ISSN 2709–3662 (Print)
ISSN 2709–3670 (Online)
https://doi.org/10.52587/JAF050101
Journal of Agriculture and Food
2024, Volume 5, No.1, pp. 1-15

Integrated pest management strategies for controlling potato late blight and enhancing crop and yield

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Abstract

One of the most popular non-grain crops worldwide is the potato. Pests and diseases, however, cause a 17% reduction in global production. After rice, wheat, and maize, potatoes (*Solanum tuberosum* L.) are the fourth most significant crop in the world. The Irish famine of the 1840s was brought on by the illness known as potato late blight, which is still the most detrimental to potato output worldwide and is brought on by the oomycete pathogen Phytophthora infestans. This study used a randomized complete block design during the 2022 growing season at the National Agriculture Research Center (NARC), Islamabad, to effectively control *Phytophthora infestans* and increase Potato productivity. The inquiry covered a variety of treatments, such as conventional methods, chemical insecticides, biological agents, and a combined strategy. The selected Potato variety, Kuroda, was subjected to careful plot design and management. Sesame crop rotation dramatically decreased the incidence of *Phytophthora infestans* (42%, severity 2.2). When using chemical pesticides, *late blight* disease incidence was reduced to 59% and severity to 2.9, demonstrating a reasonable level of effectiveness. The incidence of the disease

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(34%) and its severity (1.4) significantly decreased after *Trichoderma harzianum* or Bacillus spp were introduced as a biological agent. Impressively, the combined strategy that included Trichoderma harzianum and Fungazil produced outstanding results with disease incidence at 26% and severity at 1.1. The yield of crops had been impacted in significant ways. The study emphasizes the value of integrated approaches to controlling potato late blight, including methods to increase crop output through chemical, biological, and cultural means. However, difficulties brought on by the condition hinder optimal light intensity and yield. These results indicate the combined strength of chemical and biological agents and emphasize the effectiveness of integrated disease control systems.

Keywords: Potato late blight, Phytophthora infestans, Integrated pest management (IPM), Crop yield enhancement, Biological and chemical control

Article History: **Received:** 30th July, 2024; Revised: 13th August, 2024; Accepted: 12th October, 2024

Introduction

Potato (*Solanum tuberosum* L.) holds the position of the fourth significant crop globally, trailing only behind rice, wheat, and maize Prabha et al. (2018). The potato has a competitive advantage over other major food crops because of its intrinsic qualities. In fact, compared to cereals and some leguminous plants, like soybeans, it has the potential to generate higher levels of protein and carbs per unit area Furrer et al. (2018). The oomycete plant pathogen *Phytophthora infestans* is responsible for the devastating global disease known as potato *late blight* (PLB). According to Bourke, (1964) Savary et al. (2017), this condition was a major contributing factor in the tragic Irish Potato Famine of 1845–1852. This disease spread to practically all major potato-producing countries, including the United States, Canada, China, and India, after having its origins in Central Mexico or South America Fry et al. (2015, 2016). PLB continues to be the principal obstacle to potato cultivation globally, posing a serious threat to the world's food security. This has an especially negative effect on less developed areas where potatoes are a major source of food Pennisi, (2010) Andersson et al. (2015).

Potato farming is severely hampered by the widespread problem of late blight, which is predominantly caused by *Phytophthora* infestans (Mont) de Bary, both in Ethiopia Jimma, (2018) and in many other parts of the world Goutam et al. (2018). Among all potato diseases, it continues to be the most widely known and thoroughly investigated, maintaining its position as the most destructive. According to Chowdappa et al. (2015), *late blight* has the distinction of possibly being the worst disease to ever strike both potatoes and Potatoes worldwide. Considering anticipated annual losses reaching $5 billion, *late blight* has a significant economic impact and is now considered a threat to global food security Newbery et al. (2016). According to Haderkort et al. (2016), *late blight* is responsible for the destruction that resulted in the historic Irish potato famine of the 1840s. Depending on the potato variety used, yield decreases of between 31% and 100% have been observed in Ethiopia. The effective management of *late blight* in the Sub-Saharan Region was significantly aided using phenyl amide fungicides, such as Ridomil Tsedaley, (2014) Subhani, (2014).

