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RESEARCH ARTICLE

Evaluating the Efficacy of Fungicides for Controlling Late Blight in Tomatoes Induced by *Phytophthora infestans*

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ABSTRACT

Tomato (*Solanum lycopersicum* L.), is an important crop in tropical and subtropical regions, but it is highly susceptible to biotic stresses, particularly late blight caused by *Phytophthora infestans.* This fungus disease can lead to sudden outbreaks, resulting in severe crop losses. Chemical control remains a vital strategy for managing such outbreak. This study evaluated the effectiveness of 20 different fungicides, sprayed at recommended doses, for controlling late blight tomato and improving tomato production. A susceptible tomato variety, Nagina, was grown under randomized complete block design (RCBD) *in vivo.* Based on the percentage of disease infections produced on tomato plants and statistical analysis results, the results found that Chlorostrobin (13.62%), Cabrio Top (14.91%), Curzate M (15.38%), Ridomil Gold (16.77%), Jalva (17.13%), Nanok (19.2%), and Antracol (19.34%) were the most effective fungicides against *P. İnfestans.* Other fungicides such as Co-pride (21.1%), Flumax (21.54%), Alliette (23.81%), Score (24.35%), Success 40 WSP (25.13%), and Melody Due (28.82%) also exhibited effective results. However, fungicides like Rally (32.23%), Cytrol (34.28%), Thrill (37.46%), Evito (37.52%), Shincar (43.63%), Topas (45.83%), and Tilt (48.59%) were less effective in controlling the disease. These findings highlight the importance of using Chlorostrobin, Cabrio Top, Curzate M, Ridomil Gold, Jalva, Nanok, and Antracol are highly effective fungicides to combat late blight. This targeted approach ensures that fungicides are applied when they are most effective at preventing disease outbreaks, reducing overall fungicides use and costs.

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1. Introduction

The increasing frequency and intensity of plant disease outbreaks present significant and escalating threats to primary productivity, global food security, and biodiversity, particularly in vulnerable regions (Mubeen et al., 2024; Nauman et al., 2023). These outbreaks result in considerable losses, with pathogens and pests alone causing as estimated annual crop loss of US$220 billion globally. This directly affects food security, economic stability, and a range of interconnected socio-economic factors significantly affecting both regional economies and global markets (Ali et al., 2020; Anwaar et al., 2022; Azeem et al., 2020; Iftikhar et al., 2024; Rehman et al., 2023).

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Pakistan is recognized for its favourable agro-climatic conditions, which support the robust cultivation of various of various fruits and vegetables. The country's total vegetable production has reached approximately 7.07 million tonnes, contributing to the overall agriculture output of 13.764 million tonnes (Abbas et al., 2023; Ahmad et al., 2021; Naqvi et al., 2024). The primary vegetables cultivated in the country are as tomato (*Solanum lycopersicum* L.), potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.), chilies (*Capsicum* spp.), turnip (*Brassica rapa* L.), okra (*Abelmoschus esculentus* L.), carrot (*Daucus carota* L.), cauliflower (*Brassica oleracea* var. *botrytis*), peas (*Pisum sativum* L.), tinda (*Praecitrullus fistulosus*) gourd, collectively occupying 78% of the total vegetable acreage and contributing 81% of the overall production. Its adaptability to both tropical and subtropical climates, coupled with its status as a key organic vegetable, underscores its role in sustainable agricultural practices in the region Tomatoes are a nutrient-rich source of essential vitamins, minerals, and dietary fibre, contributing to a well-balanced diet. They are particularly valued for their high concentration of lycopene content, a carotenoid recognized for its potent antioxidant activity, which has been extensively studies for its role in reducing the risk of various chronic diseases including cardiovascular disease and certain cancers. Interestingly, the bioavailability of the lycopene is significantly increased through thermal processing, such as during production of tomato juice or puree, enhancing its absorption and efficacy in the human body. This increased bioavailability likely explains why more than 80% of global tomato consumption occur in processed forms. In addition to lycopene, tomatoes are rich in other antioxidants, including vitamin C, beta-carotene, and phenolic compounds, which may act synergistically to provide a broad spectrum of health benefits by reducing oxidative stress and inflammations (Helyes & Lugasi, 2006).

