, higher efficiency against the disease has been on the B_5 variant, where, the average infection was in Azoxystobin and Metalaxyl combination (4.43%). High efficiency was also shown in the combination of Metalaxyl and Mancozeb in the B_1 variant (6.30%). As for the average efficiency, were shown more the fungicides Azoxystrobin and Mancozeb in the B_2 variant (77.30%). Then, comes the B_3 variant (10.76%) with the combination of Metalaxyl and Copper, the B_4 comes next, (13.23%) where the combination of Azoxystrobin and Copper was used, and the last was the B_6 variant with a percentage of infection (15.06%) and a combination of Mancozeb and Copper. In the controlling process, the average percentage of infection has been in B_7 (26.63%).

Regarding the sustainability of cultivars to the pathogen of blight, in the second year of research, cultivar Bella has shown higher sustainability compared to cultivar Amati. This sustainability is obvious in all the combinations used to fight blight and in the controlling of infection, where the percentage of infection was lower on the Bella cultivar. The sustainability of the Bella cultivar is a result of the vegetative mass that is lower than in the Amati cultivar. As a result of the lower percentage of vegetation on Bella cultivar, moisture in the fruits stays for a shorter time and in this way, light infection is avoided (Table 4).

Interpretation of results – 2022

The results of the 2022 assessment of tomato fruit blight indicate that among the seven variants tested on the Amati cultivar, the B_5 variant showed the lowest average disease percentage (5.30%) when treated with a combination of Azoxystrobin and Metalaxyl, demonstrating high efficacy against the pathogen. Following this, the combination of Metalaxyl and Mancozeb in the B_1 variant exhibited notable efficiency with a 7.03% infection rate. In the B_2 variant, the combination of Azoxystrobin and Mancozeb displayed

Table 4. Percentage of blight infection (*Phytophthora infestans*) in tomato fruits during the year 2022

Cultivar	Chemicals factors	Evaluation of the disease factor (C)			$\bar{x}$ (Mean)
Factor (A)	Factor (B)	C_1	C_2	C_3	
AMATI	B_1	7.10	8.00	6.00	7.03
	B_2	8.00	9.10	8.20	8.43
	B_3	14.10	15.00	9.10	12.73
	B_4	15.00	16.20	15.10	15.43
	B_5	5.00	6.10	4.80	5.30
	B_6	17.20	18.10	16.80	17.36
	B_7	25.60	31.90	35.70	31.06
BELLA	B_1	5.10	7.20	6.60	6.30
	B_2	7.30	8.00	6.80	7.30
	B_3	11.00	12.00	9.30	10.76
	B_4	14.00	13.80	11.90	13.23
	B_5	4.10	5.20	4.00	4.43
	B_6	16.30	15.10	13.80	15.06
	B_7	21.80	28.00	30.10	26.63

Note: factors B_1 to B_7 are variants of cultivars, and factors C_1, C_2, and C_3 presented the evolution of disease and the x is the present average percentage of infection.

average efficiency (8.43%). Conversely, less effective combinations included Metalaxyl and Copper in the B_3 variant (12.73%), Azoxystrobin and Copper in the B_4 variant (15.43%), and Mancozeb and Copper in the B_6 variant (17.36%). The average infection rate during the control process was highest in the B_7 variant at 31.06%.

In contrast, in the Bella cultivar, the highest efficiency against the disease was observed in the B_5 variant, where the combination of Azoxystrobin and Metalaxyl resulted in an average infection rate of 4.43%. The combination of Metalaxyl and Mancozeb in the B_1 variant also demonstrated high efficiency (6.30%). Additionally, the fungicides Azoxystrobin and Mancozeb in the B_2 variant displayed average efficiency (7.30%). The least effective combinations were Metalaxyl and Copper in the B_3 variant (10.76%), Azoxystrobin and Copper in the B_4 variant (13.23%), and Mancozeb and Copper in the B_6 variant (15.06%). The average infection rate during the control process was lower in the Bella cultivar, with the B_7 variant at 26.63%.

Comparing these results with existing studies, Ndala et al. [2019] reported similar efficacy trends of chemical combinations against *Phytophthora infestans* in tomato crops. Additionally, the resistance traits observed in the cultivars align with findings by Belkhiter et al. [2023], emphasizing the consistency of our results with previous research and underscoring the effectiveness of specific chemical treatments and cultivar resistance traits highlighted in this study.

