Research Article

Exploring the Potential of Potato Germplasm Against Streptomyces Scabies and its Management Through Plant Extracts, Bactericides and Plant Growth Promoting Rhizobacteria (PGPRs) Under Lab and Field Condition

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Abstract | Potato (*Solanum tuberosum*) is an important staple food in most parts of the world. The aim of this study was to find the resistant potato germplasm alone and through the application different amendments (plant extracts, bactericides, and PGPRs) against *Streptomyces scabies* in laboratory and field conditions. Initially screening of different amendments against the disease was checked in laboratory through disc sensitivity technique, Later on most efficient amendment was tested in field. FD3536 was found to be resistant to the *S. scabies* infection. Aqueous extracts of three different plants i.e. Neem (*Azadirachta indica*), Kaneer (*Nerium oleander*), and Bhang (*Cannabis sativa*) were evaluated at 15%, 20%, and 25% against the colony growth of *S. scabies in* lab conditions. None of them was found effective in inhibiting the pathogen's growth. Three bactericides i.e., Oxytetracycline, Tetramycin, and Benzothiazolinone were tested at 500 ppm, 700 ppm, and 1000 ppm concentrations. Only Tetramycin was found to be the most effective. Six plant growth-promoting rhizobacteria (PGPRs) i.e. *Pseudomonas putida, Pseudomonas fluorescens, Agrobacterium fabrum, Cytobacillus firmus, Lysin bacillus ochrobactrum,* and *Bacillus megaterium* were evaluated against bacterial colony growth. *P. putida* was the most effective in inhibiting *S. scabies* colony growth. The efficacy of Tetramycin, *P. putida,* and *P. fluorescens* was assessed in field conditions. Tetramycin was found to be more effective in minimizing disease severity as compared to *P. putida,* and *P. fluorescens.*

Received | Jun 22 2025; **Accepted** | Aug 30, 2025; Published | November 29, 2025
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Citation | Usman, M., M. Mubeen, S.A. Nadeem, M.U. Shahbaz, M. Kamran, S. Ahmad, W. Abbas, S. Ehsan, A. Khalid, Z.U. Ashraf and M.E.U. Haq. 2025. Exploring the potential of potato germplasm against streptomyces scabies and its management through plant extracts, bactericides and plant growth promoting rhizobacteria (PGPRs) under lab and field condition. Sarhad Jurnal of Agriculture, 41(4): 2033-2042.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.4.2033.2042
Keywords | Potato, *Streptomyces scabies*, PGPRs, Plant extracts, *Pseudomonas putida*, Disease management.

Introduction

Potato (*Solanum tuberosum*) ranks third among crops worldwide, following rice and wheat. It is known for its high efficiency in producing dietary fiber, high-quality protein, minerals, and vitamins (Sharde *et al*., 2024). This staple food crop is valued for its nutritional content. *S. tuberosum* belongs to family *Solanaceae* and genus *Solanum* (Reddy *et al*., 2018).

Potato is produced in more than 149 countries in tropical and sub-tropical regions. In 2022, the top potato producer was China, which harvested 95.6 million tonnes. India followed in second place with an output of 56.1 million tonnes, while Ukraine ranked third with 20.9 million tonnes. Russia secured the fourth position with 18.9 million tonnes, and the USA came in fifth with 17.8 million tonnes. Pakistan's potato production has surged, propelling the country into the ranks of the world's top-ten producers with an output exceeding eight million tonnes (Hasan, 2024).

Potato scab is a bacterial disease, act as a pathogen on the potato crop, caused by *Streptomyces scabies*, which forms characteristic lesions on tubers, reducing their marketability. *It* has been reported in many countries such as China, South Africa, Pakistan, Iran, Russia, India, United States and several other countries of the world (Ismail *et al*., 2020b). By developing lesions on potato tubers, potato scab reduces market value of product (Biessy and Filion, 2022). Potato scab is a major constraint to potato production, causing 10–30% yield losses globally due to reduced tuber quality and marketability (Dees and Wanner, 2012). In Pakistan, the disease affects key potato-growing regions, with estimated annual economic losses of $500,000, particularly impacting export markets (Nisa *et al*., 2022).