Integrated Pest Management (IPM) is a comprehensive approach to pest control that emphasizes prevention, monitoring, and sustainable management techniques to reduce pest damage while reducing reliance on chemical pesticides (Ragunathan & Divakar, 2020). By combining multiple strategies, IPM promotes crop health and productivity while minimizing environmental impacts. IPM includes strategies such as cultural control, biological control, and mechanical methods, with chemical pesticides used as a last resort. By combining these approaches, IPM offers effective pest management solutions tailored to specific agricultural contexts, ultimately ensuring sustainable crop production (Baker et al., 2020).

The primary objective of integrated pest management (IPM), commonly referred to as integrated pest control (IPC), is to economically manage pests by reducing their populations to levels that are not harmful. IPM places an emphasis on safe techniques and natural pest management systems, lowering threats to the environment and public health Mitrev, (2017). IPM is more sustainable in agriculture than traditional approaches because it strikes a compromise between short-term effectiveness and long-term ecological impact. A thorough understanding of pest behavior is necessary for effective IPM implementation, allowing for precise interventions like scheduled pesticide administration and agronomic changes. While preserving crop productivity and quality, this focused method minimizes overall pest management expenses Tenkeu, (2019). This study stresses the standard method for treating Potato *Late Blight* while delving into the molecular details of *P. infestans*.

The strategy calls for a planned application of strong chemical pesticides, advanced forecasting tools, and the potential genetic modification of crop tolerance. The next stage of PLB pest management may be influenced by these combined techniques Majeed et al. (2014). Biocontrol agents play a crucial role in battling diseases in a variety of crops, particularly Plant Growth-Promoting Rhizobacteria (PGPR) like Bacillus subtilis and Plant Growth-Promoting Fungi (PGPF) like Trichoderma harzianum. According to Yedidia et al. (1999), Ahmed et al. (2000), and Compant et al. (2005), they cause systemic defense reactions in plants, including the production of defense-related proteins and enzymes. Fungicides, which are described as chemicals that inhibit growth, are essential for controlling late blight. They successfully target the pathogenic organism's zoosporangia, zoospores, and mycelium, slowing its growth Majeed et al. (2014). The cultivation of potato cultivars resistant to *late blight* presents a workable defense approach in conjunction with fungicidal methods, while achieving complete resistance is still a difficult task (Song et al., 2003). Crop rotation, or the successive cultivation of different crops, broadens the range of pest management strategies. The potential yield is increased by using allelochemicals to control weeds, diseases, and pests Mamolos et al. (2001) Narwal, (2000), Peters et al. (2003).

In summary, this study explores PLB management by chemical and biocontrol agents, and strategic crop rotation, providing insights for upcoming integrated pest management strategies Voll et al. (2004) Sauerborn et al. (2000). The effectiveness of combination chemical and biological techniques is examined in this study on integrated disease control for Phytophthora infestans in Potatoes, highlighting the potential for increased crop health and productivity.

Materials and Methods

Experimental Design

During the 2022 growing season, the field experiment was carried out at the National Agriculture Research Center, which is located at Latitude: 33.6649° N, Longitude: 73.0662° E. A randomized complete Treatment design (RCBD) was used to provide correct randomization and control for potential spatial differences. A total of 20 experimental units were created by establishing 5 Treatments, each Treatment including 4 replicates of each treatment. This layout made it possible to do thorough statistical analysis and draw reliable findings about the effectiveness of IPM tactics for preventing Potato late blight. We thoughtfully assigned the following treatments to each Treatment to thoroughly assess the efficacy of IPM techniques for preventing Potato late blight: The T1 served as the control group and received no treatment; the T2 cultural practices for disease management; the T3 evaluated the use of chemical pesticides; T4 assessed the use of biological agents; and the T5 investigated a combined approach involving both chemical pesticides and biochemical agent. These treatments were selected to evaluate different methods of controlling potato late blight. T1 was the control group, T2 tested cultural methods, T3 used chemical pesticides, T4 used biological agents, and T5 combined chemical and biological methods. They were selected to compare their effectiveness in disease prevention.

