

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.

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ABSTRACT

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. It is commonly hailed as the "King of Vegetables" due to its significance as a tuberous crop grown for consumption and various processed goods. The term "Potato" is derived from the Spanish word "patata," the name used in Spain. The Food and Agriculture Organization of the United Nations has designated the potato as a key crop for future food security, as demonstrated in a study titled "Integrated management of late blight of Potato (*Phytophthora infestans*) by using isolates of *Trichoderma* spp. and plant extract" conducted at an Organic Research Farm in Iraq during the spring season of 2024-2025. The study was carried out using a Randomized Block Design (RBD) with three replications and nine treatments. The effects of various *Trichoderma* spp. and plant extracts on parameters such as plant height, fresh and dry shoot weight, root length, fresh and dry root weight, number of branches per plant, number of tubers per plant, and tuber yield were observed to be positive and significant. The highest tuber yield of 10.85/ha was achieved with *Trichoderma viride* treatment (T2), while the control treatment resulted in the lowest tuber yield of 7.32 t/ha. Notably, the tuber yield of 11.91 t/ha from Neem oil treatment surpassed that of other plant extract treatments. This study demonstrates the potential of bioagents and plant extracts in effectively managing diseases, offering a sustainable alternative to chemical disease control in agriculture.

Key words: control, Late Blight, Potato, disease, *Phytophthora infestans*, plant extracts, Trichoderma.

Introduction

Potato, scientifically known as *Solanum tuberosum* L., holds the distinction of being the fourth most significant food crop globally, following wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and rice (*Oryza sativa* L.). This versatile crop offers a well-rounded supply of starch, essential vitamins, and minerals to various communities spanning across different regions worldwide. Widely recognized as the "King of Vegetables," the potato 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 term "Potato" originates from the Spanish word "patata," a common name for the vegetable in Spain. 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]. The origins of the potato can be traced back to South American natives around 5000 B.C. in the elevated regions of the Peruvian Andes Mountains. Approximately around 1570, the potato was introduced to Europe by Spanish explorers upon their return. There exist over 160 wild potato species, many of which contain elevated levels of alkaloids. The first domesticated potato is believed to have been cultivated in Peru about 4000 years ago. The initial cultivated potato species were diploid, some of which are still grown in South America today. The development of tetraploid species in contemporary varieties can be attributed to advanced research, resulting in superior yielding characteristics. [4] Traditionally, potato cultivation has been limited to cooler climates, but there are now new varieties that can thrive in almost any region of the world. Areas situated between 300 to 1300 meters in elevation are deemed suitable for potato cultivation. Specifically, regions between 300 to 600 meters in elevation are ideal for winter potato cultivation, while areas between 600 to 1300 meters can accommodate both winter and autumn season potato crops. In India, the majority of potatoes, approximately 80%, are grown during the winter months spanning from October to February. Approximately 10% of potatoes are grown in the summer, with only 7% being cultivated during both the rainy season and winter

[5-7]. Potatoes have the ability to thrive in various soil conditions, however, they thrive best in moist, acidic soil with a pH slightly below 6. Potato 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. Production in the lower Tigris-Euphrates valley is limited due to the constraints posed by saline soils. Potato cultivation in Iraq is primarily located in the northern regions near Mosul and central areas near Baghdad, although there has been notable growth in the Kurdistan Region, where over 600,000 tons are harvested annually and new markets are being explored. The potato industry in Iraq holds potential for significant economic growth outside of the oil sector, with continuous efforts aimed at enhancing the value chain through advancements in farming practices, processing methods, and market accessibility. 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. Production in the lower Tigris-Euphrates valley is limited due to the constraints posed by saline soils [8-11].

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Material and Methods

The study was conducted through a combination of field experiments (in vivo) at a research farm in Iraq and laboratory experiments (in vitro) at the Department of Plant Pathology during the cropping season of 2024-2025. The forthcoming section will provide a thorough examination of the materials, techniques, and methodologies employed throughout the research endeavor.

Experimental site

The experimental site was situated at the Research Farm, Iraq during 2024-2025.

Tubers

Tubers of the potato susceptible varieties procured for the experimental work from local market in Iraq

Bio-agents:

Various strains of Trichoderma, along with their respective optimal dosages, were employed as biological agents to combat late blight in potatoes and related crops. These bioagents were procured from the Department of Plant Pathology at the University of Kufa in Iraq, specifically Trichoderma viride, Trichoderma asperellum, Rhizobium, Pseudomonas fluorescens, and PSB, for use in the experimental investigations.

Botanicals

The botanical plant extract, known for its efficacy against late blight in potato and related crops, 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.

Gradually, 20 grams of dextrose was introduced into hot water to facilitate its dissolution. Simultaneously, 20 grams of agar-agar powder was combined with boiled water and stirred thoroughly. The resulting medium was transferred into a conical flask which was then sealed with non-absorbent cotton and covered with butter paper secured with a rubber band. This flask was subjected to autoclaving at a pressure of 15 pounds per square inch (15psi) for 15 minutes at a temperature of 121 degrees Celsius.

Preparation of plant extract:

Fresh leaves and bulbs were gathered and cleansed meticulously with fresh water. 100 grams of each cleaned plant specimen were ground in a mortar and pestle while adding an equal quantity (100 ml) of sterilized water (1:1 w/v) and subjected to heat at 80°C for 10 minutes in a hot water bath. The resulting mixture was then strained through a double layer of muslin cloth, then filtrated through a sterilized Whatman No. 1 filter paper, ultimately yielding a standardized plant extract (100%).

