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Research Article

Discover the Most Effective Disease Management Strategies for *Fusarium* Dry Rot of Potato through Comprehensive Bio-assay of Three Techniques (Chemical, Plant extracts, and Bio-control)

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Abstract: Potato (*Solanum tuberosum*) is a multicultural staple food and cash crop. Unfortunately, production of potatoes is predominantly constrained by diseases including dry rots. To evaluate management of dry rots, three *in vitro* sub-trials were set up using the completely randomized design with each treatment replicated thrice for each trial. Firstly, synthetic fungicides were assayed against *Fusarium oxysporum* f.sp. tuberosi. Secondly, plant extracts were assessed against *F. oxysporum*. Finally, the efficacy of *Trichoderma harzianum* applied against *F. oxysporum* was evaluated. The colony radii were measured. The inhibition of *F. oxysporum* by Ketoconazole (at 100% concentration) was significantly ($p \leq 0.05$) highest, followed by Ketoconazole (50% concentration), Itraconazole (100% concentration), Itraconazole (50% concentration), Sulphur (100% concentration), Ridomil (100% concentration), Sulphur (50% concentration), and finally Ridomil (50% concentration). Percentage inhibition of the growth of the *Fusarium* species by fungicides ranged from 39.5-95.7%. Blue gum (*Eucalyptus globulus*) (at 100% concentration) gave the highest inhibition, followed by blue gum (50% concentration), Sweet alligator-pepper (*Aframomum melegueta*) at 100% concentration, locust bean (*Parkia biglobosa*) at 100% concentration, Sweet alligator-pepper (50% concentration), candle bush (*Senna alata*) (100% concentration), locust bean (50% concentration), and *Senna alata* (50% concentration) in descending order of percentage inhibition. Plant extracts caused a percentage inhibition of the fungus between 20.6-100% inhibition with time. Inhibition of *Fusarium* by *T. Harzianum* isolate BGMZ4 was significantly ($p \leq 0.05$) highest, followed by *T. Harzianum* isolate NSBM then *T. Harzianum* isolate BGMZ3. Control of *F. Oxysporum* by *T. Harzianum* ranged from 23.5-94.1% inhibition. All the methods evaluated successfully inhibited the pathogen compared to the control.

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1. Introduction

Potato (*Solanum tuberosum* L.) in the family Solanaceae, is a cosmopolitan staple food and cash tuber crop, that grows exceedingly well globally and is consumed by more than 1000 000 000 persons in 150 countries (Devaux et al., 2019; Mengui et al., 2019; Ehiobu et al., 2022; Tiwari et al., 2023). The leading global potato-producing countries include China, India, and Russia (Muthoni et al., 2022). These countries have huge populations that will have to be properly fed and potatoes can come in very useful.

Thus, Ehiobu et al. (2022) revealed that potato cultivation has been increasing expressly because potato is one of the tuber crops that can compete with cereals in terms of productivity (potato gives 15 times more yield w/w per hectare than cereals) according to the United Nations. Potato is used mainly in the food industry (for making chips, crisps, vegetable relish/salad, canning, French fries, potato flour, potato dice, potato flakes, sauces, thickeners, and binders of soups) as well as raw material in industry (for brewing alcoholic drinks (e.g. vodka), livestock feed, in the textile industry/potato starch, as adhesives, and for making paper, boards, dextrin, and ethanol) (Horton, 1992; Gopal et al., 2006; Ogunsola and Aduramigba-Modupe, 2014; Riaz et al., 2022). Potato is a key crop that can be used to alleviate poverty and attain zero hunger globally. Potato is a complete food that contains enough nutrients, vitamins, and minerals.

However, potato production is highly constrained by the utilization of rudimentary farming practices, high incidence of pests and diseases, inefficient use of improved technologies (e.g. limited or no crop rotation and inability to take advantage of irrigation to enable year-round production), low soil fertility or declining soil fertility, high cost of inputs (like fertilizers, certified seed potato, and fungicides), poor access to credit (Ministry of Agriculture, 2006; Mengui et al., 2019; Mulema et al., 2021; Riaz et al., 2022). Production of potatoes can be given a boost if policymakers and funding agents can give it enough attention because the resource-poor farmers can barely change their status on their own.