Plant Spacing: The ideal plant-to-plant spacing for this crop is 6 to 8 inches within rows, 18 to 28 inches between rows. This arrangement allows for adequate air flow and sunlight penetration, which promotes optimal growth and reduces the risk of disease. Closer spacing within rows ensures efficient use of space and maximizes yield, while wider spacing between rows allows for easier access to cultivation, irrigation, and pest management practices. Overall, this spacing scheme strikes a balance between plant density and field management considerations, contributing to successful crop production.

Selection of Potato Cultivars: Selection of Kuroda potato cultivars can be based on various factors, including resistance to late blight, yield potential, adaptability to local growing conditions, market demand, and agronomic characteristics such as that tuber size, shape, and cooking characteristics.

Timing of fungicide application relative to disease development stage: The timing of fungicide application relative to disease development stage depends on a variety of factors, including the specific disease targeted, the fungicide's mode of action, and environmental conditions and the biology of the pathogen. In general, applying fungicides at an optimal time relative to disease development stages can maximize efficacy and reduce the risk of resistance development. This may include using fungicides as a treatment before disease symptoms appear or after symptoms are detected but before they become severe.

Potato Cultivar and Plot Preparation

Kuroda was chosen as the Potato cultivar for this study because of its vulnerability to *late blight* (*Phytophthora infestans*). The experimental site, which had a total area of 5 marla (about 1361.25 square feet), was prepared using standard agricultural practices, such as harrowing, leveling, and plowing. For accurate assessment, a distinct plot of one marla was allocated to each single treatment. Prepare well-drained soil, make furrows or ridges, and plant seed potatoes at a 30-35 cm spacing at a depth of 10-15 cm in Pakistan. The suggested seed rate is between 750 and 1000 kg for 1 acre (about 0.4 hectares), ensuring the best plant density and yield potential.

Cultural Control

To influence the environment and lower the risk of illness onset and spread, cultural control techniques have been used. Sesame was planted in the preceding growing season as part of crop rotation, a well-accepted cultural practice for disease management. Each of the 5 rotation Treatments that made up the experimental area had 4 replicas. Proper plant spacing and sanitation were upheld to further improve disease suppression. To allow adequate sunlight, airflow, and access for maintenance and harvesting. In Pakistan, prepare well-drained soil, develop ridges or furrows, then plant seed potatoes at a spacing of 30-35 cm and a depth of 10-15 cm. This improves air circulation and lowers humidity around the leaves. Weeds and plant debris from fallen trees were quickly taken out to avoid creating potential inoculums sources.

Biological Control

The effectiveness of biological control agents against P. infestans was assessed. The chosen agents were from the Ayub Agriculture Research Institute and included Trichoderma harzianum or Bacillus spp. A. Through laboratory tests, the viability and purity of the biological control agents were verified before application. Beginning two weeks after transplanting the Potato plants, 10-day intervals of biological control treatments were given. It is advised to employ Trichoderma harzianum at a concentration of roughly 1 × 10^7 colony-forming units (CFUs) per milliliter. Trichoderma harzianum and Bacillus spp should be diluted with water to the required concentration before being added to the solution. Applying the treatment with a handheld sprayer will provide complete and even coverage of the entire plant canopy.

Chemical Control

A selection of fungicides known to have activity against *late blight* was included in the study. The fungicides used were Fungazil, obtained from Ayub Agriculture Research Institute. Fungicide treatments were applied according to the recommended application schedule provided by the manufacturer. Care was taken to adhere to label instructions and appropriate safety measures during application.

Application Method

Apply 10 grams of fungazil for every marla. 10 grams of Fungazil should be dissolved in 1 liter of water. Spray the mixture on the crop foliage evenly after thoroughly mixing it to ensure complete coverage. Apply as a preventative measure or in the early stages of an illness.

