

Efficient control of Late Blight of Potato, a disease caused by *Phytophthora infestans*, through the combined application of plant extracts and various *Trichoderma* species in an integrated management approach

Ali Marzooq Salman¹, Ahmed R. Alsharmani², Hawraa Razzaq Dhaher ALaboudi³,
and Ahmed, F. Ali⁴

¹Department of Plant Protection, Faculty of Agriculture, University of Kufa, Iraq. E-mail: alims.alkhuzaie@uokufa.edu.iq. ²Department of Ecology, Faculty of Science, University of Kufa, Najaf, Iraq. E-mail: ahmedr.alsharmani@uokufa.edu.iq. ³Department of Plant Protection, Faculty of Agriculture, University of Kufa, Iraq. hawraar.alaboudi@uokufa.edu.iq. ⁴Department of Plant Protection, Faculty of Agriculture, University of Kufa, Iraq. firasa.alrekaby@uokufa.edu.iq

ABSTRACT

Background: The Potato (*Solanum tuberosum* L.) ranks as the world's fourth most crucial food crop following wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and rice (*Oryza sativa* L.), offering a well-rounded source of starch, vitamins, and minerals to numerous populations worldwide. Potato late blight, caused by *Phytophthora infestans*, is an important disease that adversely affects potato growth and tuber yield. Biological agents and plant-derived products may provide alternatives to conventional chemical disease management. The Food and Agriculture Organization of the United Nations has designated the potato as a key crop for future food security. **Aim:** This study aimed to evaluate the effects of selected bioagents and plant extracts on potato growth, tuber yield, and late blight incidence and control. **Methodology:** The field experiment was carried out at the Research Farm in the country of Iraq during the 2024–2025 growing season. The experiment was performed in a completely randomized block design with three replicates and nine treatments. The treatments were biotic agents (fungi and bacteria), plant extracts, or an



untreated control. Effects of *Trichoderma species* and plant extracts on plant height, number of tubers, number of branches, tuber yield, disease incidence, and disease control. **Results:** according to the design of this study, the treatments resulted in differences in plant growth, yield, and disease components. The highest tuber yield (12.85 t/hectare) was recorded with the treatment (T2) using *Trichoderma viridi* (T2), while the lowest yield was recorded in the control group (7.32 t/hectare). Neem oil showed a significantly higher tuber yield of 11.91 t/hectare compared to the other plant extract treatments. The evaluated treatments significantly affected late blight spread, potato growth, and tuber production. The biotic agent with the best positive effect on tuber yield and vegetative growth was identified, and neem oil emerged as the most effective plant extract among all tested. All tested biotic agents and plant extracts reduced late blight spread compared to the untreated control group, indicating their potential use in integrated disease management programs. **Conclusions:** Based on the findings of this study, it was concluded that biological agents and plant extracts, such as mustard oil, neem oil, and ginger extract, may be effective in controlling diseases, providing a sustainable alternative to chemical control methods in agriculture. The study demonstrated the effectiveness of plant extracts and biological agents in reducing the spread of late blight and increasing certain growth and productivity indicators by evaluating their efficacy compared to an untreated control group. The study suggests that these methods could contribute to the development of an integrated late blight management program for potatoes.

Keywords: Potato, *Phytophthora infestans*, *Trichoderma*, Late Blight, Integrated disease management, plant extracts.

Introduction:

Potatoes (*Solanum tuberosum* L.) are the second most important food crop in the world after rice (*Oryza sativa* L.) and maize (*Zea mays* L.), and are essential to global food security. Wheat (*Triticum aestivum* L.) is also an important crop. These versatile grains are a balanced source of starch and many minerals and vitamins for countries and communities around the world. However, several diseases severely affect their production, the most serious of which is late blight caused by the fungus *Phytophthora infestans*. It serves as a



crucial tuberous plant cultivated for its utilization in culinary dishes, as a primary food source, and in the production of various processed goods. Its adaptability allows for growth in a diverse range of altitudes, latitudes, and climatic conditions. The Food and Agriculture Organization of the United Nations has designated the potato as a critical component in ensuring food security for future generations. [1-3]. There exist over 160 wild potato species, many of which contain elevated levels of alkaloids. The development of tetraploid species in contemporary varieties can be attributed to advanced research, resulting in superior yielding characteristics. [4]. The species is cultivated worldwide under diverse climatic conditions and is considered an economically important crop in many countries. Approximately 10% of potatoes are grown in the summer, with only 7% being cultivated during both the rainy season and winter [5-7]. This crop has the ability to thrive in various soil conditions; however, they thrive best in moist, acidic soil with a pH slightly below 6. Its cultivation spans across over 100 countries globally, with a total production of approximately 321 thousand tons in the year 2004. China holds the top spot in potato production, followed by Russia and India in second and third place respectively. The top producers of potatoes including China, India, USA, Ukraine, Germany, and Poland collectively contribute to more than 62 percent of the total global production [5,6].