Kankoranta (1996), Larkin and Lynch (2018), Singh and Singh (2018), and Kim et al. (2024) testified that potato yield can be negatively influenced by roughly 160 diseases. Amongst these diseases are 40 soil-borne diseases. Other constraints include post-harvest storage diseases, environmental changes, and climate change. Lee et al. (2019) lamented that 20–40% of potato yield is lost globally to pests and diseases annually despite the efforts being put in.

In India (second largest global producer), 15–22% of potato dry rot disease incidence was reported (Sagar et al., 2011). Adolf et al. (2020) reported that globally the annual potato yield loss is about €6 100 000 000. The quantitative potato yield loss ranges between 25–60% in cold storage (Masum et al., 2011; Du et al., 2012; Merlington et al., 2014; Chen et al., 2020). This yield loss could be the answer to overcoming global hunger if post-harvest pathogens are properly tackled as shown in this study.

Cullen et al. (2005), Xue and Yang (2021), Xue et al. (2023), Tiwari et al. (2023), Zongur (2024), and Kim et al. (2024) pointed out that globally, potato dry rot disease is caused by many *Fusarium* species which include *Fusarium oxysporum* f.sp. tuberosi, *Fusarium sambucinum*, *Fusarium solani*, *Fusarium graminearum*, *Fusarium coeruleum* (Libert), and *Fusarium proliferatum*. Tiwari et al. (2023) expounded that *Fusarium* species affect this crop in the field causing *Fusarium* wilt and in the store they cause dry rots.

Singh and Singh (2018) concurred that due to disease complexes, the common control measures employed worldwide (including the use of tolerant cultivars, crop rotation, and other practices; singly or collectively) have met with limited success. This is quite true disease complexes result in more damage to crops and complicate the work of breeding for resistance against most pathogens.

Fortunately, Riaz et al. (2022) reported that integrated disease management using individual or combined application of plant growth-promoting bacteria with commercial fertilizers can be effective. Proper cultural practices coupled with chemical seed-dressing (using 1200 ppm thiabendazole) can be used to manage diseases caused by *Fusarium* species (Leach and Nelson, 1975).

Singh and Singh (2018) agreed that effective disease management is essential to overcome these diseases. It is common knowledge that the principle of integrated disease management (involving chemical control in combination with bio-control agents), is the most efficient and eco-friendly way to effectively combat pathogens. The struggle against pests and pathogens is never one-off. The pests and pathogens keep evolving and adapting to the new measures being utilized to curtail their effects.

Aydın and İnal, (2018) reported that potato cultivars reacted differently to the dry rot agents *F. sambucinum* and *F. solani*, with cultivar Broke® showing more promise for selection as a potential source of resistant genes against the pathogens. With this obvious lack of highly resistant materials against this disease, an integrated approach will ultimately be our best sustainable strategy (Bojanowski et al., 2013; Xue et al., 2023).

Adolf et al. (2020), Xue and Yang (2021) and Xue et al. (2023) noted that the application of fungicides is still the most effective approach for the management of dry rots, but environmental considerations are increasing the pressure to use host resistance and other measures. Biocontrol agents (like *Trichoderma* spp. and *Pseudomonas aeruginosa*) are effective disease management agents (Gupta et al., 1999).

For instance, Aydın (2019) determined that *Trichoderma* species were effective at different levels against *F. sambucinum,* which causes potato dry rot disease. The most effective *Trichoderma* isolates were *T. viride* VG18, *T. asperellum* ÖT1, *T. harzianum* TZ16, *T. virens* KB31, and *T. inhamatum* KEB12 respectively. Additionally, commercial seed fungicides formulated using Fludioxonil (SC 100 g L^{-1}) and Azoxystrobin (SC 250 g g L^{-1}) when applied to potato tubers, revealed that Fludioxonil was more effective compared to Azoxystrobin and the biological control agents. Likewise, Orina et al. (2024) demonstrated that control of *Fusarium* species was more effective when benomyl was applied compared to Azoxystrobin.