DISCUSSION

In our study, we observed similar disease reduction trends in both tomato varieties, Amati and Bella, when treated with the same combinations of chemicals. However, there were variations in the degree of reduction, indicating that while the chemical composition plays a significant role, the genetic characteristics of the tomato varieties also contribute to their resistance to *Phytophthora infestans*. The regarding the importance of chemical composition in reducing morbidity is supported by the consistent efficacy demonstrated by certain combinations, such as Azoxystrobin and Metalaxyl, across both varieties. While genetics influence the baseline resistance of tomato plants.

The findings from this study offer valuable insights into the management of fruit blight in tomato crops and the resilience of different cultivars to the pathogen *Phytophthora infestans*. Fruit blight, caused by this devastating pathogen, poses a significant threat to tomato production worldwide, leading to substantial yield losses and economic repercussions for farmers. Therefore, understanding effective strategies for blight management and identifying resilient cultivars is crucial for sustainable tomato cultivation.

One of the key highlights of this study is the efficacy of various chemical combinations in protecting tomatoes against fruit blight. Over the two-year period, the combination of Azoxystrobin and Metalaxyl consistently demonstrated superior efficacy in mitigating disease incidence and severity [Sangeetha et al., 2021; Leesutthiphonchai et al., 2018; Olanya et al., 2015]. This combination proved highly effective across different variants and cultivars, consistently yielding lower infection rates compared to other treatments [Seidl Johnson et al., 2015; Brus-Szkalej, 2019; Wang et al., 2020]. The robust performance of Azoxystrobin and Metalaxyl underscores its potential as a reliable treatment option for blight management in tomato crops. Moreover, the study sheds light on the sustainability of different tomato cultivars *to Phytophthora infestans*. Cultivar Bella exhibited higher resistance to the pathogen compared to cultivar Amati, as evidenced by consistently lower infection rates across all chemical combinations and control groups [Montes et al., 2016; Chen et al., 2018; Pánek et al., 2022]. This cultivar resilience is attributed to factors such as genetic traits, physiological characteristics, and possibly environmental factors, which contribute to reduced susceptibility to disease [Maridueña-Zavala et al., 2017; Wang et al., 2021].

These findings have significant implications for tomato growers and agricultural stakeholders. By identifying effective chemical treatments and resilient cultivars, farmers can implement targeted strategies to mitigate the impact of fruit blight and safeguard tomato yields. Additionally, the insights gained from this study can inform breeding programs aimed at developing blight-resistant tomato cultivars, ultimately enhancing the sustainability and resilience of tomato production systems [Pirondi et al., 2017; Jansen et al., 2017; Keller et al., 2018]. Overall, this study contributes valuable knowledge to the field of plant pathology and agricultural science, offering practical solutions for managing fruit blight in tomato crops and enhancing the sustainability of tomato cultivation in the face of *Phytophthora infestans*.

CONCLUSIONS

In conclusion, this research aimed to evaluate the efficacy of chemical preparations and the resistance of tomato cultivars against *Phytophthora infestans*-induced fruit blight, with the overarching goal of enhancing tomato crop protection and sustainability. Over the course of two years, comprehensive experimentation and analysis were conducted, revealing valuable insights into effective blight management strategies and cultivar resilience.

The results consistently demonstrated that the combination of Azoxystrobin and Metalaxyl exhibited the highest efficacy in protecting both Amati and Bella cultivars against *Phytophthora infestans*. In 2021, this variant recorded percentages of 7.93% for Amati and 5.46% for Bella, while in 2022, the percentages were 5.30% and 4.43%, respectively. The B_1 variant, featuring Metalaxyl and Mancozeb, also displayed notable effectiveness in both years. The cultivar Bella exhibited higher sustainability against the blight pathogen compared to Amati, evident in lower infection rates across all combinations and control groups. Notably, the smaller vegetative mass of Bella contributed to reduced moisture retention, thus minimizing infection risks. Across both years, the B_7 variant (control) consistently had the highest average percentage of infection, highlighting the necessity of fungicide application for effective blight management.

These findings have significant implications for tomato growers and agricultural stakeholders, offering practical solutions for mitigating the impact of fruit blight and safeguarding tomato yields. By identifying effective chemical treatments and resilient cultivars, farmers can implement targeted strategies to enhance the sustainability and resilience of tomato production systems.

Overall, this research contributes valuable knowledge to the field of plant pathology and agricultural science, providing actionable insights for developing sustainable practices for tomato crop protection. The findings emphasize the importance of continued research and innovation in blight management strategies to ensure the long-term viability of tomato cultivation in the face of evolving pathogenic threats.

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