Efficacy of Plant Extracts

The investigation focused on the effects of aqueous extracts from four different botanicals on late blight infected potatoes in a controlled greenhouse setting. Furthermore, 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. Disease severity was evaluated using six leaves per plant for each assessment.

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).

$$\frac{\text{Sum of numerical rating}}{\text{Total number of leaves examined} \times \text{maximum rating}}$$

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

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. The percentage of disease control was determined using the mathematical equation established by Vincent in 1927.

Percent disease control

$$\frac{(C-T)}{C} \times 100$$

Whereas, C = Per cent disease in control

T = Per cent disease in treatment

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 investigation focused on symptomatology, morphological identification, pathogenicity, and the efficacy of botanicals and bio-agents for disease management. The findings from this study will be outlined in the subsequent paragraph [16, 17].

Investigation of the impact of *Trichoderma* spp. and various plant extracts on the control of late blight in potatoes in field conditions from 2024 to 2025.

Plant height (cm)

The data concerning plant height in centimeters, as influenced by various *Trichoderma* species and different plant extracts, is presented in Table 1. 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) [18, 19].

Table (1): During the course of 2024-2025, the impact of various *Trichoderma* isolates and different botanical extracts on the growth of potato plants was examined.

Treatments	Plant height (cm)		
	30 DAT	45 DAT	60 DAT
T ₁ - Control	5.35	17.22	31.30
T ₂ - <i>Trichoderma viride</i>	5.22	15.60	31.37
T ₃ - <i>Pseudomonas fluorescense</i>	4.38	15.59	31.30
T ₄ - <i>Rhizobium</i>	4.11	14.57	31.29
T ₅ - <i>Trichoderma asperellum</i>	3.35	14.42	29.33
T ₆ - PSB Fertilizer	3.45	11.33	28.40
T ₇ - Neem oil extract	3.33	11.11	25.33
T ₈ - Garlic extract	3.25	11.10	27.55
T ₉ - Ginger extract	3.05	11.02	25.23
SEm±	0.13	0.18	0.13
CD at 5%	0.41	0.55	0.32

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). The disparity in the number of branches per plant was substantial, with plants treated with *Trichoderma viride* producing the highest number [20] .

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[21].

Table(2): Impact of various plant extracts from *Trichoderma* spp. on the branch count and tuber production per potato plant in the years 2024-2025.

Treatments	Number of per branches plant	Number of tubers per plant
T ₁ - Control	2.44	14.75
T ₂ - <i>Trichoderma viride</i>	4.43	14.40
T ₃ - <i>Pseudomonas fluorescense</i>	4.18	14.22
T ₄ - <i>Rhizobium</i>	4.33	14.36
T ₅ - <i>Trichoderma asperellum</i>	3.63	14.30
T ₆ - PSB Fertilizer	3.22	12.22
T ₇ - Neem oil	5.26	14.52
T ₈ - Garlic extract	4.44	14.42
T ₉ - Ginger extract	2.60	11.42
SEm±	0.10	0.10
CD at 5%	0.33	0.33

Tuber's yield (t ha⁻¹):

Data regarding the yield of potato tubers in terms of metric tons per hectare during the experiment, influenced by different *Trichoderma* isolates and plant extracts compared to the control group, are outlined 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. On the contrary, the lowest tuber yield was observed in T1- Control (11.91 t ha⁻¹) during the investigation [22].

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 [23-25].

Table (3): During the time frame of 2024 to 2025, an investigation was conducted to observe the impact of *Trichoderma* spp and different botanical extracts on both the yield of potato tubers and the percentage of disease suppression.

Treatments	Tuber yield (t ha ⁻¹)	Percent increase in yield over control
T ₁ - <i>Trichoderma viride</i>	11.91	47.32
T ₂ - <i>Trichoderma asperellum</i>	12.85	48.11
T ₃ - <i>Trichoderma citrinoviride</i>	9.22	8.14
T ₄ - <i>Trichoderma harzianum</i>	9.12	7.13
T ₅ - Neem leaf extract	8.55	2.14
T ₆ - Tulsi leaf extract	12.30	45.00
T ₇ - Datura leaf extract	12.22	43.14

T ₈ - Lemon grass leaf extract	8.55	2.10
T ₉ - Control	8.39	-
SEm±	0.14	-
CD at 5%	0.50	-

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 [26].

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. Once again, it is evident that all *Trichoderma* spp. and plant extracts exhibited significantly better results than the control group during the investigation[27-30].

Table (4): The impact of various plant extracts from *Trichoderma* spp on the percentage of disease incidence in potatoes is being studied for the years 2024 to 2025.

Treatments	Percent disease incidence	Percent Disease control
T ₁ - Control	27.22	-
T ₂ - <i>Trichoderma viride</i>	11.11	56.00
T ₃ - <i>Pseudomonas fluorescense</i>	13.22	47.22
T ₄ - <i>Rhizobium</i>	12.33	42.45
T ₅ - <i>Trichoderma asperellum</i>	11.6	52.22
T ₆ - <i>PSB Fertilizer</i>	18.53	32.22
T ₇ - Neem oil	11.10	40.22
T ₈ - Garlic extract	14.55	42.66
T ₉ - Ginger extract	27.55	34.76
SEm±	0.15	-
CD at 5%	0.50	-

Conclusion

Based on the current study, it was found that various species of *Trichoderma* and Botanical plant extracts have positively and significantly impacted plant growth variables such as height, shoot and root weights, length, number of branches and tubers, and fruit yield.

In field conditions, the biocontrol agents *Trichoderma viride* and Neem oil demonstrated the highest efficacy in controlling late blight disease in potatoes compared to other tested treatments.

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