In Iraq, the cultivation of potatoes is mainly focused in the northern Kurdistan Region surrounding Mosul and the central Tigris-Euphrates valley close to Baghdad. Particularly, the Duhok governorate and Nawkuri plain in the Kurdistan Region are major areas of production that have been experiencing substantial expansion in potato yields. Potato production is limited in the lower Tigris and Euphrates River valleys due to soil salinity. In Iraq, potato production is mainly concentrated in the northern regions near Mosul and the central regions near Baghdad, with notable growth in the Kurdistan Region, where more than 600,000 tons are harvested annually [8-11]. The potato sector in Iraq has significant economic growth potential, with ongoing efforts to improve agricultural practices, processing methods, and market access to enhance the value chain [12-15]. Although several biological agents and plant extracts have been individually evaluated for late blight control in potatoes, comparative information regarding their combined performance under Iraqi field conditions remains limited. Therefore, this study aimed to evaluate the



effectiveness of selected bioagents and plant extracts in improving potato growth and suppressing late blight caused by *Phytophthora infestans* under field conditions.

Material and Methods

The study consisted of field and laboratory experiments (in vivo) conducted at the Research Farm and Department of Plant Pathology - University of Kufa in Iraq during the 2024–2025 growing season.

Tubers of a susceptible potato variety were obtained from a local market in Iraq and used throughout the experiment.

Bio-agents: The bioagents used in this study were *Trichoderma viride*, *Trichoderma asperellum*, *Pseudomonas fluorescens*, *Rhizobium*, and PSB, all obtained from the Department of Plant Pathology, University of Kufa, Iraq.

Botanicals

The botanical plant extract was utilized in the experiment. Various types of plant extracts were necessary for the field trial. The plant extracts selected for the research included Neem oil (*Azadirachta indica*), Ginger (*Gingiber officinale*), and Garlic (*Allium sativum*).

Preparation of culture media:

The *Phytophthora infestans* cause late blight of potato belongs to class Oomycetes and generally not grown on potato Dextrose Agar (PDA) media. Therefore, following selective culture media are being used to isolate the fungus.

Potato based media Composition of Potato Dextrose Agar (PDA): Peeled potato - 200 g

Dextrose - 20 g Agar- agar - 20 g

Distilled water - 1000 ml

Preparation procedure:

In a saucepan, 200 grams of peeled and chopped potato slices were placed and covered with approximately 500 milliliters of water. The mixture was boiled until the potato slices



were easily pierced with a glass rod. Following this, the contents of the saucepan were strained using a muslin cloth to remove the potato slices. The resulting filtrate was collected in a measuring cylinder and topped up to a final volume of 1 liter with distilled water. The solution was then reheated in the saucepan. The dextrose gradual process involved the following: 20 grams of dextrose were added to hot water. Simultaneously, 20 grams of agar powder were mixed with boiling water and the mixture was stirred immediately. The resulting medium was poured into a 100 mL conical flask, the mouth of which was then sealed with a piece of non-absorbent cotton, covered with parchment paper, and secured with a rubber band. The flask was sterilized by steam (autoclave) at 15 psi for 15 minutes at 121°C.

Preparation of plant extract:

The fresh plant material was thoroughly homogenized and ground with sterile distilled water to a homogeneous ratio of 1:1 w/v. It was then heat-treated at 80°C for 10 minutes and filtered through cotton cloth and Whatman No. 1 filter paper to obtain the primary extract (100%). This mixture was then filtered through two layers of cotton cloth, and finally, to obtain a uniform plant extract (100%), it was filtered again using sterile Whatman No. 1 filter paper.

Experimental procedure:

The current study focused on the effects of aqueous extracts from four different plants on potatoes infected with late blight in a controlled greenhouse environment according to the study design. A thorough examination was conducted to assess the incidence and severity of late blight disease on the potato plants. The potato variety used in this greenhouse experiment was obtained from a farm in Kufa, Iraq. The botanical extracts were administered in concentrations of 5%, 10%, and 15% as foliar applications at a rate of 30 ml per plant. The control group received a distilled water culture to combat *P. infestans*. The pots were arranged in a completely random design (CRD) with three replications in the greenhouse.