Orina et al. (2024) reported that benomyl was the best agent against *F. sambucinum* and *F. solani* compared to the control. However, they reported that Azoxystrobin was the least inhibitory among the agents applied against dry rot agents which contradicts the findings of Aydin (2019). Zongur (2024) reported that the essential oils of *Beta vulgaris* successfully inhibited these *Fusarium* species.

Bojanowski et al. (2013) reiterated that previously thiabendazole was very effective against these fungi but resistant strains have developed against it coupled with the lack of adequate resistance in potato varieties against dry rotting. The application of different agents against these pathogens has to be carefully studied to avoid damage to the environment, and the health of man, animals, and plants. Besides, the rate of developing new effective control materials agents pathogens tends to lag behind the development of resistance against those presently being used.

This research was conceived with this foregoing information in mind. Thus, this research was carried out to put up solutions applicable against *Fusarium* dry rot of potatoes using chemical, plant extract, and biological control methods.

2. Material and Methods

2.1 Experimental site

The Faculty of Agriculture Laboratory complex (Plant Pathology Laboratory), Alex Ekwueme Federal University Ndufu-Alike, Abakaliki (6.069°N by 8.199°E) in Ebonyi State of Nigeria was used for this experiment. Many root and tuber crops (e.g. sweet potato, potato, cassava, and yams) are cultivated in this state. The area has lush vegetation and experiences high relative humidity for most of the year. The rainy season here lasts more than three-quarters of the year with high wind speeds.

2.2 Sourcing of *Fusarium* and *Trichoderma* species

Potato tubers were obtained from Bamenda, in the West Cameroons and Jos in the Plateau State of Nigeria, cleaned by washing with running tape water, dried and packaged in manila envelopes, sealed, and taken to the Laboratory for processing. Potato tubers were labeled/tagged taken from each of the samples and processed to isolate the associated fungi in the laboratory.

Potato dextrose agar (PDA) was prepared as recommended by the manufacturer (Lifesave™, USA), and then streptomycin sulphate (1 g L^{-1}) was added to it to prevent the growth of bacteria contaminants. The infected potato tubers were surface sterilized in 1% sodium hypochlorite solution for 10 minutes; based on the fact that tuber surfaces are bound to carry more pathogens than leaves and other tissues. Peeling the tubers, and surface sterilizing the peeled tubers before slicing off tissues for isolation could be very problematic. Using mild concentrations of surface disinfectants could not get rid of all the different classes of pathogens on tuber surfaces. Besides the pathogen of interest was expected to be inside the tuber. The surface sterilized tubers were then cut with infected portions and placed aseptically on each Petri dish containing PDA.

This general purpose medium usually yields many fungi isolates. The cut pieces were also placed on Acetate Differential Agar enriched with Dextrose (prepared similarly to PDA). This medium based on our experience yields many fungi isolates as well. The Actetate medium was originally meant for bacteria culture but it proved very useful for fungal isolation especially when isolating *Trichoderma* and *Fusarium* species. The isolation of *Trichoderma* species was done using these standard media and it was similar to the isolation of any fungi agent.

Seven days were necessary for incubation of the plate at circa 29°C (Shahnaz et al., 2015; Khare et al., 2016). The emergent fungi were sub-cultured on PDA to obtain pure cultures. The fungi were identified by microscopy (ZEISS compound microscope), literature, and manuals on fungi (Barnett and Hunter, 1972). The fungal isolates were sent for confirmation of the identity of the species especially concerning the species epithet to the Crop Protection Department, Ahmadu Bello University Zaria. The identification was positively confirmed and tallied with ours.

2.3 Experimental design

2.3.1 Management of Fusarium dry rot of potato utilizing synthetic fungicides

The subtrial was conducted using a standard in the form of Ridomil (Ridomil gold plus at 2.5 g L^{-1}), Ketoconazole (2500 mg L^{-1}), Itraconazole (2500 mg L^{-1}), sulphur dust (2.5 g L^{-1}), and a Control. The synthetic fungicides utilized in this study were weighed using a mettler balance and dissolved in sterile distilled water. This rate was considered as the 100% concentration. The 50% concentration was made by diluting the 100% concentration using sterile distilled water.