Data Record

Disease Assessment

Following the injection with the pathogen, periodic disease assessments were done. Plant material that had been infected with P. *infestans* was placed into the experimental area as the first inoculums. Using a standardized disease severity scale, disease incidence and severity were documented. To ensure unbiased and trustworthy data collection, each experimental unit was evaluated by qualified assessors who were unaware of the treatments they were evaluating.

Incidence data: The number of new cases of the disease within a certain time should be recorded for disease incidence (%). The incidence rate should then be calculated as a percentage of the population at risk.

Severity Scale: Create or decide on a disease-appropriate severity scale. This can be a uniform scale applied in the medical industry. Assign suitable scores after gathering severity information from patients or medical providers.

Yield: Collect data on Potato yield through choosing sources, a technique, collecting and recording data (including manual harvesting), analyzing results, and distributing information for informed decision-making.

Data Analysis

Using Statistix 8.1, the relevant statistical analyses were performed on the acquired data about disease incidence and severity. To find significant variations between treatments, a two-way analysis of variance (ANOVA) was carried out. At a significant threshold of = 0.05, the Least significant difference (LSD) test was used to separate the means.

Table1. Comparative analysis of treatment approaches on Potato crop, yield, and disease management:

Treatment	**Chemical/Biological Agent**	**Doses**
T1 Control no Treatment)	Control	Control
T2 (Cultural Practices)	Sesame crop rotation	Sesame
T3 (Chemical)	Fungicide (Fungazil)	10 grams
T4 Biological agent)	Bacillus spp. + Trichoderma harzianum (Biocontrol)	1 × 10^7 (CFUs) per milliliter.
T5 (Combine Approches)	Fungazil+Trichoderma harzianum	10 grams + 1 × 10^7 (CFUs) per milliliter

Table 2. Examination of soil physical and biochemical characteristics

Parameter	**Value**
Location	NARC Islamabad
Electrical Conductivity (EC)	0.22 dS m^-1
pH	8.26
Organic Matter	0.65%
Textural Class	Sandy Clay Loam
Bulk Density	1.45 g cm^-3
Available Phosphorus	6.71 mg kg^-1
Extractable Potassium	72.54 mg kg^-1
Total Nitrogen	0.031%

Results

In the current study, we investigated the effectiveness of various management strategies for disease incidence and severity in Potato crops. The therapies were divided into several chemical and biological agents as well as their mixtures. These therapies' effects on disease occurrence, illness severity, and crop yield were all carefully evaluated. The results offer useful information about practical methods for managing disease in Potato farming.

Table 3. Impact of treatment strategies with chemical and biological agents on disease incidence and severity in Potato crops

Treatment	**Chemical/Biological Agent**	**Disease Incidence (%)**	**Disease Severity (Scale)**
T1 Control no Treatment)	Control	83%	3.7
T2 (Cultural Practices)	Sesame crop rotation	42%	2.2
T3 (Chemical)	Fungicide (Fungazil)	59%	2.9
T4 Biological agent)	Bacillus spp. + Trichoderma harzianum (Biocontrol)	34%	1.4
T5 (Combine Approches)	Fungazil+Trichoderma harzianum	26%	1.1

The 83% *late blight* disease incidence rate was significantly higher in the untreated control group. A *late blight* disease severity score of 3.7 was obtained as a result, indicating a significant effect on the Potato crop. These findings highlight Potato plants' susceptibility to the prevalent disease *late blight* pressure in the absence of any interventions. When cultural techniques were used, especially crop rotation with sesame, the incidence of *late blight* disease decreased significantly and declined to 42%. Additionally, the disease *late blight* severity level reduced to 2.2, indicating the beneficial effects of crop rotation on *late blight* disease control in Potato crops. This strategy shows promise as a sustainable and environmentally responsible way to reduce the impact of disease. The use of fungicides like Fungazil, which are chemical pesticides, resulted in a slight reduction in *late blight* disease incidence, with the proportion declining to 59%. Additionally, the *late blight* disease severity scale decreased to 2.9, showing a marginal improvement in the management of the disease. Chemical pesticides do provide some amount of control, but it is important to consider their potential effects on the environment and sustainability.

