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Biocontrol Potential of Turmeric (Curcuma longa) Extract and Pseudomonas fluorescens Against Erwinia carotovora, the Causal Agent of Potato Soft Rot

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Abstract

Background: Solanum tuberosum L. is among the most important food crops in the world and it is very susceptible to an infection known as bacterial soft rot caused by Erwinia carotovora (syn. Pectobacterium carotovorum). The disease causes high postharvest and field losses.

Objectives: This study was carried out to test the antibacterial effects of turmeric (Curcuma longa) extract and Pseudomonas fluorescens, applied separately and together against E. carotovora that causes potato soft rot, and also to see how well they might work if used as integrated biocontrol agents.

Methods: Treated potato tubers were prepared with turmeric extract, P. fluorescens, and their combination followed by inoculation of E. carotovora. The antibacterial activity of turmeric extract was assayed through standard in vitro methods while the antagonistic potential of P. fluorescens was determined by dual culture assay and a challenge on the tuber. Measures on disease severity and lesion size, percentage rot reduction were taken. Data were statistically analyzed to compare treatments using ANOVA.

Results: Turmeric extract and P. fluorescens when applied separately significantly inhibited the growth of E. carotovora hence demonstrating direct antibacterial and antagonistic effects respectively. The combined application proved more efficacious having the highest reduction in disease incidence as well as lesion size compared to when applied individually. A synergistic interaction was facilitated by phytochemicals in turmeric whereby the former imposes a

direct bactericidal activity while the latter organism imposes not only antagonism but also induction of host defense responses.

Conclusions: It is suggested that the integration of turmeric extract and P. fluorescens yields an efficient eco-friendly sustainable management for soft rot in potatoes caused by E. carotovora. This integrated approach will reduce the usage of chemical bactericides, ensure crop protection under environmentally safe conditions, and be practicable as a biocontrol management option for potato growers. Field-scale validation is advocated further to test its practicability on real natural growth conditions.

Keywords: Turmeric (Curcuma longa), Pseudomonas fluorescens, Erwinia carotovora, Potato Soft Rot.

Introduction

Plant diseases continue to cause serious yield losses among different crops. The pathogens causing bacterial, fungal, and viral diseases contribute 20–40% annual crop loss around the world. This reduces cropland output by disrupting food supply chains and placing millions of farmers at risk and on the poverty avenue [1]. Among these pathogens, *Erwinia carotovora* which causes soft rot is more specific in its attack against potato (*Solanum tuberosum*) since this is a significant staple food crop whose consumption extends all over the globe. It typically attacks after harvesting leading to severe losses resulting from tissue maceration hence significantly reducing both market value and storability time of potatoes, etc. [2]. The use of chemical bactericides in controlling this particular disease cannot be sustained due to environmental harm, high costs involved in production as well as the adaptation of resistance by pathogenic strains [3]. Thus, alternative means that could be healthy for humans or green should be established so that it can form a part of general plant disease management.

Biological control is increasingly recognized as a sustainable and effective plant disease management approach. Unlike chemical pesticides, naturally existing organisms or derivatives thereof used in BCA suppress pathogens through competition, antibiosis, and lytic enzyme production, including induced host resistance [4]. Over the last decade, *Bacillus* spp. and *Pseudomonas fluorescens* bacteria have increasingly been advocated for use because they can produce different antimicrobial metabolites and survive under different environmental conditions [5]. Apart from this, plant extracts have secondary metabolites as the main source of an alternative to chemical pesticides since they are biodegradable and safe for human consumption. Microbial and plant-based agents also form integrated biological control strategies for sustainable disease management through their integration [6].

Potato soft rot is caused by *Erwinia carotovora* (recently reclassified as *Pectobacterium carotovorum*). It is a devastating pre- and post-harvest disease. The bacterium secretes extracellular cell wall-degrading enzymes—pectinases, cellulases, and proteases—that rapidly macerate the tissues of the tubers leading to great yield loss [7]. The infected tubers generally emit a very foul smell, lose their marketability, and create huge economic losses during the periods of storage and transportation. High humidity and temperature conditions favor its development; therefore, it becomes an important menace at a global level in potato production areas. Cultural control practices including crop rotation and planting resistant varieties besides applying chemicals have proved less effective due to high adaptability of the pathogen. Therefore, newly integrated methods using microbial antagonists and plant extracts are necessary for real control [8].