The chemical agents were applied on the surface of the agar once the agar had set. The chemical agent was allowed to cover the whole surface of the plate then the excess chemical was removed with the pipette. The agar was allowed to dry in the airflow hood and no excess chemical that could be seen as runoff was permitted to remain in the agar surface.

The experiment was carried out in vitro using Petri dishes which were laid out using a completely randomized design with nine treatments that were replicated three times. Potato dextrose agar was used for this trial. The treatments included the following: Ridomil 100%, Ketoconazole 100%, Itraconazole 100%, sulphur 100%, Ridomil 50%, Ketoconazole 50%, Itraconazole 50%, sulphur 50%, and a Control. These treatments were applied once per petri dish and according to the replications of the treatments.

2.3.2 Effects of plant extract applied against Fusarium dry rot of potato

Aqueous extracts (at 100% concentration) containing candle bush (*Senna alata*) leaves (at 150.0 g L^{-1}) or locust bean (*Parkia biglobosa*) bark (at 150.0 g L^{-1}), and *Eucalyptus globulus* (i.e. blue gum) resin (at 70.0 g L^{-1}), and sweet alligator pepper (*Aframomum melegueta*) (at 70.0 g L^{-1}) were prepared per liter of distilled water. The plant tissues were collected from the university and its environs. The plant tissues were blended using a Warrington blender and the aqueous extracts were filtered using a double-layer sterile muslin cloth placed in a funnel over a beaker.

Potato dextrose agar was used for this trial. The set of treatments included 50% and 100% concentrations of the aqueous extracts of the plant materials (candle bush, locust bean, blue gum (i.e. *Eucalyptus globulus*), sweet alligator pepper, and a control (without plant extract). The nine treatments were replicated three times in the completely randomized design layout *in vitro*.

The plant extracts were applied on the surface of the agar once the agar had set. The plant extract was allowed to cover the whole surface of the plate then the excess extract was removed with the pipette. The agar was allowed to dry in the airflow hood and no excess plant extract that could be seen as runoff was permitted to remain in the agar surface.

Sweet alligator pepper (*Aframomum melegueta*) (in the ginger family Zingiberaceae) is also known as Grain of Peace. *Senna alata* is commonly called candle bush, ringworm cassia, ringworm shrub, or wild senna. *S. alata* is also called *Cassia alata. Eucalyptus globulus* (in the family Myrtaceae) is commonly known as southern blue gum or blue gum.

2.3.3 Effects of some biocontrol agents against potato dry rot pathogen

The experiment was carried out in Petri dishes which were laid out using a completely randomized design with three replications for each treatment. Thus, there were four treatments which were each replicated in triplicates. The set of treatments consisted of the following isolates: *T. harzianum* isolate BGMZ3, *T. harzianum* isolate BGMZ4, *T. harzianum* isolate NSBM, and a Control.

Potato dextrose agar was used for this trial. The isolates were applied using a cork borer. The cork borer was flamed over a bunsen burner flame and used to cut the colony which was placed at the edge of the petri dish/plate. This method ensured that fairly equal amount of propagules for the trial.

2.4 Data collection and analyses

The radius of the fungus colony was measured at 24-hour intervals from the first to the seventh day during each of the three sub-experiments. The analysis of variance (ANOVA) was utilized to determine the significance of the data and the means were ranked using Duncan's multiple range test (DMRT) ($p \leq 0.05$) as available in the Genstat 2nd Edition Discovery version. Equation (1) was employed to calculate percentage inhibition:

$$PI = [(CT-TC)/CT)]*100 \qquad (1)$$

Where
PI = percentage inhibition of the pathogen (%)
CT = mean radius of the control plot (measured through the center of the plate)
TC = mean radius of the treated plot (measured through the center of the plate) (Ndifon, 2023).

3. Results and Discussion

3.1 Effects of synthetic fungicides applied against *Fusarium* species.

The results revealed that Ketoconazole (at 100% concentration) was the best fungicide which was consistently able to control ($p \leq 0.05$) dry rot agent compared to the other treatments (Figure 1). This excellent performance was followed by that of Ketoconazole-50%, Itraconazole-100%, Itraconazole-50%, Sulphur-100%, Ridomil-100%, Sulphur-50%, and finally Ridomil-50%.