Late blight, caused by the oomycete *Phytophthora infestans*, is a highly destructive pathogen affecting both tomatoes and potatoes. Its origins are traced to the Andes Mountains, with its global spread facilitated by cool, humid environments. The co-evolutionary relationship between the host plants and the pathogen, hypothesized in 19th century following the Irish potato famine of 1845-46 (De Bary, 1876; Ghorbani et al., 2004) has been confirmed by modern genetic analyses, including isozyme profiling, DNA sequencing, and pathogenicity comparisons. These studies have revealed striking genetic similarities among *P. infestans* isolates from Peruvian, U.S., and Europe (Foolad et al., 2008; Nowicki et al., 2012; Vleeshouwers et al., 2011) supporting the hypothesis of a common evolutionary origin. On tomatoes, the disease was first reported in France by Payen in 1847, and it is now known to infect all parts of the tomato plant, including leaves, stems, fruits, and seeds, leading to substantial crop losses (Reeves et al., 2023; Vincent et al., 2023). Symptoms typically begin as water-soaked lesions on the leaves, which can rapidly progress to blight and death of the entire plant within days. In the presence of moist weather, a whitish growth forms on the margins of the lesions on the underside of the leaf.

Once an unprotected crop (field, greenhouse, and/or plastic-cover cultures) is infected by *P. infestans*, the whole crop can be devastated within seven to ten days (Foolad et al., 2008). Economic losses may be in the form of reduced yield, lower quality of the fruit (such as low specific gravity), diminished storability, and increased cost associated with fungicide applications (Nowicki et al., 2012).

Different management strategies are adopted by the various researchers and farmers towards late blight of tomato and the most economical and environment friendly is the use of resistant varieties (Kanwal et al., 2024). Late blight of tomato disease can also be managed through the application of biocontrol agents and crop rotation. However, farmers need quick action in case of severe infection or the emergence of epidemics, and quick action can be acquired through the use of fungicides. Integrated Pest Management (IPM) suggests the application of fungicides after the appearance of typical disease symptoms (Mazumdar et al., 2021). Spraying fungicides at seven to ten days interval leads high crop quality and best average yield potential (Zhi et al., 2021).

This study aimed to evaluate the effectiveness of twenty fungicides available in Pakistan against *P. infestans* in field conditions to identify the most potent antifungal agent for managing late blight in tomatoes. The widespread application of fungicides in Pakistan necessitated a meticulous evaluation to identify the most efficacious fungicide for disease control, thereby optimizing resource allocation and minimizing financial burdens on farmers. The fungicides tested included Cholorostobin, Score, Alliette, Success, Antracol, Melody Due, Cytrol, Ridomil Gold, Curzate M, Rally, Cabrio Top, Co-Pride, Thrill, Evito, Shincar, Topas, Score, Flumax, Jalva, and Nanok, each applied as foliar sprays at recommended doses.

2. Materials and Methods

2.1. Study Design and Agronomic Practices

The study was conducted at the Vegetable Research Institute, AARI Faisalabad, Pakistan, during the 2017 growing season. The highly susceptible variety Nagina was used to evaluate the efficacy of twenty different fungicides (Table 1). The nursery was sown in October, and transplanting was completed in November. The seedlings were arranged in a randomized complete block design (RCBD) with three replications. Each treatment plot measured 1×10 m, with plant-to-plant spacing of 50 cm and row-to-row spacing of 60 cm. Conventional agronomic practices were followed throughout to maintain optimal crop conditions.

Table 1. List of used fungicides and their recommended dozes.

Fungicides	Formulations	Active Ingredients	Manufacturers	Recommended doses (per Liter)
Chlorostrobin	56 EC	Azoxystrobin Chlorothalonil	Sitara	5 mL
Cabrio Top	60 WDG	Pyraclostrobin Metiram	FMC	5 g
Curzate M	72 WP	Cymoxanil Mencozeb	Arysta	6 g
Ridomil Gold	68 WG	Metalaxyl-m, Mencozeb	Syngenta	3 g
Jalva	325 SC	Azoxystrobin Difenoconazole	Orange Protection	3 mL
Nanok	25 SC	Azoxystrobim Flutrifol	Swat Agro Chemicals	3 g
Antracol	70 WP	Propineb	Bayer	5 g
Co-pride	50 WP	Copper Oxychloride	FMC	10 g
Flumax	60 EC	Fluazinam Metalaxal-M	Evyol Group	2 mL
Alliette	80 WP	Fosetyl Aluminium	Bayer	3 g
Score	250 EC	Difenoconazole	Syngenta	2 mL
Success 40 WSP	72 WP	Chlorothalonil Metalaxyl	Arysta	3 g
Melody due	66.8 WP	Propineb, Iprovalicarb	Bayer	3 g
Rally	40 WSP	Myclobutanil	Dow AgroSciences	1 g
Cytrol	75 WP	Thiophanate Methyl Chlorothaloni	Sitara	5 g
Thrill	20 WP	Bismerthiazole	FMC	3 g
Evito	480 SC	Fluoxastrobin	Arysta	1 mL
Shincar	50 EC	Carbendazim	FMC	3 mL
Topas	100 EC	Penconazole	Syngenta	1 mL
Tilt	250 EC	Propiconazol	Syngenta	2 mL
Control	-	Distilled water	-	-