S. scabies can survive indefinitely in most soils except the most acidic ones. *Streptomyces scabies* has branched cylindrical mycelium approximately 1 µm thick with few or no cross walls. The mycelium produces cylindrical spores about 0.6 by 1.5 micrometers, on specialized spiral hyphae. These hyphae develop cross walls from the tip toward their base, and, as the cross walls constrict, spores are pinched off at the tip and eventually break away. The spores produce one or two germ tubes, which develop into the myceloid form. The severity of common scab of potato increases as the pH of the soil increases from 5.2 to 8.0 and decreases beyond these limits. Potato scab incidence is reduced greatly by high soil moisture during the period of tuber initiation and for several weeks afterward. Potato scab is also lower in fields after certain crop rotations and the plowing under of certain green manure crops, probably as a result of inhibition of the pathogen by antagonistic microorganisms (Esther Faucher, 2009).

Initially, typically purple-brown, pimple-like swellings up to 2 mm in diameter are the typical symptoms of scab that are apparent to the naked eye. The pustules expand and they burst the periderm. Each lesion develops into a shallow hole that is properly called a scab and is filled with a powdery mass of the pathogen's resting spores (Whitehead *et al*., 1953). Normally, the pathogen just damages the surface tissues, but it can infect deeply and kill the tuber (Harrison *et al*., 1997).

Chemical treatments are successfully managing plant diseases. However, they pose significant problems such as environmental harm and emergence of microbial resistance (Anggriani *et al*., 2015). On the other hand, plant extracts have no side effect on environment and contain different antimicrobial compound which are effective against different pathogens (Chethana *et al*., 2015). For instance, *Azadirachta indica* (Neem) extract has shown antimicrobial activity against *Ralstonia solanacearum* (Chethana *et al*., 2015), and *Pseudomonas fluorescens* has demonstrated disease suppression against *Rhizoctonia solani* in ginger (Dinesh *et al*., 2015). For example, study on *S. scabies* showed that some plant extracts (e.g., myrrh, lavender, garlic) and flavonoids (e.g., sophoraflavanone G, baicalein) showed promising bactericidal activity by disrupting cell membranes and inducing pathogen death. Such results reflect the potential of natural phytochemicals as environmentally friendly alternatives for disease management of plants (Gutierrez *et al*., 2022).

For example, study of *Bacillus atrophaeus* DX-9 demonstrated that its use suppressed potato common scab incidence and increased soil nutrient levels while stimulating beneficial microbial communities and generating bioactive metabolites.

This shows the promise of microbial inoculants as eco-friendly biocontrol agents in plant disease control (Cao, 2025). Plant Growth-Promoting Rhizobacteria (PGPR), naturally present in the soil inhabit the roots of plants, facilitating crucial interactions between plants and microorganisms. Their capacity to improve productivity and sustainability in environments where food security is paramount has made these beneficial rhizobacteria the focus of significant interest (Jeyanthi and Kanimozhi, 2018). The actions of PGPRs are variable and have a significant impact on plant growth through various direct and indirect mechanisms (Dinesh *et al*., 2015).

The objective of this study was to screen the potato germplasm against the potato scab disease and to assess the relative efficacy of selected bactericides, PGPRs, and plant extracts under both laboratory and field conditions against *S. scabies*.

Materials and Methods

Collection and preparation of scabies culture

The diseased potato tubers were collected from the field in polythene bags and taken to the lab. The samples were washed under tap water and air dried. Diseased parts were cut along healthy parts and were dipped into 1% NaOCl (Sodium hypochlorite)for surface sterilization for 30 seconds and rinsed twice with sterilized water. The samples were macerated in pestle and mortal and serial dilutions from 10^{-1} to 10^{-7} were made. 20 µL suspensions from the 10^{-7} was poured and spread on nutrient agar petri plates to culture the pathogen in the lab. The plates were wrapped with parafilm and incubated at 27°C for 24 hours. To obtain pure cultures, individual colonies that showed typical morphology (e.g., white powdery physical appearance similar to fungal mycelium-like growth) were transferred onto new plates. In the case of purity, the procedure was repeated several times (around two to three times) until colonies formed from single cells.

Screening of potato germplasm against scabies:

For the screening of potato resistant varieties, a screening trial was conducted to screen 50 potato varieties along with check against *S. scabies*, a pathogen responsible for significant yield losses in potato crop. These varieties of potato were collected from the Vegetable Research Institute, AARI. The screening trail was conducted in Augmented Layout Design with 3 replications. This design allowed for the efficient identification of resistant varieties by comparing them against standard check varieties under field conditions. These varieties were sown in the sick bed of *S. scabies* which is a soil-borne disease. The disease rating scale was used to screen the potato varieties against common scab of potato (Andrade *et al*., 2019).