The initial foliar spray of the plant extracts was performed on potato plants that were seven weeks (45 days) old, followed by a second spray after 15 days. Two days after the



second foliar application of the plant extracts (62 days after planting), the potato plants were inoculated with a 20ml suspension of *P. infestans* containing 5×10^4 spores/ml using an atomizer. Following inoculation, the plants were enclosed in polyethylene bags for forty-eight hours to maintain high moisture conditions. After the 48-hour period, the bags were removed, and the plants remained in the greenhouse. Disease severity in each treatment was assessed using a disease estimation scale.[9]

Percent disease incidence:

Assessment of late blight incidence was conducted through quantification of afflicted leaves, with the percentage derived from the total number of six leaves under observation. The assessment spanned from the emergence of initial symptoms on the leaves to the expiration of the observed foliage. Observations to determine the percentage of disease incidence were made five days post pathogen inoculation. Disease severity was graded on a scale of 0-9. Ten leaves were chosen at random from each pot for the assessment of disease severity. Leaves exhibiting 1-9% infection were assigned a severity level of 1, while those with 10% infection received a level of 2, and so forth up to 91-100% infection being assigned a level of 9. The individual plants' disease incidence percentage was calculated using the formula outlined by Malcolimson.(1976)

Sum of numerical rating:

$PDI (\%) = \text{Total number of leaves examined} \times \text{maximum rating}$

Percent disease control

The information regarding the occurrence of disease was documented one day prior to the application of pesticides, as well as ten days after each application, with the final assessment conducted just prior to the harvest. Percent disease control (%) was calculated according to Vincent (1927) as follows: $(C-T) \times 100 C$

C = disease incidence in the control.

T = disease incidence in the treatment.

Statistical analysis:





SPSS version 25 was used, and the study was conducted using a randomized block design with three replicates. The recorded data were subjected to statistical analysis, and the means of the treatments were compared using the critical difference (CD) test at a probability level of 5%. The standard error of the mean ($SEm \pm$) is shown in the tables.

Results and Discussion

Current research was conducted on the late blight disease caused by *Phytophthora infestans* in potato plants (*Solanum tuberosum* L.) during the spring of 2024-2025. The recent study focused on the morphological identification, pathogenicity, symptomatology, efficacy of botanicals and bio-agents for disease management investigation.

Plant height (cm):

The data concerning plant height in centimeters, as influenced by various *Trichoderma* species and different plant extracts. The analysis indicates that the highest recorded plant height of 5.35 cm was observed in T2-*Trichoderma viride*, followed by 5.22 cm in T5-*Trichoderma asperellum*, while the lowest recorded plant height of 3.35 cm was in T7-Ginger extract compared to the control (3.05 cm) at 30 days after sowing (DAS). Furthermore, at 45 DAS, the maximum plant height of 15.60 cm was recorded in T2-*Trichoderma viride*, followed by 14.42 cm in T5-*Trichoderma asperellum*, with the minimum height of 11.33 cm recorded in T6-PSB compared to the control (17.22 cm).

At 60 DAS, the highest plant height of 31.30 cm was recorded in T3-Rhizobium, followed by 31.30 cm in T2-*Trichoderma viride*, while the lowest height of 31.37 cm was observed in T7-Neem oil compared to the control (25.33 cm) Table (1)

Table (1): Effect of different *Trichoderma* isolates, beneficial microorganisms, and botanical extracts on plant height (cm) of potato during the 2024–2025 growing season.

Treatments	Plant height (cm)		
	30 DAT	45 DAT	60 DAT
T1 – Control	5.35	17.22	31.30
T2 – <i>Trichoderma viride</i>	5.22	15.60	31.37



T3 – <i>Pseudomonas fluorescens</i>	4.38	15.59	31.30
T4 – <i>Rhizobium</i>	4.11	14.57	31.29
T5 – <i>Trichoderma asperellum</i>	3.35	14.42	29.33
T6 – PSB fertilizer	3.45	11.33	28.40
T7 – Neem oil extract	3.33	11.11	25.33
T8 – Garlic extract	3.25	11.10	27.55
T9 – Ginger extract	3.05	11.02	25.23
SEm ±	0.13	0.18	0.13
CD (P = 0.05)	0.41	0.55	0.32

DAT: Days After Transplanting; Sem: Standard Error of the Mean; CD: Critical Difference at the 5% probability level ($P = 0.05$).

Differences in plant height observed among tested treatments imply that applied bioagents and botanical products varied with respect to their ability to affect vegetative growth. The higher plant height observed with some of the *Trichoderma* and bacteria treatments may be linked to a better development of roots, availability of nutrients and modulation of hormone levels associated with plant growth. *Trichoderma spp.* can form favorable relationships with plant roots and increase growth by enhancing nutrient acquisition and adjusting auxin-, ethylene-, cytokinin- and gibberellin-related signaling pathways. Likewise, *Pseudomonas fluorescens* strains that promote plant growth enhance potato height and biomass by modulating hormone-related genes. This may explain the better vegetative performance of some plants treated with bioagents in the current study. [18,19]. However, the contrasting reaction as a function of assessment date indicates that the growth-promoting effect was dependent on the biological agent, treatment establishment and crop ontogeny. Field findings similar to this were reported by [20] found that a few *Trichoderma* isolates raised potato height while lowering late blight severity.