2.2. Disease Inoculation and Fungicide Application

Late blight disease was artificially induced using a 20 µl zoospore suspension of *Phytophthora infestans* cultured from infected leaves, following the method described by Pliakhnevich and Ivaniuk (2008). High humidity levels were maintained by regular water spraying to promote disease development. Fungicides were applied as foliar sprays (Sharma et al., 2011), after the onset of disease symptoms, with two applications administered at a seven-day interval using a battery-operated knapsack sprayer. The fungicides used included Chlorostobin, Score, Alliette, Success, Antracol, Melody Due, and others, at recommended doses.

2.3. Data Collection and Statistical Analysis

Disease incidence was recorded weekly for three intervals, beginning seven days after the fungicide treatments, using the following formula:

$$\text{Disease incidence (\%)} = (\text{Number of infected plants})/(\text{Total number of plants}) \times 100 \quad (1)$$

Statistical analysis was performed using Statistix 8.1 (Mitani et al., 2001), with graphical representation generated through Minitab 18. Pairwise comparisons were made using the Least Significant Difference (LSD) test at a 0.05 significance level to determine the effectiveness of the fungicides.

3. Results and Discussion

Pathogenicity tests confirmed symptoms consistent with late blight in tomatoes, as reported in the literature (Figure 1). The effectiveness of the tested fungicides varied significantly in controlling the late blight disease. Chlorostrobin was the most effective, reducing disease incidence to 13.62%, followed closely by Cabrio top (14.91%), Curzate M (15.38%), Ridomil Gold (16.77%), Jalva (17.13%), Nanok (19.2%), and Antracol (19.34%). These treatments demonstrated substantial reductions in disease prevalence compared to untreated plants.

Other fungicides such as Co-pride (21.1%), Flumax (21.54%), Alliette (23.81%), Score (24.35%), Success 40 WSP (25.13%), and Melody due (28.82%) showed moderate effectiveness but did not match the performance of the top-tier treatments. Despite reducing the incidence of late blight, their efficacy was comparatively lower.

In contrast, fungicides including Rally (32.23%), Cytrol (34.28%), Thrill (37.46%), Evito (37.52%), Shincar (43.63%), Topas (45.83%), and Tilt (48.59%), were far less effective. These treatments failed to sufficiently control the spread of the disease, with exhibited a significantly higher disease incidence at 68.31% (Figure 2, Table 2). The limited effectiveness of these fungicides suggests their reduced capacity to mitigate fungal infestation, further underscoring the superior performance of the top-performing fungicides.

Figure 1. Healthy tomato plants (A), late blight diseased tomato plants in the field (B).

The fungicides Chlorostrobin, Cabrio Top, and Curzate M showed the highest efficacy with the lowest disease incidences, making them ideal candidates for controlling late blight (Table 2). In contrast, fungicides like Rally, Cytrol, and Tilt exhibited lower efficacy, with significantly higher disease incidences. This highlights the critical importance of selecting the most effective fungicides, particularly those with a disease incidence below 20%, to ensure optimal late blight management in tomatoes.

Table 2. Correlation based on disease incidence and the efficacy of each fungicide.

Fungicide	Disease Incidence (%)	Rank
Chlorostrobin	13.62	1
Cabrio Top	14.91	2
Curzate M	15.38	3
Ridomil Gold	16.77	4
Jalva	17.13	5
Nanok	19.20	6
Antracol	19.34	7
Co-pride	21.10	8
Flumax	21.54	9
Alliette	23.81	10
Score	24.35	11
Success 40 WSP	25.13	12
Melody Due	28.82	13
Rally	32.23	14
Cytrol	34.28	15
Thrill	37.46	16
Evito	37.52	17
Shincar	43.63	18
Topas	45.83	19
Tilt	48.59	20