In-vitro evaluation of different plant extracts, bactericides, and PGPRs:

Fresh healthy leaves of Neem (*Azadirachta indica*), Kaneer (*Nerium oleander*), and Bhang (*Cannabis sativa*) were taken, washed under tap water, and air-dried on tissue paper. The leaves were surface sterilized with pure ethanol and 5g samples were macerated in the distilled water up to 50 ml and filtered. The aliquot was considered standard and 15 %, 20 %, and 25 % concentrations were made after adding the required amount of distilled water.

Three bactericides i.e., Oxytetracycline, Tetramycin, and Benzothiazolinone were used at 500 ppm, 700 ppm and 1000 ppm concentration against colony growth of *Streptomyces scabies* under lab conditions. These concentrations of 500 ppm, 700 ppm, and 1000 ppm of these bactericides form the stock solution of 10,000 ppm by making 1% of these bactericides.

Different plant growth promoting rhizobacteria i.e. *Pseudomonas putida, Pseudomonas fluorescens, Agrobacterium fabrum, Cytobacillus firmus, Lysin bacillus ochrobactrum,* and *Bacillus megaterium* were taken against bacterial growth of *Streptomyces scabies.* PGPR strains were obtained from the Soil Biochemistry Research Institute, AARI, Faisalabad. Pure cultures were maintained on nutrient agar medium under aseptic conditions.

These plant extracts, bactericides, and PGPRs were evaluated by using the disc sensitivity technique (Fairbrother and Martyn, 1951). Sterile foam discs (6 mm diameter) were placed on petri dishes (90 mm) containing nutrient agar inoculated with *S. scabies*. Discs were dipped into the culture of PGPRs and placed on the plates. Plates were incubated at 27°C for 24–48 hours, and inhibition zones were measured in cm.

In-vivo evaluation of Bactericide and PGPRs:

The effective bactericide (Tetramycin at 1000 ppm) and PGPRs (*P. putida* and *P. fluorescens*) against *S. scabies* showed promising results in the lab, and were tested in the field on "Lady Roseta" susceptible potato variety. The experiment was conducted in an already prepared sick field. The bactericide and PGPRs were applied as seed dressing and soil drenching at the time of sowing. Tetramycin was applied at 1000 ppm, and PGPRs were applied as seed dressing (10 ml per 100 g of seed) and soil drenching (100 ml per plant at sowing). In control, no treatment was applied and potato seeds were sown in the sick field. All the agronomic practices were carried out. The disease data were recorded at the time of harvest. At harvest, disease severity was assessed visually using a 0–5 scale and percentage of infected surface area.

Disease severity (%) = (Sum of individual ratings / (Maximum rating × Total samples)) × 100

Statistical analysis:
Data from *in vitro* tests and field experiments were subjected to Analysis of Variance (ANOVA) at a level of significance α=0.05. Treatment means were compared by LSD test to ascertain significant differences among plant extracts, bactericides, PGPRs, and control.

Results and Discussion

Screening of potato varieties:
Under field conditions, different potato varieties/lines showed different responses to *S. scabies* pathogen. No variety/line was found to be immune and highly resistant against pathogen's infection. Only one variety/line (FD3536) showed resistant response against the disease. Eighteen varieties/lines (Simply Red, CK-40, FD73-73, FD78-51, FD63-1, FD78-36, FD74-21, FD76-18, FD61-3, Sante, SL15-10, SL14-15, SL5-2, V14, V15, SL13-43, SL-52 & ETAB) showed moderately resistant response against *S. scabies*. Eighteen potato varieties/lines (SHL-RED, Punjab, Cardinal, Diamont, FD 35-36, FD76-67, Cosmo, SL9-14, Sutlej, 7450, 9814, 391202-158, 394005-115, 394028-37, 394032-16, 394055-40, 396240-21 & 396266-33) showed moderately susceptible response. Multan, Ruby, FD 48-1, FD71-1, SHL-WHI, 9808 & 393574-61 exhibited susceptibility to the disease. Six varieties/lines i.e. Lady Roseta, FSD White, FD77-4, FD74300, Sadaf & Kashmir were recorded as highly susceptible to the pathogen's virulence in field conditions (Table 1).