Trichoderma harzianum and Bacillus spp, a biological agent, was initially employed as a biocontrol strategy with positive results. *Late blight* disease incidence was substantially reduced to 34%, and the *late blight* disease severity scale was significantly decreased to 1.4. This demonstrates that effective *late blight* disease management can be achieved with biocontrol agents while reducing the negative environmental consequences caused by chemical treatments. The combined method, which used the fungicide Fungazil as well as the biocontrol agent Trichoderma harzianum, produced the most outstanding results. Disease incidence fell to 26%, indicating a significant decrease in comparison to alternative treatments. The *late blight* disease severity index further reduced to an incredible 1.1, demonstrating the effectiveness of an integrated approach to managing disease in Potato crops.

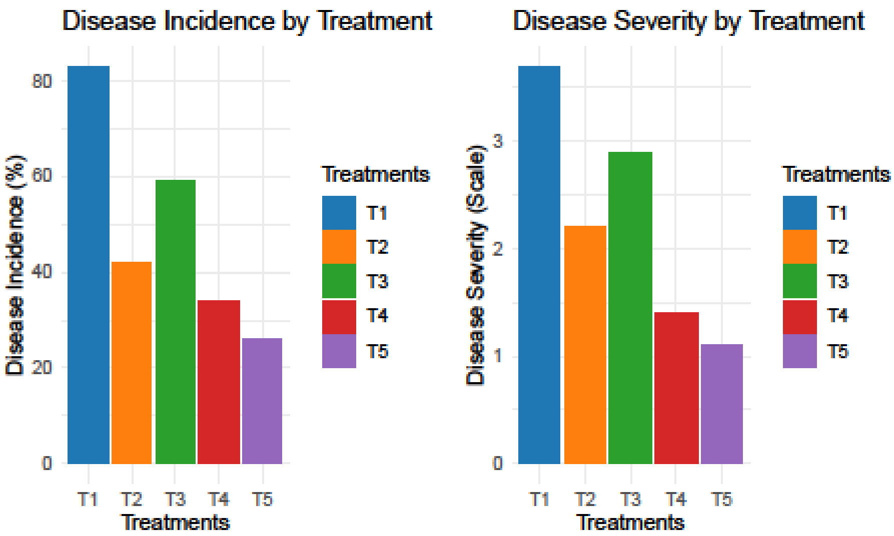

Figure 1. Effect of different treatments on disease Incidence and Severity in Potato crop: Disease control analysis.

Comparison of the effects of various treatments on disease prevalence (%) and severity scale. The graph illustrates how different treatments have different effects on the prevalence and severity of disease, suggesting alternative tactics for efficient disease management.

This study examined the effects of several treatment approaches on Potato crop yield and disease control, exposing their potential to raise productivity and defend off diseases. As a baseline, the control group without treatment produced 51.1 kg of yield per marla (Table 3). Sesame crop rotation increased yields to 63.2 kg per Marla, demonstrating its contribution to improving soil health and nutrient uptake. Due to its ability to control *late blight* disease, the application of 10 grams of fungazil per marla considerably increased yield to 67.2 kg per Marla. A yield of 60.3 kg per Marla was achieved using Trichoderma harzianum and Bacillus spp as a biocontrol, demonstrating increased plant health and *late blight* disease control. The effective 71.1 kg per Marla (Table 3) produced by the combined method indicated the beneficial relationship between chemical and biological agents. The integrated approach had the greatest promise for disease prevention and crop development, with beneficial contributions from individual agents and cultural practices as well. To achieve sustainable agriculture, food security, and resilient farming systems, it is possible to combine chemical, biological, and cultural approaches.