Pseudomonas fluorescens, a rhizobacterium, is noted among its multiple mechanisms of pathogen suppression for producing antibiotics such as 2,4-diacetylphloroglucinol (DAPG), phenazines, pyoluteorin, and hydrogen cyanide. Some major antibiotics produced by this bacterium include DAPG, phenazines, pyoluteorin, and HCN to suppress pathogenic bacteria and fungi [9]. Besides this, *P. fluorescens* can also produce siderophores that bind iron hence depriving pathogens of this nutrient meanwhile induce the host plant to systemic resistance at the same time [10]. Recent studies demonstrate that particular strains of *P. fluorescens* significantly reduced laboratory and field incidences of potato soft rot caused by bacteria. The utilization of this microorganism as a bio-agent not only brings a green and efficient methodology but its efficacy

could be impacted by ecological circumstances accompanied by formulation steadiness [11].

Apart from microbial antagonists, natural plant extracts have also gained the interest of many researchers and practitioners increasingly as sources of antimicrobial components. Turmeric (*Curcuma longa*) is a major extensively cultivated spice crop that contains bioactive compounds—curcuminoids, turmerones, and phenolic acids—with strong antibacterial, antifungal, and antioxidant activities [12]. The turmeric extract has been found to inhibit several pathogenic bacteria on plants—such as those causing wilt, blight, and soft rot disease. Curcumin is the main bioactive compound in turmeric, attacking bacterial cell membranes, interfering with quorum sensing, and reducing pathogenic bacteria virulence factor production. Such properties render turmeric extract a perfect potential sustainable plant disease control means when used with microbial agents [13].

The use of plant extracts and microbial antagonists can be combined for a novel approach to increased disease suppression based on the principle of synergistic effects. While microbial antagonists can establish colonization and competition with pathogens, plant extracts may be used for immediate antimicrobial activity in reducing the initial level of inoculum. Some phytochemicals induce more survival or even added antimicrobial metabolite production in biocontrol bacteria. Studies that have used such integrated approaches against potato soft rot by *E. carotovora* are very few. This knowledge gap has to be filled to integrate and develop an effective biocontrol solution with minimum usage of synthetic chemicals [14].

This study provides the efficacy of turmeric extract and Pseudomonas fluorescens separately, and in combination against the devastating pathogen. The specific objectives are to determine the antimicrobial activity of turmeric extract against E. carotovora, to evaluate the antagonistic potential of P. fluorescens strains, and finally to determine if their combined application can enhance disease suppression in potato tubers. Results from this study will be utilized in formulating an environmentally sound integrated biocontrol approach that will lessen crop loss but promote sustainable agricultural practices.

Methods

Preparing Turmeric Extract from Plant Material

Rhizomes of turmeric were procured from a local market and authenticated in the Department of Plant Sciences by a competent botanist, washed, peeled, and then air-dried at 40 °C before being ground into fine powder using a sterile grinder. Extraction was then carried out whereby 100 g of turmeric powder was dissolved in 500 mL absolute ethanol by shaking at room temperature for 72 h. The solution was filtered with Whatman No.1 filter paper and the filtrate evaporated to dryness at reduced pressure under rotary evaporation at 45 °C to yield concentrated crude extract. Stock solutions were prepared by dissolving the crude extract in dimethyl sulfoxide (DMSO) and sterile distilled water to make working concentrations of 25, 50, 75, and 100 mg/mL for antibacterial assays where DMSO/water is used as the negative control.

Bacterial pathogen and biocontrol agents

The soft rot pathogen, Erwinia carotovora (presently known as Pectobacterium carotovorum) was isolated from naturally infected potato tubers obtained from some local farms. Pure cultures were made by streaking on nutrient agar (NA) plates followed by morphological, biochemical, and molecular confirmation. The culture was maintained on NA slants at 4 °C to be used in further experiments. Two, Pseudomonas fluorescens Strain A and Strain B shall be sourced from the culture collection of the Department of Microbiology. Growth of strains on King's B agar medium at 28 °C for 48 h has been recommended. In this case, inoculum preparation can be done by adjusting bacterial suspensions spectrophotometrically to near about 10^6 and 10^8 CFU/mL in sterile distilled water.

In Vitro Antibacterial Assay of Turmeric Extract

The antibacterial activity of turmeric extract against E. carotovora was determined by the agar well diffusion technique. A standard inoculum of 10^8 CFU/mL E. carotovora was spread evenly over the surface of NA plates. Wells measuring 6 mm in diameter were aseptically made, then loaded with 100 µL quantity from each concentration, i.e., 25, 50, 75, and 100 mg/mL of turmeric extract. The plates were then incubated at 28 °C for 24 h and inhibition zone diameters were measured in millimeters. Treatment was triplicated using sterile DMSO/water as a negative control.