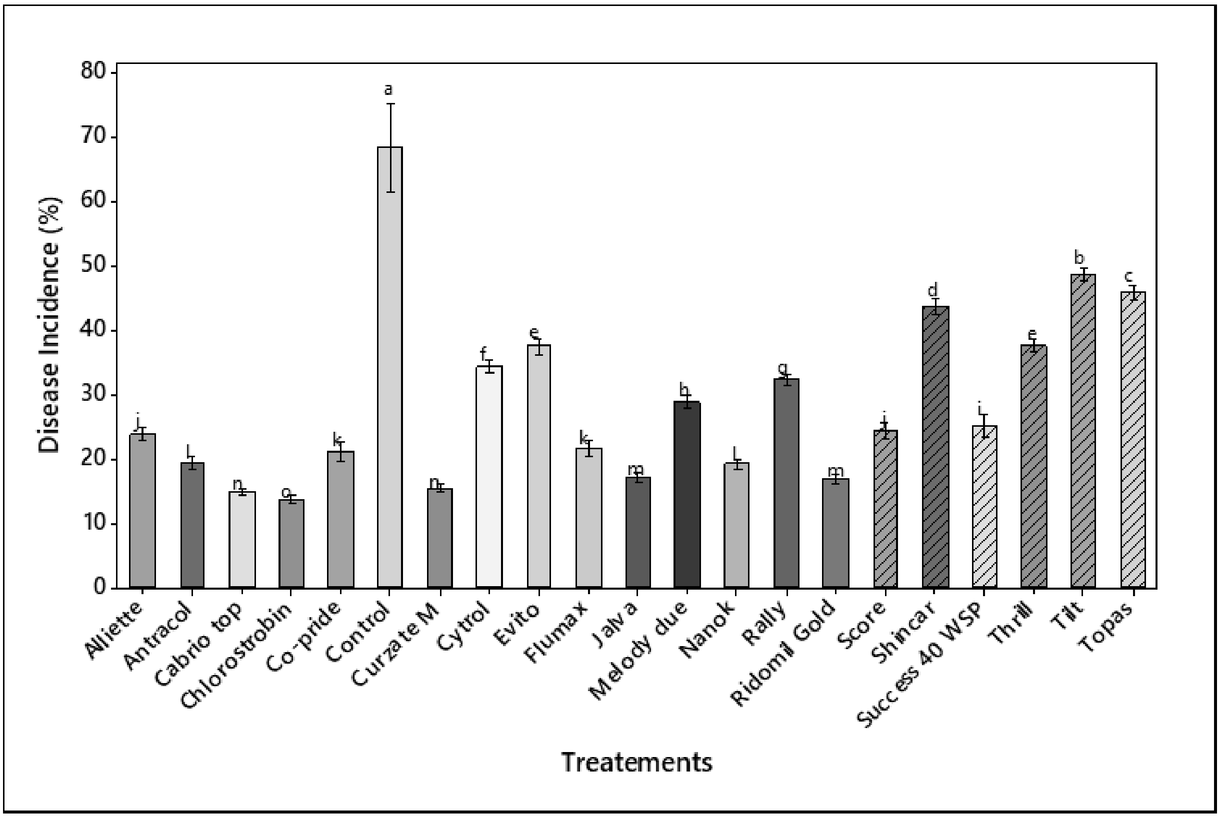

Figure 2. Fungicides’ potential in mitigating the incidence of late blight of tomato.

Tomato a widely cultivated vegetable crop in tropical and subtropical regions, faces various biotic and abiotic challenges, particularly from fungal, bacterial, and viral pathogens, as well as several insect pests. Major fungal diseases of tomatoes include early blight, late blight, botrytis blight, alonf with widespread viral diseases include tomato leaf curl virus pathogen. All of these diseases reduce the tomato fruit size and leave it unmarketable. The best approach to control these diseases by use of effective fungicides.

Previous research by Peerzada et al. (2020) aligns with our findings, demonstrating the positive impact of fungicide application on controlling late blight. Their observations support the notion that fungicides effectively inhibit spore germination, sporulation, and intercellular mycelial growth of the late blight pathogen. This study further highlights a significant correlation: untreated control plots displayed higher AUDPC values, indicating a more rapid spread of the disease. Conversely, fungicide application significantly reduced AUDPC values, primarily by hindering spore germination and sporulation, which are crucial factors in the disease's progression. The severity of late blight directly translates to yield losses. These losses were quantified by measuring the yield difference between fungicide-treated and untreated plots. Notably, plants treated with systemic fungicides, particularly those receiving foliar sprays of Curzate, produced the highest tuber yield. In contrast, untreated control plots exhibited the lowest tuber yield (11.40 t/ha) alongside higher levels of defoliation at season's end and elevated AUDPC values. This observed variation in tuber yield across different treatments can be primarily attributed to the differing severities of late blight experienced in each treatment group.