All the synthetic fungicides (at both 50% and 100% concentrations) were significantly different ($p \leq 0.05$) compared to the control. The percentage inhibition of the growth of *Fusarium oxysporum* by synthetic chemicals ranged from 21.7-100% with time. All the potential chemical fungicides applied against dry rot disease agents were very effective.

These findings agree with those of Aydin (2019) who reported that Fludioxonil controlled the pathogen of dry rot more compared to Azoxystrobin and *Trichoderma* species. Likewise, Ndifon (2024) showed the efficacy of Ketoconazole when combined with *Trichoderma* species to combat the effects of *Agroathelia rolfsii* which corroborates these present findings on the excellent performance of ketoconazole.

Leach and Nelson (1975) revealed that thiabendazole was able to reduce diseases caused by *Fusarium* species which confirms the fact that chemical agents can inhibit these *Fusarium* agents effectively. Thus, Ab Rahman et al. (2017), Adolf et al. (2020), and Riaz et al. (2022) reiterated that the application of synthetic pesticides remains the main method employed to mitigate infection by almost all potato diseases. They emphasized that these pesticides significantly contribute to environmental damage and lead to pesticide resistance by pathogens when the pesticides are abused.

For example, Bojanowski et al. (2013) pointed out that sufficient resistance against potato dry rot agents is lacking coupled with the discovery that these pathogens have developed resistance against thiabendazole which was relied on for years. A need for diverse agents and methods to combat potato dry rots is prominent to prevent the development of resistance to effective agents. This current study has shown that diverse control agents can be equally effective against *F. oxysporum.*

Presently we saw that chemical fungicides caused inhibition of *Fusarium* sp. by 39.1-95.7% with time during this trial which corroborates these findings. The table for percentage inhibitions is not presented herein to avoid any implied double presentation or so. The calculation was carried out using Equation 1 for those who want to confirm the figures presented here.

Md-Mahi and Nayem (2023) utilized Mancozeb 80% WP against late blight of potato but they observed that plant infection increased to 71.7% from the prevailing 22.0% infection rate. They utilized Lycomax™ to effectively control both late blight and early blight, while Mancozeb 80% WP was potent against early blight only. This shows that the efficacy of agro-fungicides varies with the pathogen and the type of chemical as was shown in this current research.

Aydın and İnal (2018) reported the presence of some limited resistance in potato cultivar Broke against potato dry rot agent in Turkey which is a sure sign of some hope that integrated management can be carried out using such limited resistance. In the absence of full resistance against pathogens causing dry rot of potatoes, we may depend confidently on the application of the principle of integrated management.

Draper et al. (1994) reported that Chlorothalonil fungicides (i.e. an ortho multi-purpose fungicide) offer the best control of early blight, while copper fungicides are less effective, providing only fair control. Ndifon and Inyang (2022) observed that solutions of mancozeb (at 100% concentration) and mancozeb+carbendazim (at 50% and 100% concentrations) were more effective in suppressing the development of pathogenic *Lasidioplodia theobromae* compared to a combination of mancozeb+metalaxyl+copper. Thus, tank mixtures of fungicides do not always give additive effects.

Waterworth (2023) said azoxystrobin, chlorothalonil, mancozeb, pyraclostrobin, and pyraclostrobin can be applied against potato blights. These chemical fungicides are still being relied on by farmers.

3.2 Effects of plant extracts applied against potato dry rot disease agent

The results revealed that *Eucalyptus* sp. (at 100% concentration) was the best plant extract which was consistently significantly different ($p \leq 0.05$) compared to the other treatments (Figure 2). This excellent performance was followed by that of *Eucalyptus* sp.-50%, Sweet alligator pepper-100%, locust bean-100%, Sweet alligator pepper-50%, *Senna alata*-100%, locust bean-50%, and *Senna alata*-50%.