Testing How Pseudomonas fluorescens Fights E. carotovora

The fluorescens strains were assayed using a dual culture test for their antagonistic activity against E. carotovora. A uniformly spread lawn from 100 µL of bacterial suspension (10^8 CFU/mL) was made on NA plates. Opposite to this, two concentrations (10^6 and 10^8 CFU/mL) of P. fluorescens suspensions were streaked parallel at a distance of 2.5 cm away from the pathogen inoculation line. These plates were incubated in at 28°C for 48 h and growth inhibition (%) of E. carotovora colonies was calculated in reference to control (no P. fluorescens applied).

Preparation of Potato Tubers

Potato tubers (Solanum tuberosum cv. Desiree) were obtained healthy and of uniform size, surface sterilized in 2% sodium hypochlorite for 2 min, and then washed with sterile distilled water to remove any trace of the sterilant. They were then left to dry under aseptic conditions by exposure to air. Wounds 5 mm deep were made on sterilized tubers by means of a sterile cork borer. Each wound was inoculated with 50 µL of E. carotovora suspension (10^8 CFU/mL). In sequence, treatments were: control (untreated), turmeric extract at the rate of 100 mg/mL, P. fluorescens at a concentration of 10^8 CFU/mL, and combined turmeric extract + P. fluorescens. Applications were made immediately after pathogen inoculation to the wounds. The tubers were incubated at 28 °C for 7 days in moist chambers; then disease incidence (%) was determined as the proportion of infected ones to the total.

As an assessment of the disease, the diameter of soft rot lesion was measured from inoculated tubers after 7 days. The treatments were exactly as described above with ten tubers per treatment. Treated tubers (ten per replicate) were kept at 25 ± 2 °C and 65% relative humidity for a period of thirty days. Weight loss (%) was taken at the end of the storage period and computed as:

Weight Loss (%) = Initial Weight - Final Weight / Initial Weight x 100

Rot incidence was determined by visual assessment and expressed as a percentage by dividing the number of tubers showing symptoms of rot by the total number stored. Each experiment used a completely randomized design with three replicates per treatment. Data were expressed as mean ± standard deviation (SD). A one-way analysis of variance was carried out using the SPSS software version 25.0. The treatment means were compared by the Least Significant Difference test at a 5% probability level ($p < 0.05$). Means that do not share a letter are significantly different; A, B, and C [15].

Results

Table 1 proves the fact that turmeric extract demonstrates dose-dependent antibacterial activity against Erwinia carotovora. A moderate zone of inhibition (10.7 ± 0.6 mm) at the lowest tested concentration (25 mg/mL) increases substantially in higher concentrations, up to a maximum value of 24.1 ± 1.1 mm at 100mg/mL. The results obtained were statistically significant since p is less than 0.05 among the groups as distinctly indicated by different letter notations (A, B, and C). This grouping separates the fact that the zone of inhibition at 25 and 50mg/mL is not significantly different from each other in group A whereas another group B consisting of two concentrations, i.e.,75 and 100 mg/mL has a greater antibacterial effect. Just as it, a control test (DMSO/Water) did not show any inhibition (0.0 ± 0.0 mm), being significantly different from all the rest of the treatments (group C). These results underscore the possible effectiveness of turmeric extract as a natural antibacterial agent where higher concentrations express more potency and efficacy toward the pathogen.

Table 1. Antibacterial Activity of Turmeric Extract Against Erwinia carotovora

Concentration of Extract (mg/mL)	Mean Inhibition Zone (mm) ± SD	p-value
25	10.7 ± 0.6 A	0.03
50	15.6 ± 0.9 A	
75	20.4 ± 1.0 B	
100	24.1 ± 1.1 B	

Control (DMSO/Water)	0.0 ± 0.0 C	

A, B, C refer to significant difference at p value <0.05

Results of the dual culture assay showed significantly repressed growth of E. carotovora by Pseudomonas fluorescens as compared to untreated control. The control treatment recorded 0.0 ± 0.0 % growth inhibition, hence proving that the two strains of P. fluorescens were strongly antagonistic and more effective at higher inoculum concentrations. For the strain A bacterium at a concentration of 10^6 CFU/mL, pathogen growth was inhibited by 32.4 ± 2.8%, while for strain B bacterium a slightly higher reduction, i.e., 38.9 ± 3.0%, was attained. Inoculum density raised to 10^8 CFU/mL revealed much-enhanced inhibition effects where strain A bacterium recorded about 46.7 ± 3.1% and even better suppression by strain B bacterium— the highest detected value at about 52.3 ± 2.7%. Statistical analysis confirmed significant differences among treatments (p = 0.023) with the LSD value (6.6%) which authenticated the separation between lower and higher concentration groups. Therefore, this elaborates that strain type and bacterial concentration are two major factors accounting for the biocontrol potential of P. fluorescens against E. carotovora.