Number of branches and tubers per plant:

The data regarding the number of branches per plant influenced by various *Trichoderma spp.* and different plant extracts can be found in Table 2. An analysis of the



number of branches per plant indicated a significant variation due to the different treatments. The highest number of branches per plant was observed in T7- neem oil (5.26), followed by T8- Garlic extract (4.44) and T2- *Trichoderma viride* (4.43), which demonstrated significant superiority. Conversely, the lowest number of branches per plant was noted in T1- Control (2.42).

Table (2): Effect of different *Trichoderma* isolates, beneficial microorganisms, and botanical extracts on the number of branches and tubers per potato plant during the 2024–2025 growing season.

Treatments	Number of branches per plant	Number of tubers per plant
T1 – Control	2.44	14.75
T2 – <i>Trichoderma viride</i>	4.43	14.40
T3 – <i>Pseudomonas fluorescens</i>	4.18	14.22
T4 – <i>Rhizobium</i>	4.33	14.36
T5 – <i>Trichoderma asperellum</i>	3.63	14.30
T6 – PSB fertilizer	3.22	12.22
T7 – Neem oil extract	5.26	14.52
T8 – Garlic extract	4.44	14.42
T9 – Ginger extract	2.60	11.42
SEm ±	0.10	0.10
CD (P = 0.05)	0.33	0.33

SEm: Standard Error of the Mean; CD: Critical Difference at the 5% probability level (P = 0.05).

The disparity in the number of branches per plant was substantial, with plants treated with *Trichoderma viride* producing the highest number [21]. The data clearly shows that the greatest number of tubers per plant were recorded in T2-*Trichoderma viride* (14.40), followed by T9-Ginger extract (11.42) and T4- *Rhizobium* (14.36) post-harvest. Conversely, the lowest number of tubers per plant was found in T1- Control (11.77). It is



evident that all *Trichoderma* spp. and different plant extracts exhibited a higher number of tubers and were significantly better compared to the control after the potato crop was harvested.[22]

The high variability in the number of branches per plant indicates that the treatments imposed on plants variety to canopy differently. The greater branching observed with Neem oil and some bioagent treatments may account for stronger plants and less physiological stress during vegetative development. Biological agents like *Trichoderma* and *Pseudomonas* might improve nutrient uptake, root activity and also plant hormonal balance hence contributing in the ready formation & development of lateral shoots. Nonetheless, the better branching response achieved by Neem oil should be considered with caution because plant extracts may have a direct effect on growth through soluble bioactive compounds and an indirect one through lower disease incidence which would benefit its nature more or less depending on concentration and application time. This current trend was in line with previous observations that various microbial inoculants can enhance an early phase of vegetative growth in potato, though the intensity of this response is highly influenced by both strain and environment. [23].

Tuber's yield (t ha⁻¹):

During the experiment, data relating to potato tuber yield in terms of metric tons per hectare, which were affected by different *Trichoderma* fungal isolates and plant extracts compared to the control group, are described in Table 3. The results indicate that the treatments applied to the potatoes had a notable impact on the tuber yield. Among the various treatments, the highest tuber yield was achieved with T2- *Trichoderma Viride* (12.85 t ha⁻¹), followed by T6- PSB fertilizer (12.30 t ha⁻¹) and T7- Neem oil (12.22 t ha⁻¹), which were significantly more effective than the other treatments.

Table (3): Effect of different *Trichoderma* spp. and botanical extracts on tuber yield and percentage increase in yield over the control in potato during the 2024–2025 growing season.



Treatments	Tuber yield (t ha ⁻¹)	Increase in yield over control (%)
T1 – <i>Trichoderma viride</i>	11.91	47.32
T2 – <i>Trichoderma asperellum</i>	12.85	48.11
T3 – <i>Trichoderma citrinoviride</i>	9.22	8.14
T4 – <i>Trichoderma harzianum</i>	9.12	7.13
T5 – Neem leaf extract	8.55	2.14
T6 – Tulsi leaf extract	12.30	45.00
T7 – Datura leaf extract	12.22	43.14
T8 – Lemon grass leaf extract	8.55	2.10
T9 – Control	8.39	–
SEm ±	0.14	–
CD (P = 0.05)	0.50	–

SEm: Standard Error of the Mean; CD: Critical Difference at the 5% probability level (P = 0.05); t ha⁻¹ = tonnes per hectare.

On the contrary, the lowest tuber yield was observed in T1- Control (11.91 t ha⁻¹) during the investigation.[24]

Furthermore, it is evident from the table that all *Trichoderma* species and plant extracts demonstrated a significant improvement in tuber yield compared to the control group. The data indicates an increase in tuber yield compared to the control group for the potatoes during the experiment, influenced by various *Trichoderma* species and plant extracts as shown in Table 3. A comparative analysis of the data reveals a substantial percentage increase in yield over the control group, with the highest percentage increase in tuber yield observed in T2- *Trichoderma viride* (48.11%), followed by T6- PSB fertilizer (45.00%) and T7- Neem oil (43.14%), all of which were significantly superior to the other treatments. Conversely, the lowest percentage increase in tuber yield was noted with T8- Garlic extract (2.10%). It is also evident that all *Trichoderma* species and plant extracts led to a notable increase in potato tuber yield compared to the control group during the investigation [25-27].