All the plant extracts (at both 50 and 100% concentrations) were significantly different ($p \leq 0.05$) compared to the control. The plant extracts caused 20.6-100% inhibition of this *Fusarium* species with time. The effective control by plant extracts lasted for 192 hours compared to the synthetic chemicals which lasted just 120 hours after inoculation.

The efficacy of plant extracts revealed that *Senna alata* was able to control the pathogenic fungus. Chatterjee (1990) reported that the oils of *Cassia* sp. and clove inhibited the growth of *Aspergillus flavus*, *Curvularia pallescens,* and *Chaetomium indicum* isolated from maize, which corroborated the findings on candle bush or *Cassia alata / S. alata* and other plant extracts.

Ehiobu et al. (2022) reported that significant antifungal activity against *Fusarium solani*, (the causal agent of potato rot disease) was obtained using *Eucalyptus camaldulensis* and five other plant extracts exhibited *in vitro* and *in vivo* which confirmed the findings on *Eucalyptus* sp. and other plant extracts tested herein.

Ndifon and Inyang (2022) inhibited the growth of *Lasidioplodia theobromae* by 70% or more using *Eucalyptus* sp. (at 100% concentration), *Ricinus* soap (at 50% and 100% concentrations), and *Guieria* sp. (at 100% concentration) which affirmed these present findings on the use of plant extracts to manage fungi infections.

Amienyo and Onuze (2015) reported that *Lantana camara* controlled the growth of *Phytophthora infestans* and *Aspergillus solani* in potatoes by 50%. Abdu et al. (2020) in Nigeria (both *in-vitro* and *in-vivo*) proved effective inhibition of potato fungal diseases (caused by *Aspergillus flavus, Thielavia terricola, Rhizopus stolonifer*, and *Scoupulariopsis brevicaulis*) using garlic oil, neem oil, and *Tridax* leaf ash.

Adolf et al. (2020) propounded the use of live garlic plants during intercropping for the management of late blight potato disease. These sources all show the potential of plant extracts, as antimycotic materials against potato diseases. Zongur (2024) revealed that *Beta vulgaris* essential oils inhibited *Fusarium* species which affirms the present findings that plant extracts were effective against *F. oxysporum*.

Özcan et al. (2024) reported that *Mentha piperita* and *Thymus vulgaris* (essential oils) completely inhibited the radial growth of *Aspergillus carbonarius*. Chatri et al. (2024) revealed that leaf extracts from *Muntingia calabura, Terminalia cattapa, Syzygium oleina, Dimocarpus longan*, and *Artocarpus altilis* effectively inhibited the growth of *S. rolfsii* compared to the control. These two trials using medicinal plant corroborated our findings on the potency of some medicinal plants against plant pathogens.

3.3 Effects of *Trichoderma* species against fungi

The results revealed that *T. Harzianum* isolates BGMZ4 was the best isolate which was significantly different in comparison with other assayed treatments (Figure 3). This excellent performance was followed by that of *T. Harzianum* isolate NSBM and then *T. harzianum* isolate BGMZ3. These *T. harzianum* isolates performed significantly better than the control. The isolates of *T. harzianum* (23.5-94.1% inhibition with time) effectively controlled the pathogen *in vitro*.

Adolf et al. (2020) reported that only a few biological control measures are used by non-organic growers of potatoes due to their slow efficacy, farmers' lack of knowledge about them, and lack of access to the most efficient biocontrol agents. These results agree with the findings of Ndifon and Inyang (2022) who reported that four isolates of *T. harzianum* inhibited the radial growth of *L. theobromae* by 8.0–100%.