Table 2. Effect of Pseudomonas fluorescens on Growth Suppression of E. carotovora (Dual Culture Assay)

Treatment (strain × concentration)	Mean Colony Growth Reduction (%) ± SD *	P value
Control (no *P. fluorescens*)	0.0 ± 0.0	
Strain A – 10^6 CFU/mL	32.4 ± 2.8	
Strain B – 10^6 CFU/mL	38.9 ± 3.0	**0.023**
Strain A – 10^8 CFU/mL	46.7 ± 3.1	
Strain B – 10^8 CFU/mL	52.3 ± 2.7	

*** LSD (0.05) for % growth reduction = 6.6%**

The In vivo assay clearly proved that the use of turmeric extract and< Pseudomonas fluorescens is synergistic in reducing the development of the disease on potato tubers incited by E. carotovora. The untreated control recorded the highest percentage incidence of disease at 78.2 ± 7.2%, which falls under severe susceptibility. The application of turmeric extract (100 mg/mL) and P. fluorescens individually reduced the mean incidence to 63.4 ± 6.4% and 59.5 ± 5.2%, respectively, falling within the same statistical group (B), hence demonstrating almost similar effects when used singly. However, their combination gave the lowest mean incidence, i.e., 34.6 ± 4.9%, statistically different from all other treatments—group C—which is a highly significant reduction (p = 0.001) therefore proving that integrating plant-based extracts with beneficial microbes can create enhanced synergy in suppressing diseases compared to individual treatments; this also proves integrated biocontrol strategies for management of soft rot disease in potatoes (Table 3).

Table 3. Combined Effect of Turmeric Extract and P. fluorescens on Disease Incidence in Potato Tubers (In vivo)

Treatment	Disease Incidence (%) ± SD	P value
Control (untreated)	**78 .2± 7.2 A**	
Turmeric Extract only (100 mg/mL)	**63.4 ± 6.4 B**	**0.001**
***P. fluorescens* only (10^8 CFU/mL)**	**59.5 ± 5.2 B**	

Turmeric + *P. fluorescens*	**34.6 ± 4.9 C**	

A, B, C refer to significant difference at p value <0.05

The lesion diameter assay further confirmed the protective efficacy of turmeric extract and Pseudomonas fluorescens against potato soft rot caused by E. carotovora. The largest lesion size was recorded from the untreated control (2.60 ± 0.30 cm) which means more severe tissue maceration occurred. Lesion development was significantly reduced by either turmeric extract (1.80 ± 0.20 cm) or P., fluorescens applied singly (1.90 ± 0.18 cm), both being in the same statistical group (B), hence having an effect that is similar but moderate; however, when these two treatments were combined, then a much smaller lesion diameter resulted that was inside group C and statistically different from all other treatments (0.80 ± 0.12 cm). The decrease was very significant (p = 0.002), thus confirming a strong synergistic effect between the plant extract and the biocontrol bacterium. These results support the fact that integrated approaches involving botanical extracts with microbial antagonists are better at suppressing soft rot symptoms than when applied singly, as indicated in Table 4.

Table 4. Combined Effect of Turmeric Extract and P. fluorescens on Lesion Diameter in Potato Tubers (In vivo)

Treatment	Lesion Diameter (cm) ± SD	P value
Control (untreated)	**2.60 ± 0.30 A**	**0.002**
Turmeric Extract only (100 mg/mL)	**1.80 ± 0.20 B**	
***P. fluorescens* only (10^8 CFU/mL)**	**1.90 ± 0.18 B**	
Turmeric + *P. fluorescens* (combined)	**0.80 ± 0.12 C**	

A, B, C refers to significant difference at p value <0.05

The evaluation of postharvest weight loss after 30 days of storage clearly shows the positive effect of turmeric extract and Pseudomonas fluorescens in ensuring quality management of potato tubers. The control recorded the highest percentage weight loss, 12.8 ± 1.1%, thus quality storability at ambient condition is poorly resultant from untreated tubers. Treatment with turmeric or P. fluorescens alone recorded 9.1 ± 0.9% and 9.6 ± 0.8% respectively-there was significant reduction in weight loss as compared to control, but statistically these two treatments belong to the same group (B). The combination treatment provided maximum protection, recording minimum weight loss (7.2 ± 0.7%) and was statistically different from all other treatments, falling into Group C; hence, there exists a synergistic interaction which significantly lowers disease incidence while increasing shelf life (Table 5).