Table 3. Enhancing Potato crop yield through innovative treatment approaches with chemical and biological agents (kg marla^{-1})

Treatment	Chemical/Biological Agent	Yield (kg/marla)
Control (No Treatment)	None	51.1
Cultural Practices	Crop Rotation (Sesame)	63.2
Biological Agents	Trichoderma harzianum + Bacillus spp (Biocontrol)	60.3
Chemical Pesticides	Fungazil (Fungicide)	67.2
Combined Approach (Bio+ Chem)	Fungazil + Trichoderma harzianum	71.1

These results highlight the value of interdisciplinary approaches to disease management. The combination uses of chemical and biological treatments produced better results than either method alone, successfully lowering *late blight* disease incidence and severity while also increasing Potato crop output. Such a thorough strategy has a lot of potential for sustainable Potato farming methods. The findings of this study add to the body of information on efficient disease management techniques and offer useful advice for agricultural experts seeking to improve the health and productivity of Potato crops.

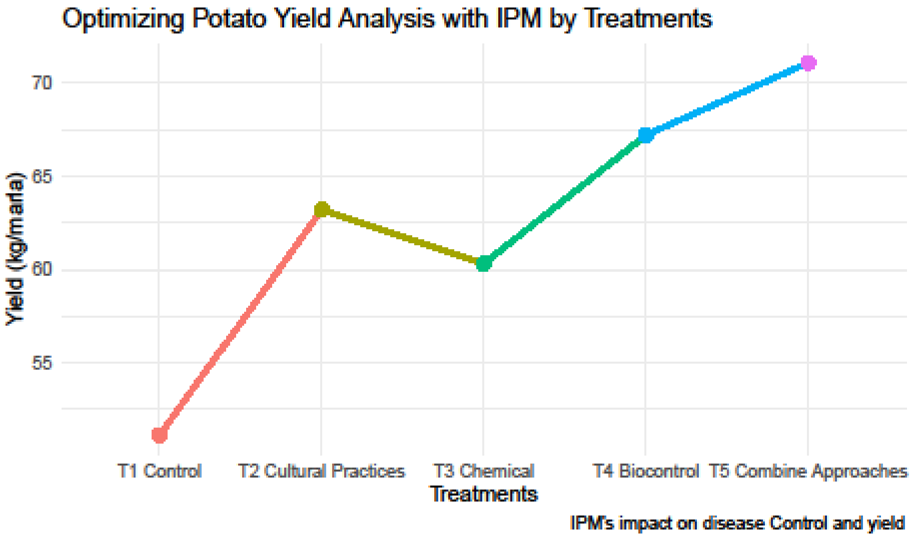

Figure 2. IPM techniques for enhanced Potato Crop Yield: Disease control analysis (Attach with manuscript)

Graph showing the effect of different disease control methods on potato crop yield. The effectiveness of IPM strategies, such as cultural practices, chemical applications, biocontrol techniques, and integrated approaches, is investigated in the study. The kg/Marla yield statistics indicate the potential of coordinated solutions to increase potato production.

Our study explored different approaches to pest management for potato crops and found that the most successful method was an integrated one that used biological (Trichoderma harzianum) and chemical (fungazil) agents. Compared to alternate treatments, this strategy considerably reduced the incidence of late blight illness to 26% and its severity to 1.1. The interaction between biological and chemical agents emphasizes how integrated pest management can improve agricultural output and disease control. In addition to alleviating disease strain, this strategy reduces the need for chemical pesticides, which supports sustainable agriculture. All things considered, our research highlights the importance of multidisciplinary methods in attaining the best possible disease control and raising potato crop yield.