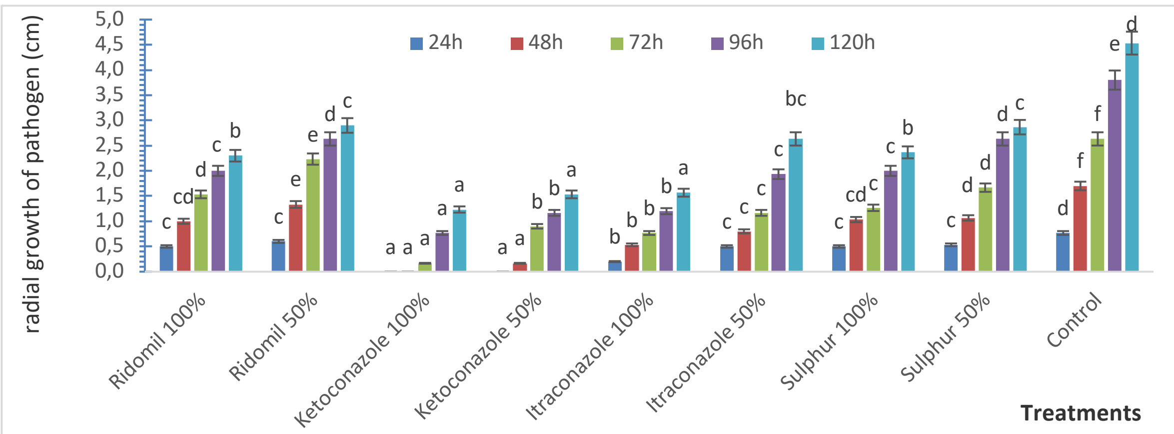
Ayed et al. (2007) and Ehiobu et al. (2022) reported that *Bacillus subtilis* var. amyloliquefaciens and *T. harzianum* inhibited the growth of *Fusarium oxysporium* from potatoes. Md-Mahi and Nayem (2023) in Bangladesh reported on the efficacy of *T. harzianum* against late blight and early blight of potatoes. These findings are in tandem with the findings of this present study.

Gupta et al. (1999) observed that *Trichoderma* spp. and *Pseudomonas aeruginosa* could successfully reduce the effects of pathogenic agents which concurs with the present findings using isolates of *Trichoderma* species. Meanwhile, Ndifon (2024) successfully utilized *T. viride, T. virens,* and *T. harzianum* isolates to inhibit *S. rolfsii* which agrees with the finding of this study herein on the use of *Trichoderma* species against pathogens.

Thus, Riaz et al. (2022) stated that the bacteria agents (like *Pseudomonas* sp., *Pantoea*, *Enterobacter*, *Bacillus cereus*, *Bacillus cepacia*, *Pseudomonas fluorescens),* and *T. harzianum*, play a major role in the mitigation of potato rot diseases. *Pseudomonas syringae* in the USA controls dry rots and silver scurf in potatoes (Al-Mughrabi et al., 2016). Seed priming with *Bacillus subtilis* formulation resulted in an approximately 56% reduction of potato common scab (Al-Mughrabi et al., 2016), which is quite promising.

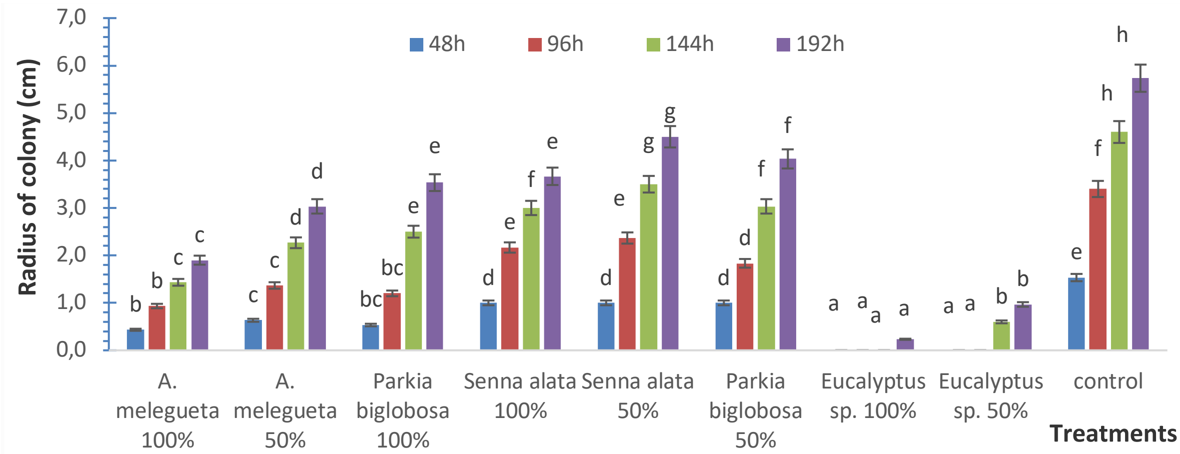
Meanwhile, Riaz et al. (2022) pointed out earlier that plant-growth-promoting bacteria are successful in reducing the growth of this fungus. In Siberia, potatoes and raspberries require maximal usage of biological agents (*Bacillus velezensis* strains) for plant protection (instead of chemicals) against *Rhizoctonia solani* (Lugtenberg, 2018; Asaturova et al., 2021).