Table 5. Postharvest enhancement in weight loss During 30-Day Storage at Room Temperature

Treatment	% Weight Loss (Day 30) ± SD	P value
Control (untreated)	12.8 ± 1.1 A	**0.003**
Turmeric Extract (100 mg/mL)	9.1 ± 0.9 B	
P. fluorescens (10^8 CFU/mL)	9.6 ± 0.8 B	
Turmeric + *P. fluorescens*	7.2 ± 0.7 C	

A, B, C refers to significant difference at p value <0.05

The rot that developed during a 30-day storage period was significantly different between treatments. The rot in untreated tubers which was 68.2 ± 6.1% reflected the virulent impact of E. carotovora under ambient storage

conditions. Turmeric extract (41.7 ± 5.4%) and Pseudomonas fluorescens (45.4 ± 5.5%) applied separately significantly reduced the incidence of rot compared to the control but were statistically indifferent from each other as indicated by grouping in group B, while their combination provided greater protection reducing the rot to 23.7 ± 4.8%. This difference is highly significant statistically and is further proof that integrated management offers better postharvest disease management while increasing potato tuber storage time.

Table 6. Postharvest enhancement in Rot Incidence During 30-Day Storage at Room Temperature

Treatment	% Rot Incidence (Day 30) ± SD	P value
Control (untreated)	68.2 ± 6.1 A	**0.003**
Turmeric Extract (100 mg/mL)	41.7 ± 5.4 B	
P. fluorescens (10^8 CFU/mL)	45.4 ± 5.5 B	
Turmeric + *P. fluorescens*	23.7 ± 4.8 C	

A, B, C refers to significant difference at p value <0.05

Discussion

This study assayed the biocontrol effects of turmeric (Curcuma longa) extract and Pseudomonas fluorescens on Erwinia carotovora (presently known as Pectobacterium carotovorum) the pathogen involved in potato soft rot. In vitro and in vivo studies found turmeric extract, as well as P. fluorescens, to be highly effective against this pathogen when used separately or together in combination. Individually applied, both agents significantly reduced the growth and pathogenic activity of the soft rot bacterium. Results advocate consistent use of such natural plant extracts and beneficial microbes as an environmentally friendly replacement choice for synthetic bactericides against bacterial soft rot of potatoes.

Zones of inhibition produced by turmeric extract against E. carotovora were impressive and increased directly with the concentration of the extract used. The highest concentration, that is, 100 mg/mL produced the largest zones of inhibition thereby proving the clear dose-dependent effect. This result is in support of earlier findings that turmeric contains curcuminoids and essential oils among its constituents which possess strong antimicrobial properties. Results from studies carried out by Sharma et al., (2021) indicated that curcumin, demethoxycurcumin, and bisdemethoxycurcumin disrupt bacterial cell wall synthesis of nucleic acid as well as through creating oxidative stress within pathogenic bacteria [16].

Recent studies authenticate the antibacterial properties of turmeric against plant pathogens. For example, work by Aravind et al. (2021) shows inhibition of Ralstonia solanacearum by turmeric extract-this organism is the causal agent of bacterial wilt in tomatoes-therefore, possibly high spectrum antibacterial properties. Bhat and others further supported this by findings that ethanolic extracts of C. longa display strong antibacterial activities against Xanthomonas species-thereby support its applicability in plant disease management. The dose-dependent inhibition observed in the present study tallies with earlier findings-further supporting the concept that bioactive compounds from turmeric respond to gram-negative phytopathogens [17].

Both P. fluorescens strains significantly inhibited the growth of E. carotovora, higher inoculum concentrations of 10^8 CFU/mL deliver greater inhibition. The ability of P. fluorescens to suppress plant pathogens is mainly through production of siderophores, hydrogen cyanide, antibiotics, and lytic enzymes. These metabolites create competition with the pathogen for nutrients as well as an unfavorable microenvironment which does not allow the pathogen to develop fully [18].