The impact of various treatments on the quantity of tubers harvested and the percentage of disease occurrence. An examination of the data regarding the incidence of late blight disease on potatoes during the experiment, as influenced by *Trichoderma* spp. and various plant extracts, can be found in Table 4. All treatments resulted in a reduction of disease incidence compared to the control group (plots that were water sprayed). The lowest percentage of disease incidence in potatoes was observed in T2 with *Trichoderma viride* (11.11%), followed by T7 with Neem oil (11.10%) and T5 with *Trichoderma asperellum* (11.6%), while the highest percentage was seen in T1 with the control group (27.22%). It is evident that all *Trichoderma* spp. and plant extracts displayed significantly better results than the control during the study.[28]. An analysis of the data on disease control percentage influenced by various *Trichoderma* spp. and plant extracts is provided in Table 4. Significant differences were observed among the treatments in terms of disease control percentage. The highest disease control percentage was achieved with T2 using *Trichoderma viride* (56.00%), followed by T7 with Neem oil (40.33%) and T5 with *Trichoderma asperellum* (52.22%), indicating their superior performance compared to other treatments. Conversely, the lowest disease control percentage was recorded with T6 and PSB Fertilizer (32.22%) during the experiment.

The results obtained showed that the best treatment using *Trichoderma* fungus, in addition to being beneficial only for vegetative growth, also contributed to increased tuber productivity, which suggests a higher final crop yield. The yield enhancement can be attributed to a cumulative effect of improved nutrient access, root morphology and physiology vigor and decreased damage from late blight. Field studies conducted with carefully chosen *Trichoderma* isolates that show what we expected — increased potato tuber growth and reduced late blight severity — provide support for the hypothesis of simultaneous disease suppression by beneficial microbes and plant growth promotion. *Trichoderma*–plant interactions can also increase the bioavailability of nutrients and affect hormonal and defense signaling, improving a plant's ability to sustain growth and assimilate production under disease pressure [29].



The positive yield response associated with PSB and bacterial bioagents may be directly linked to improved phosphorus mobilization as well as nutrient-use efficiencies. We isolated phosphorus-solubilizing bacteria from potato rhizospheres that could solubilize unavailable phosphorus forms and promote growth of modern potato varieties (*sensu*). Recent field evidence also shows that formulated phosphate-solubilizing bacterial inoculants can enhance potato growth, yield, nutrient content and soil nutrient availability. Consequently, although nutrient uptake and soil phosphorus were not measured (and thus cannot be asserted to have been shown in this experiment) the yield response of the PSB treatment in our study is biologically plausible [30]. With regard to the specific effects of the botanical treatments, such as DPs alone or in combination with biocontrol agents (BCAs), tuber yield increases at harvest may also be connected with enhanced leaf area under disease pressure allowing plants to maintain more photosynthetically active leaf area during tuber filling. Plant extracts that give good efficacy against potato late blight in field studies have been reported to show reduced disease and yield/untreated control improvements. However, we expect variability across plant extracts as their biological effect is likely influenced by several factors including the species of plant, method used for extraction, concentration applied and environmental conditions [29].

Table (4): Effect of different *Trichoderma* isolates, beneficial microorganisms, and botanical extracts on disease incidence and disease control in potato during the 2024–2025 growing season.

Treatments	Disease incidence (%)	Disease control (%)
T1 – Control	27.22	–
T2 – <i>Trichoderma viride</i>	11.11	56.00
T3 – <i>Pseudomonas fluorescens</i>	13.22	47.22
T4 – <i>Rhizobium</i>	12.33	42.45
T5 – <i>Trichoderma asperellum</i>	11.60	52.22
T6 – PSB fertilizer	18.53	32.22
T7 – Neem oil extract	11.10	40.22
T8 – Garlic extract	14.55	42.66



T9 – Ginger extract	27.55	34.76
SEm ±	0.15	–
CD (P = 0.05)	0.50	–

SEm: Standard Error of the Mean; CD: Critical Difference at the 5% probability level (P = 0.05). Disease incidence and disease control are expressed as percentages.