Corroborating our findings, Neupane et al. (2018) investigated the efficacy of various active ingredients against late blight in tomato plants. Their study encompassed a broad spectrum of fungicides, including dimethomorph, cymoxanil, azoxystrobin, famoxadone, chlorothalonil, fenamidone, fosetyl-AL, cupric oxychloride, and cupric hydroxide, as well as several commercially available products. Notably, all tested fungicides with the exception of azoxystrobin (Quadris) demonstrated suppressive effects on late blight development. This aligns with previous research suggesting the effectiveness of contact fungicide applications applied towards the end of August in providing robust protection for both leaves and fruit throughout the growing season until harvest (Alexandrov, 2011; Mugao et al., 2020).

Our study aligns with the observations of Töfoli et al. (2014), who reported enhanced efficacy of fungicide combinations against potato blight under specific precipitation regimes. Their findings demonstrate that mefenoxam + mancozeb, mefenoxam + chlorothalonil, dimethomorph + ametoctradin, dimethomorph + chlorothalonil, propamocarb, fenamidone + propamocarb, benthiavalicarb + fuazinam, mandipropamid, mandipropamid + chlorothalonil, ametoctradin + metiram, cyazofamid, cymoxanil + zoxamide, and cymoxanil + famoxadone exhibited superior blight control when the initial rainfall event occurred 30 minutes after application, followed by progressively increasing simulated rain. Conversely, the activity of dimethomorph + mancozeb, fuopicolide + propamocarb, pyraclostrobin + metiram, fuazinam, chlorothalonil, and mancozeb NT was demonstrably diminished up to the 1-hour post-application interval (HAA). Notably, blight control by fenamidone treatments displayed a significant decline that extending up to the 2-hour HAA interval.

A growing body of research has investigated the effectiveness of various fungicides in combating late blight disease, a destructive illness caused by the pathogen *P. infestans* and plaguing crops like potato and tomato. Vincent et al. (2023) identified Bonsoin as the most potent fungicide against tomato late blight in their study, advocating for its use to control the disease and bolster tomato production within Cameroon. Furthermore, Ben Naim and Cohen (2023) observed that two applications of Zorvec Endavia yielded significantly superior late blight control compared to six applications of Ranman or four applications of Revus. These findings suggest these fungicides as potential alternatives to Mancozeb, offering the possibility of effective late blight management while reducing the risk of *P. infestans* developing resistance to mandipropamid and oxathiapiprolin.

Although my current research involves the use of fungicides to control plant infections, it is recommended that future strategies focus on prioritizing the utilization of biocontrol agents and the development of crop types that are more resistant to pathogens. Sometimes, the beneficial microorganisms and natural predators, known as biocontrol agents, provide a sustainable and ecologically sound substitute for synthetic fungicides (Ali et al., 2024a, 2024b). In addition, the process of breeding and genetically modifying crops to have improved resistance against infections might greatly decrease the need for chemical treatments (Ali et al., 2024c; Baloch et al., 2023). By implementing these strategies, the adverse environmental effects of fungicides can be reduced, biodiversity can be promoted, and long-term agricultural sustainability and food security can be ensured. It will be essential to prioritize the implementation of integrated pest management solutions for effective disease control in the future.

4. Conclusion

The results revealed Chlorostrobin, Cabrio top, Curzate M, Ridomil Gold, Jalva, Nanok, and Antracol as the most effective fungicides in field situations against *P. infestans*. Co-pride, Flumax, Alliette, Score, Success 40 WSP, and Melody Due were also found effective. On the other hand, Rally, Cytrol, Thrill, Evito, Shincar, Topas and Tilt were found less effective.

The on-time pervasive application of the most effective fungicide optimizes resource utilization and mitigates financial strains on farmers by minimizing the need for multiple fungicide applications throughout the growing season. Based on the current research, a fungicide program utilizing Chlorostrobin, Cabrio top, followed by sequential applications of Curzate M, Ridomil Gold, Jalva, Nanok, and Antracol is recommended for combating late blight in tomatoes and a range of other fungal diseases.

Conflict of Interest

The authors declare that they have no conflict of interest.

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