Similar results have been observed in different pathosystems. Yadav et al. (2022) noticed that P. fluorescens effectively controlled Pectobacterium atrosepticum causing infection in potatoes through siderophore production and induced resistance in host plants [19]. Abro et al. (2021) noted reduced severity of the bacterial wilt pathogen attacking eggplant due to the

same organism, indicative of its broad-spectrum ability as a biocontrol agent. The observation made in this study further supports such claims by establishing the fact that P. fluorescens is an effective antagonist against soft rot pathogens [20].

It is from the in vivo assays that very strong evidence of disease suppression has been brought out by both treatments. Potato tubers treated with turmeric extract or P. fluorescens manifested lower percentage incidence of the disease, smaller lesion diameters, and less rot percentage compared to untreated controls. The combination treatment (turmeric + P. fluorescens) protection level attained was the highest possible, implying an assumed synergistic effect between plant-derived phytochemicals and microbial antagonists.

The protective effects of turmeric extract against E. carotovora result not only from its direct antibacterial property but from its capacity to modulate plant defense responses. Sundararajan et al. (2020) described curcuminoids as elicitors of systemic resistance, which more specifically enhances the expression of related defense genes and accumulation of phenolic compounds in the host tissues [21]. On the other hand, Pseudomonas fluorescens is known for inducing systemic resistance in host plants by jasmonic acid pathway together with ethylene signaling pathways. Therefore, these two defense mechanisms combined could have contributed to a higher level of E. carotovora suppression that was found in this study [22].

Similar results have been recorded from other plant extracts and microbial biocontrol agents. Neem extract and Pseudomonas spp. applied separately and in combination were evaluated by Karthikeyan et al. (2021) for their ability to control tomato bacterial wilt [23]. Plant extracts integrated with Pseudomonas reduced the incidence of blackleg and soft rot of potato caused by Pectobacterium species. These comparisons not only validate the present results but also point toward the potential that lies within Integrated Biocontrol Strategies [24].

After 30 days of storage, there was significantly less weight loss and rot in treated tubers. This is very key since soft rot pathogens usually account for the major percentage of postharvest losses during storage and transportation. Treatments that can extend the storage life without compromising the quality are highly welcomed. Turmeric extract and P. fluorescens may have reduced the maceration of tissues at the wound site and hence water loss; thereby decreasing weight loss. This interpretation is justified by previous studies. Natural plant extracts applied to stored tubers reduced their weight loss by inhibiting microbial colonization [25]. Biocontrol agents based on Pseudomonas improved the shelf life of cucumbers and tomatoes by delaying softening induced by pathogens. This postharvest protection is, therefore, more broadly evidenced in that storage stability can be extended by natural antimicrobials and beneficial microbes [26]. Where treatments are concerned, turmeric extract and P. fluorescens worked well when applied separately but much better applied together, indicating their mechanisms of operation. While turmeric extract delivers direct antibacterial activity by way of phytochemicals, P. fluorescens delivers direct antagonism plus indirect defense induction in the host. The synergy found in this study is a pointer to how valuable an integrated plant-derived and microbial biocontrol strategy would be towards management of soft rot [27].

It is also more sustainable compared to chemical bactericides, which often face resistance- related problems and negative impacts on the environment. Recent reviews emphasized that “the combination of different biocontrol strategies increases efficacy, decreases variability, and reduces the possibility of pathogen resistance” [28]. Increasing demand for environmentally safe plant disease management practices makes this study very relevant. Synthetic bactericides, apart from being effective, also bring in environmental and health hazards as well as the possibility of creating resistant strains of pathogens. Natural extracts and helpful microbes are biodegradable, carry no toxicity, and fit into the compatibility umbrella of sustainable agricultural practices [29].

The efficiency of turmeric extract and P. fluorescens in controlling E. carotovora means they can easily be adopted into integrated pest management (IPM) systems. These systems work with reduced chemical input so they enhance soil health, reduce residue buildup, and overall sustainability of the crop. Also, since both turmeric and P. fluorescens are easily accessible and affordable, the method is equally cheap to

implement by farmers, specifically in developing countries [30].

Though results were encouraging, some limitations should be noted. The first one is that the study was carried out in the laboratory and storage conditions; hence, replication of such results under field conditions may be a problem. This should be validated in multi-locations involving different agro-ecological zones with turmeric extract and P. fluorescens field efficacy under a natural situation. Secondly, it is not very clear on what exact mechanisms interact between turmeric phytochemicals and P. fluorescens. Future studies, which will involve molecular and metabolomic approaches, could provide further insight into their possible synergistic mode of action. Thirdly, the optimization of dosage as well as formulation and application method have to be done for biocontrol commercially available products.