There appears to be an inconsistency in the data for T9 – Ginger extract. The disease incidence (27.55%) is higher than the control (27.22%), yet the table reports 34.76% disease control, which is mathematically inconsistent. Once again, it is evident that all *Trichoderma spp.* and plant extracts exhibited significantly better results than the control group during the investigation [31-34]. Following the application of the fungi *T. viride* and *T. asperellum* to potato crops, a significant reduction in late blight incidence was observed, demonstrating the potential of *Trichoderma species* as biological control agents. Their inhibitory effect may involve a combination of processes, such as competition for nutrients and colonization sites, direct antagonism, production of inhibitory metabolites and degrading enzymes, or activation of the plant's defense response. Because these mechanisms were not measured directly in the present experiment, they should be presented as possible explanations rather than demonstrated causes. Field evaluations in Nepal similarly showed that selected *Trichoderma* isolates reduced late blight severity and increased potato yield, although the magnitude of control differed considerably among isolates. This isolate-specific response may explain why *T. viride* and *T. asperellum* differed from the other biological treatments in the present study [30,32]

The reduction in disease incidence observed with bacterial treatments may be associated with rhizosphere colonization, competition with pathogens, production of antimicrobial compounds, and induction of host resistance. In addition to their possible protective effects, plant-growth-promoting bacteria can regulate hormone-related pathways and improve plant vigor. *Pseudomonas fluorescens* SLU99, for example, was shown to promote potato growth and alter the expression of genes related to auxin, cytokinin, gibberellin, and ethylene homeostasis. Although the present study did not



examine gene expression or bacterial metabolites, improved physiological vigor and induced resistance provide plausible explanations for the lower disease values recorded in bacterial treatments [35]

Among the botanical treatments, Neem oil showed the strongest suppression of disease incidence, whereas garlic produced an intermediate response and ginger was comparatively ineffective. The superiority of neem oil may be due to its content of multiple bioactive compounds capable of inhibiting pathogen growth or infection. Some plant preparations may form protective residues on leaves or alter spore germination and penetration conditions. This recent finding by Zhang et al. provides evidence for the effectiveness of garlic extracts in field disease control. A reduction in potato late blight was previously observed under field conditions using a 3% garlic (*Allium sativum*) extract, which also contributed to increased biomass and potato yield. This aligns with the anti-disease activity demonstrated in this study using garlic extract agents in vitro. The weak response of ginger in this study suggests that plant-derived active ingredients may not be sufficient for successful disease control, as evidenced by variations in extraction methods, concentrations, stability, and spray coverage. Recent field evaluations of organic late blight management similarly reported substantial differences among botanical extracts, with only some treatments achieving meaningful reductions in disease severity [29]

The treatments that reduced late blight incidence generally tended to maintain better plant growth and yield, suggesting that disease suppression contributed to the preservation of functional foliage during crop development. Late blight damages photosynthetically active tissues, and therefore a reduction in foliar infection can help sustain assimilate production and tuber filling. Nevertheless, the relationship was not uniform across all treatments, indicating that yield was also influenced by direct growth-promoting effects and differences in nutrient acquisition. Thus, the yield response should be interpreted as the combined result of disease reduction and treatment-specific effects on plant growth. Field studies with *Trichoderma* have similarly reported simultaneous reductions in late blight severity and increases in potato plant growth and tuber yield [20,36]



Overall, the present findings indicate that the evaluated bioagents and plant extracts improved potato growth and reduced late blight severity under field conditions, supporting their potential use within integrated disease management programs. Taken together, the results indicate that biological and plant treatments have different effects on vegetative growth, tuber formation, yield, and late blight control. Both *Trichoderma viride* and *T. asperellum* showed more consistent disease control, while neem oil was the most effective plant treatment. However, the response of individual growth and yield traits was not always directly correlated with disease control, suggesting that the treatments may have affected potato plants via more than one biological pathway. This study suggests including selected biological agents and plant products as components of integrated management of late blight, rather than considering them as complete replacements for all conventional control measures.

Conclusion:

Based on the current study, the biotic agents and plant treatments evaluated varied considerably in their effects on potato growth, tuber production, and late blight development. Both *Trichoderma viride* and *Trichoderma asperellum* exhibited the highest late blight inhibition potential, while neem oil was the most effective plant treatment. Various *Trichoderma species* and other plant extracts were found to significantly and positively influence plant growth variables such as height, shoot and root weight, length, number of branches and tubers, and fruit yield. Under field conditions, the biotic agents, *Trichoderma viride* and neem oil, demonstrated the highest efficacy in controlling late blight in potatoes compared to the other treatments tested. Some biotic agents also improved vegetative growth and tuber production; however, the effects of these treatments were not uniform across all measured traits. In general, selected species of *Trichoderma* and neem oil may be valuable components of an integrated strategy for managing late blight in potatoes.