Recently, Özakın et al. (2021) observed that eight isolates (out of 11 local isolates) belonging to Actinobacteria (mostly member of genus *Streptomyces*) exhibited antimicrobial activity against *Candida albicans* and other bacteria pathogenic species assessed. This finding is in agreement with the current study.



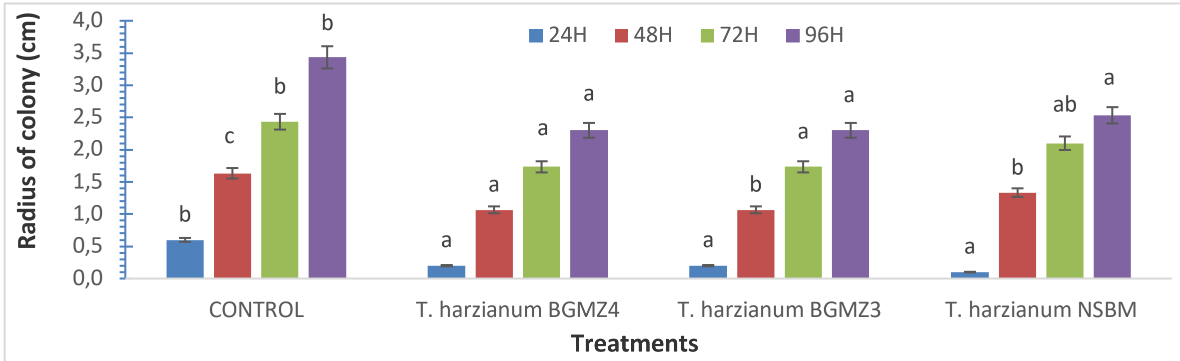
*The means of the bars in a series with similar letter(s) above them are statistically at par based on their ranking using DMRT (p≤0.05)

Figure 1. The effect of synthetic chemicals on the radial growth of *Fusarium oxysporum.*



*The means of the bars in a series with similar letter(s) above them are statistically at par based on their ranking using DMRT (p≤0.05)

Figure 2. The impact of plant extracts on the growth of *Fusarium* species.



*The means of the bars in a series with similar letter(s) above them are statistically at par based on their ranking using DMRT (p≤0.05)

Figure 3. The effect of isolates of *Trichoderma harzianum* on the radial growth of *Fusarium oxysporum*.

4. Conclusion

Potato production is a cosmopolitan activity that is carried out to obtain the tubers but this activity is consistently hindered by diseases. Three sub-trials were set up *in vitro* to determine the efficacy of different measures against potato dry rots. This study revealed that biocontrol agents (*Trichoderma harzianum* isolates), plant extracts (Blue gum, Sweet alligator pepper, and Candle bush), and synthetic chemicals (Ketoconazole, Itraconazole, Sulphur, and Ridomil) can effectively control dry rot of potato induced by *Fusarium oxysporum* f.sp. tuberosi. This study indicates that these control agents could be recommended against *Fusarium* dry rot of potatoes. Researchers should further determine the effects of these disease management materials against other fungi, bacteria, viruses, and nematodes associated with potatoes. This will help in avoiding disease replacement and the development of resistance due to suboptimal application of pesticides against these pathogens.

Ethical Statement

Ethical approval is not required for this study because the study is on plant diseases and the control agents are not poisonous to humans.

Conflict of Interest

The Author(s) declare(s) that there are no conflicts of interest.

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Author Contributions

EN: conceived the topic, designed it, carried it out, analysed and interpreted the data, wrote the article, edited it, proof read it.

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