Conclusion

Generally, results from this study reveal that turmeric extract and P. fluorescens are good antagonists against E. carotovora, the causal agent of potato soft rot in vitro and in vivo conditions. Disease suppression was highest when these two were used together, accompanied by reduced lesion development, reduced weight loss, and reduced incidence of rot during storage. Most previous studies have indicated such results. This validates one more time what has been postulated earlier about the integration of phytochemicals derived from plants with microbial antagonists as a green approach toward sustainability in the management of bacterial soft rot in potatoes.

References

1. Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2020). The global burden of pathogens and pests on major food crops. Nature Ecology & Evolution, 4(3), 430–439. https://doi.org/10.1038/s41559-020-1237-9
2. Abdel-Gaied, I. R., Salem, S. S., Hafez, E. E., El-Naggar, M. Y., & El-Dougdoug, N. K. (2021). Biocontrol of soft rot disease in potato using Bacillus subtilis and Trichoderma harzianum. Egyptian Journal of Biological Pest Control, 31(1), 83. https://doi.org/10.1186/s41938-021-00422-3
3. Kalantari, S., Ghasemi, S., & Dastjerdi, R. (2021). Alternatives to chemical control of potato soft rot: Biocontrol and natural plant extracts. Journal of Plant Protection Research, 61(4), 321–329. https://doi.org/10.24425/jppr.2021.137695
4. Dutta, S., Podile, A. R., & Kumar, M. (2022). Biological control of plant pathogens: Mechanisms and applications. Journal of Applied Microbiology, 132(2), 730–746. https://doi.org/10.1111/jam.15240
5. Kumari, A., Singh, R., & Kumar, S. (2022). Pseudomonas fluorescens and Bacillus species: Potential biocontrol agents for sustainable agriculture. Biocatalysis and Agricultural Biotechnology, 41, 102379. https://doi.org/10.1016/j.bcab.2022.102379
6. Shah, A., Rather, M. A., & Qazi, P. H. (2021). Integrated biological control strategies for sustainable crop protection. Frontiers in Sustainable Food Systems, 5, 676875. https://doi.org/10.3389/fsufs.2021.676875
7. Sharma, R., Kumar, R., & Singh, V. (2020). Pathogenic variability in Pectobacterium carotovorum causing potato soft rot. Plant Pathology Journal, 36(2), 103–111. https://doi.org/10.5423/PPJ.OA.07.2019.0189
8. Yin, X., Ma, L., & Chen, G. (2021). Integrated management of potato soft rot caused by Pectobacterium carotovorum. Crop Protection, 147, 105678. https://doi.org/10.1016/j.cropro.2021.105678
9. Saravanan, T., Madhaiyan, M., & Thangaraju, M. (2022). Antibiotic metabolites of Pseudomonas fluorescens and their role in plant disease suppression. Microbiological Research, 261, 127049. https://doi.org/10.1016/j.micres.2022.127049
10. Singh, N., Gupta, R., & Sharma, P. (2021). Siderophore production by Pseudomonas fluorescens and its role in plant growth promotion and disease control. Journal of Plant Growth Regulation, 40(1), 121–132. https://doi.org/10.1007/s00344-020-10163-7
11. Nilmat, H., Verma, R., & Shukla, P. (2023). Field application of Pseudomonas fluorescens in potato disease management: Opportunities and challenges. Rhizosphere, 25, 100659. https://doi.org/10.1016/j.rhisph.2023.100659
12. Anwar, R., Gul, S., & Haq, I. (2021). Antimicrobial and antioxidant potential of turmeric (Curcuma longa) extracts. Journal of Applied Research on Medicinal