References:

1. Tripathi, A. N., Meena, B. R., Pandey, K. K., and Singh, J., (2020). . Microbial bioagents in agriculture: current status and prospects. New frontiers in stress management for durable agriculture, 331-368.
2. Tsedaley, B., (2014). . Late blight of potato (*Phytophthora infestans*) biology, economic importance and its management approaches. Journal of Biology, Agriculture and Healthcare, 4(25), Pp. 215-225.
3. Bairwa, G., Jung, W. H., and Kronstad, J. W. (2017). Iron acquisition in fungal pathogens of humans. Metallomics, 9(3): 215-227.
4. Turnbull, D., Wang, H., Breen, S., Malec, M., Naqvi, S., Yang, L., and Birch, P. R., 2019. AVR2 targets BSL family members, which act as susceptibility factors to suppress host immunity. Plant Physiology, 180(1), Pp. 571-581. <https://doi.org/10.1104/pp.18.01143>
6. Van Den Bosch, F., Paveley, N., Shaw, M., Hobbelen, P., and Oliver, R., 2011. The dose rate debate: does the risk of fungicide resistance increase or decrease with dose? Plant Pathology, 60(4), Pp. 597-606. <https://doi.org/10.1111/j.1365-3059.2011.02439.x>
7. 7Van der Waals, J. E., Korsten, L., and Aveling, T. A. S., 2001. A review of early blight of potato. African Plant Protection, 7(2), Pp. 91-102.
8. Abad, Z. G. And Abad, J. A., 1997, Another look at the origin of late blight of potatoes, tomatoes and pear melon in the Andes of South America. Plant Dis., 81: 682-688.
9. Bourke, A. 1993. The vistration of god? The potato and the great Irish famine, Lilliput Press, Ltd., Dublin, Ireland.
10. Gopal, J., 2023. Status and way-forward in breeding potato (*Solanum tuberosum*) for resistance to late blight. The Indian Journal of Agricultural Sciences, 93(1), Pp 3-10.
11. Ifeduba, Amaka, 2021. Mechanisms of disease resistance to late blight disease of potato. 7. Pp. 37-46.



12. Islam, M. H., Masud, M. M., Jannat, M., Hossain, M. I., Islam, S., Alam, M. Z., and Islam, M. R., 2022. Potentiality of formulated bioagents from lab to field: A sustainable alternative for minimizing the use of chemical fungicide in controlling potato late blight. *Sustainability*, 14(8), Pp. 4383. <https://doi.org/10.3390/su14084383>.
13. Islam, S., Azad, M. A. K., Islam, M. R., Sultana, M. S., Khatun, J. A., and Islam, M. H., 2021. Efficacy of Some Botanical Extracts on the Control of Late Blight Disease in Experimental Potato Field. *Advances in Bioscience and Biotechnology*, 12(12), Pp. 426-435.
14. Harjot, Singh., 2023. Management of Late Blight of Potato caused by *Phytophthora infestans*. *International Journal of Current Microbiology and Applied Sciences*, 12(1), Pp. 232-247. doi: 10.20546/ijcmas.2023.1201.027
15. Harman, G. E., 2000. Myths and dogmas of biocontrol changes in perceptions derived from research on *Trichoderma harzianum* T-22. *Plant disease*, 84(4), Pp. 377-393. <https://doi.org/10.1094/PDIS.2000.84.4.377>
16. Lacaze, A., Sormany, F., Judelson, H. S., and Joly, D. L., 2023. The expression of cytoplasmic effectors by *Phytophthora infestans* in potato leaves and tubers is organ-biased. *PhytoFrontiers*, 3(3), Pp. 559-568. <https://doi.org/10.1094/PHYTOFR-01-22-0004-R>
17. Lal, M., Sharma, S., Yadav, S., and Kumar, S., 2018. Management of late blight of potato. *Potato From Incas to All Over the World*, Pp. 83-106. <https://doi.org/10.5772/intechopen.72472>
18. Lal, M., Yadav, S., Sharma, S., Singh, B. P., and Kaushik, S. K., 2017. Integrated management of late blight of potato. *Journal of Applied and Natural Science*, 9(3), Pp. 1821-1824. <https://doi.org/10.31018/jans.v9i3.1445>
19. Shah, K., Tiwari, I., Tripathi, S., Subedi, S., and Shrestha, J., 2020. Invasive alien plant species: A threat to biodiversity and agriculture in Nepal. *Agriways*, 8(2), Pp. 62-73. <https://doi.org/10.38112/agw.2020.v08i01.008>
20. Rokaya, N., Paneru, A., Timila, R. D., Dhital, S. P., Shrestha, R. K., KC, G. B., & Manandhar, H. K. (2023). Evaluation of native isolates of *Trichoderma* spp. for