Discussions

In this study, we observed several management techniques for disease incidence and severity in potato crops. Chemical and biological agents were used in the treatments, as well as their combination, to offer insights into useful disease management strategies. A crucial line of defense against the deadly crop disease known as *late blight* is cultural practices. These procedures, according to Arora et al. (2014), are meant to lessen the pathogen's capacity for survival, reproduction, dissemination, and penetration. Utilizing disease-free seed tubers, eradicating volunteer and cull potatoes, controlling irrigation, and maintaining soil coverage are some of the techniques. Olanya et al. (2009) emphasized strategies including removing cull piles, doing appropriate harvesting, and using fungicides. Cultural tactics including using disease-free seed, getting rid of stray plants, and managing nutrients are also efficient. Crop rotation is essential because it uses allelepathic crops to control pests and disease pathogens Voll et al. (2004). These studies emphasize the value of cultural techniques and crop rotation in reducing the effects of *late blight* on crops. Fungicides have been a cornerstone in the management of the global *late blight* disease, offering momentary protection. However, fresh *Phytophthora infestans* strains have emerged that are less sensitive to fungicides Gisi & Cohen (1996) Inglis et al. (1996). The regular use of metalaxyl-based fungicides has produced resistant strains despite the fact that they have proven to be effective Clayton & Shattock (1995); Colon et al. (1995); Delen (2016). The prevalence of this resistance phenomenon highlights the necessity for an all-encompassing approach to deal with changing difficulties in *late blight* control. Potato seedling development was outstanding when B. subtilis OTPB1 and T. harzianum OTPB3 were applied to coco peat. These microorganisms' strains are known to promote crop growth by increasing nutrient absorption, which is fueled by growth-promoting substances including IAA and GA3. Additionally, by colonizing roots, they lower ethylene levels Idris et al. (2007); Gravel et al. (2007); Harman, (2011); Shoresh et al. (2010); Kloepper et al. (2004); Chen et al. (2007).

Researchers indicated that several agents, such as zoospores, sporangia, or oospores, can start the process via water from plant foliage to the soil while discussing the infection of potato tubers by *Phytophthora infestans* Fry, (2008).All strains showed pathogenicity on tuber cultivars (Spounta/Bartina), according to research done in Fatima et al. (2015) Intriguingly, a study by Deahl et al. (1993) similarly found a relationship between inoculum concentration and resistance in potato cultivars (Condor) against late blight. In terms of disease management, some Trichoderma harzianum isolates were successful in lowering the occurrence of the pathogen. According to Fatima et al. (2015), various mechanisms involving the release of toxic metabolites and antifungal compounds may account for differences in their efficiency. These discoveries improve our knowledge of the relationships between diseases and aid in the formulation of management plans for *late blight* in potato crops.

The study investigated interactions between different management strategies, highlighting the effectiveness of combined approaches in reducing disease incidence and severity. If we talk about varietal differences in disease susceptibility, not clearly mentioned in this study, the study focuses on comparing the effectiveness of management strategies in different treatments of disease. Possible interspecific differences in susceptibility warrant further investigation. The study briefly discussed the mechanisms by which biological agents promote crop growth and reduce disease incidence, including increased uptake of nutrients, production of growth-promoting substances, and inhibition of pathogen growth through release of toxic metabolites. The results of the study have applications for farmers and other agricultural stakeholders. By mixing biological and chemical pesticides, integrated pest control lowers crop disease and increases output in a sustainable manner for potato crops. Crop rotation, for example, is one example of a cultural practice that works well to manage illness. Biological agents such as Trichoderma harzianum and Bacillus species are used in conjunction with chemical pesticides to provide efficient disease management while minimizing environmental impact. These techniques encourage sustainability and resilience in potato farming, which has measurable positive effects on crop productivity and health. All things considered, these results suggest that a thorough strategy to disease management may be adopted, which could lead to better farming methods and ensure the long-term sustainability of potato production.

Conclusion

In conclusion, our research has given important information about the best way to handle *late blight* disease in Potato crops. Researchers have discovered more about the way various chemical and biological tactics affect *late blight* disease incidence, severity, and agricultural yield through evaluating them individually and in combination. The combination of chemical and biological treatments has proven to be a very successful strategy, outperforming individual techniques in the control of disease and improvement of Potato yield. The results hold great potential for the development of environmentally friendly Potato growing methods, enhancing both the production and resilience of the agricultural sector. The comprehensive remedies presented in this study provide useful advice and emphasize the significance of interdisciplinary approaches in disease management as agricultural experts struggle to improve the health and yield of Potato crops.

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Citation

Nauman, K. M., Shoukat, S. A. R., Aziz, N., Ahmad, M., Ahmad, J. K., Rehman, S., Yousaf, M., Akba, A. F., Hashmi, Q. A., Siddique, G., Nasreen, R., & Asad, I. (2024). Integrated pest management strategies for controlling potato late blight and enhancing crop and yield. *Journal of Agriculture and Food, 5*(1), 1–15.