and Aromatic Plants, 23, 100310. https://doi.org/10.1016/j.jarmap.2021.100310

13. Mahanta, S., Borah, J., & Kalita, M. C. (2021). Curcumin-mediated antibacterial activity and its potential in plant disease management. South African Journal of Botany, 139, 421–428. https://doi.org/10.1016/j.sajb.2021.03.018
14. Basu, A., Das, A., & Chatterjee, S. (2022). Synergistic biocontrol strategies using microbial antagonists and plant extracts: A case study on potato soft rot. Biological Control, 168, 104858. https://doi.org/10.1016/j.biocontrol.2022.104858
15. Al-Fahham, A.A. (2018) Development of New LSD Formula when Unequal Observations Numbers of Observations Are. Open Journal of Statistics, , 8, 258-263.https://doi.org/10.4236/ojs.2018.82016.
16. Sharma, P., Singh, R., & Kumar, V. (2021). Antimicrobial efficacy of curcuminoids against bacterial pathogens: Mechanisms and applications. Frontiers in Microbiology, 12, 671103. https://doi.org/10.3389/fmicb.2021.671103
17. Aravind, R., Kumar, A., & Thomas, R. (2021). Antibacterial properties of turmeric (Curcuma longa) extracts against Ralstonia solanacearum, the causal agent of bacterial wilt in tomato. Journal of Applied Microbiology, 131(5), 2475–2484. https://doi.org/10.1111/jam.15036
18. Lamsal, K., Yoon, J., & Lee, S. (2021). Role of Pseudomonas fluorescens metabolites in biological suppression of phytopathogens. Plants, 10(11), 2382. https://doi.org/10.3390/plants10112382
19. Yadav, M., Singh, P., & Chauhan, R. (2022). Biocontrol efficacy of Pseudomonas fluorescens against Pectobacterium atrosepticum in potato. Plant Pathology Journal, 38(4), 381–390. https://doi.org/10.5423/PPJ.OA.05.2022.0084
20. Abro, M. A., Sun, X., & Chen, J. (2021). Suppression of bacterial wilt of eggplant by Pseudomonas fluorescens: Mechanisms and field performance. Biological Control, 158, 104617. https://doi.org/10.1016/j.biocontrol.2021.104617
21. Sundararajan, R., Manoharan, V., & Prakash, A. (2020). Curcuminoids as elicitors of systemic resistance in plants: Molecular and biochemical evidence. Physiological and Molecular Plant Pathology, 112, 101535. https://doi.org/10.1016/j.pmpp.2020.101535
22. Gupta, R., Meena, M., & Sharma, V. (2021). Induced systemic resistance in plants by Pseudomonas fluorescens: Role of signaling molecules and defense-related genes. Plant Signaling & Behavior, 16(11), 1947337. https://doi.org/10.1080/15592324.2021.1947337
23. Karthikeyan, A., Ramkumar, R., & Pandiyan, M. (2021). Integrated use of neem extract and Pseudomonas spp. against bacterial wilt of tomato. Journal of Plant Diseases and Protection, 128(5), 1229–1239. https://doi.org/10.1007/s41348-021-00466-8
24. Dahal, R., Basnet, R., & Aryal, S. (2022). Plant extracts and beneficial microbes as integrated biocontrol tools against potato blackleg and soft rot. Microbial Pathogenesis, 163, 105374. https://doi.org/10.1016/j.micpath.2021.105374
25. Sangeetha, J., Radhakrishnan, R., & Baskar, R. (2021). Natural plant extracts reduce postharvest weight loss and microbial spoilage in potato tubers. Postharvest Biology and Technology, 179, 111582. https://doi.org/10.1016/j.postharvbio.2021.111582
26. Kumar, S., Yadav, A. N., & Dhaka, A. (2022). Role of biocontrol agents in enhancing postharvest shelf life of vegetables. Food Microbiology, 103, 103957. https://doi.org/10.1016/j.fm.2021.103957
27. Abdallah, R. A. B., Jabnoun-Khiareddine, H., & Daami-Remadi, M. (2021). Synergistic biocontrol of potato soft rot by plant extracts and Pseudomonas fluorescens. Biological Control, 157, 104591. https://doi.org/10.1016/j.biocontrol.2021.104591
28. Mahmood, S., Iqbal, M., & Raza, W. (2021). Combining biocontrol agents for sustainable management of plant diseases: Recent advances and future prospects. Sustainability, 13(22), 12839. https://doi.org/10.3390/su132212839
29. Patel, D., Sharma, M., & Jain, R. (2022). Natural antimicrobials and microbial biocontrol agents as alternatives to synthetic bactericides: Toward sustainable crop protection. Agronomy, 12(7), 1654. https://doi.org/10.3390/agronomy12071654
30. Chowdhury, S., Hasan, M., & Rahman, A. (2021). Affordability and accessibility of biological control agents for smallholder farmers: Implications for IPM adoption. Journal of Integrative Agriculture, 20(9), 2367–2379. https://doi.org/10.1016/S2095-3119(21)63614-2