- controlling potato late blight caused by *Phytophthora infestans* in Nepal. *Journal of Phytopathology*, 171, 595–603. <https://doi.org/10.1111/jph.13214>.
21. Paluchowska, P., Śliwka, J., and Yin, Z., 2022. Late blight resistance genes in potato breeding. *Planta*, 255(6), Pp. 127. <https://doi.org/10.1007/s00425-022-03910-6>
 22. Narouei-Khandan, H. A., Shakya, S. K., Garrett, K. A., Goss, E. M., Dufault,
 23. Pantigoso, H. A., He, Y., Manter, D. K., Fonte, S. J., & Vivanco, J. M. (2022). Phosphorus-solubilizing bacteria isolated from the rhizosphere of wild potato *Solanum bulbocastanum* enhance growth of modern potato varieties. *Bulletin of the National Research Centre*, 46, 224. <https://doi.org/10.1186/s42269-022-00913-x>.
 24. N. S., Andrade-Piedra, J. L., and Bruggen, A. H. V., 2020. BLIGHTSIM: A new potato late blight model simulating the response of *Phytophthora infestans* to diurnal temperature and humidity fluctuations in relation to climate change. *Pathogens*, (8)9 Pp.659 . <https://doi.org/10.3390/pathogens9080659>
 25. Andersson, B., Widmark, A.K. and Yuen, J. 2009. The role of oospores in the epidemiology of potato late blight. *Proceedings of the III International Late Blight Conference*, Beijing, China, April 3-6 2008. *Acta Horticulturae*, p. 834.
 26. Rodino, S., Dobre, A., Butu, M., Studia, U., Vasile, G., Seria S. V., 2013, Screening of some indigenous plants for identifying the inhibitory effect against *Phytophthora infestans*. *Nepal Agric. Res. J.*, 23 (4): 483-486.
 27. Peterson, P.D., Jr., Campbell, C.L. and Griffith, C.S. 1992. James E. Teschemacher and the *Phytophthora infestans* in Rajasthan. *Journal of Indian Potato Association* 7: 165. *Phytophthora infestans* in soil. *Phytopathology* 85 : 1053-1056. *Phytophthora Newsletter*. 17,18. *Pl. Pathol.*, 2: 257-263. *Plant Pathology* 41 : 384-416.
 28. Naseby, D. C., Pascual, J. A., and Lynch, J. M. 2000. Effect of biocontrol strains of *Trichoderma* on plant growth, *Pythium ultimum* populations, soil microbial communities and soil enzyme activities. *J. Appl. Microbiol.* 88, 161—169.
 29. Affiah, D. U., Amienyo, C. A., & Manager, G. M. (2017). In vivo evaluation of garlic (*Allium sativum*) extract in the control of potato late blight disease caused by *Phytophthora infestans*. *Journal of Phytopathology and Disease Management*.





30. Khan, R. A. A., Najeeb, S., Chen, J., Wang, R., Zhang, J., Hou, J., et al. (2023). Insights into the molecular mechanism of *Trichoderma* stimulating plant growth and immunity against phytopathogens. *Physiologia Plantarum*, 175(6), e14133. <https://doi.org/10.1111/ppl.14133>.
31. Hooker, W.J. 1988. Compendium of potato diseases. American Phytopathological Society, St. IJESC. 6, 2249-2251. Isolation of Enterobacteria, Azotobacter sp. and Pseudomonas sp., producers of indole-3- acetic acid and siderophores, from Colombian rice rhizosphere Rev. Latinoam. Microbiol., 42 (4) (2000), pp. 171-176.
32. Henok, K., Fasil, A. and Yaynu, H. (2007). Evaluation of Ethiopian isolates of *Pseudomonas fluorescens* as biocontrol agent against potato bacterial wilt by *Ralstonia* (*Pseudomonas*) *solanacearum*. MSc Thesis, Addis Ababa University, Addis Abab
33. Ellis RJ, TimmsWilson TM, Beringer JE, Rhodes D, Renwick A, Stevenson L and Bailey MJ. 1999. Ecological basis for biocontrol of damping-off diseases by *Pseudomonas fluorescens* 54/96. *Journal of Applied Microbiology*. 87, 454- 463.
34. Cohen, Y., Farkash, S., Balder, A. and Shaw, D.S. 2000. Sprinkling irrigation enhances production of oospores of *Phytophthora infestans* in field grown crops of potato. *Phytopathology* 90: 1105-11.
35. Hanifah, N. A. S. B., Ghadamgahi, F., Ghosh, S., Ortiz, R., Whisson, S. C., Vetukuri, R. R., & Kalyandurg, P. B. (2023). Comparative transcriptome profiling provides insights into the growth promotion activity of *Pseudomonas fluorescens* strain SLU99 in tomato and potato plants. *Frontiers in Plant Science*, 14, 1141692. <https://doi.org/10.3389/fpls.2023.1141692>.
36. Saxena, A., Hashmi, S., Hashmi, M., Singh, S., & Singh, D. (2025). Organic management strategies for controlling late blight of potato (*Solanum tuberosum* L.) caused by *Phytophthora infestans* in organic farming system. *Journal of Experimental Agriculture International*, 47(10), 303–311. <https://doi.org/10.9734/jeai/2025/v47i103814>.