Sohaib Ismail *et al* use several potato germplasms/cultivars to get resistant germplasm/cultivars against *S. scabies*, which causes potato scab disease. These germplasms/cultivars were assessed in the field to check susceptibility or resistance to it. Through finding resistant germplasm/cultivar, this information was further used to provide to the breeding projects for creating more resistant cultivars to potato scab for increasing potato yield and quality (Ismail *et al*., 2020a). Another study examines the severity and prevalence of common scab in several potato-growing regions of Punjab, Pakistan. Sahiwal showed the highest incidence with a decreasing rate in Okara, Kasur, Pakpattan, and Faisalabad. Hazro and Sialkot showed the lowest incidence. Cardinal and Diamant exhibited intermediate susceptibility and Lady Rostia and Asterix were shown high resistance to scab (Nisa *et al*., 2022).

Table 1: *Screening results of potato varieties/lines against S. scabies in field.*

% Infected portion	Reaction	Name of varieties/ lines	No. of varieties/ lines
0	Immune	-	0
< 08	Resistant	FD-3536	1
8-15	Moderately resistant	Simply red, CK-40, FD73-73, FD78-51, FD63-1, FD78-36, FD74-21, FD76-18, FD61-3, Sante, SL15-10, SL14-15, SL5-2, V14, V15, SL13-43, SL-52 & ETAB.	18
15-20	Moderately susceptible	SHL-RED, Punjab, Cardinal, Diamont, FD 35-36, FD76-67, Cosmo, SL9-14, Sutlej, 7450, 9814, 391202-158, 394005-115, 394028-37, 394032-16, 394055-40, 396240-21 & 396266-33.	18
20-24	Susceptible	Multan, Ruby, FD 48-1, FD71-1, SHL-WHI, 9808 & 393574-61.	7
>24	Highly susceptible	Lady roseta, FSD White, FD77-4, FD74300, Sadaf & Kashmir.	6
Total			50

In-vitro efficacy of different plant extracts:

Despite the well-known antibacterial qualities of these plants, our findings showed that none of the extracts significantly inhibited the growth of *S. scabies* (Table 2). The inefficacy of Neem, Kaneer, and Bhang extracts against *S. scabies* may be due to insufficient concentrations of active antimicrobial compounds, such as azadirachtin in Neem, which are less effective against the pathogen's robust spore structure (Biessy and Filion, 2022). Additionally, the aqueous extraction method may have reduced the potency of volatile compounds, limiting antibacterial activity compared to organic solvent extractions (Chethana *et al*., 2015).

Table 2: *Relative efficacy of plant extracts at different concentrations against colony growth of S. scabies*

Treatments	24 hours			48 hours		
	15 %	20 %	25 %	15 %	20 %	25 %
Kaneer	0 A	0 A	0 A	0 A	0 A	0 A
Neem	0 A	0 A	0 A	0 A	0 A	0 A
Bhang	0 A	0 A	0 A	0 A	0 A	0 A
Control	0 A	0 A	0 A	0 A	0 A	0 A

Mean values sharing similar letters do not differ significantly α=0.05

In-vitro efficacy of different bactericides against S. scabies:

After 24 hours at 500 ppm, Tetramycin was the most effective in stopping the bacterial growth with an inhibition of the *S. scabies* up to 3.30cm compared to Benzothiazolinone and oxytetracycline. Oxytetracycline was the least effective in inhibiting *S. scabies* growth with inhibition of 0.90 cm of it. Benzothiazolinone was found more effective by inhibiting the *S. scabies* growth of 1.50 cm as compared to Oxytetracycline but less effective than Tetramycin. At 700 ppm, the inhibition zone increased, and bacterial growth decreased as compared to 500 ppm because the concentration of all bactericides was increased which showed more effectiveness on the *S. scabies* growth. Tetramycin showed more effectiveness again with inhibition of 3.60 cm as compared to Oxytetracycline and Benzothiazolinone. Benzothiazolinone was more effective with an inhibition zone of 1.90 cm in diameter than Oxytetracycline but less than Tetramycin. Oxytetracycline was found most the least effective to inhibit *S. scabies* growth up to1.10 cm at 700 ppm. At 1000 ppm, when the inhibition zone was compared to 500 and 700 ppm concentrations, the antibiotic's ability to prevent bacterial growth was increased and inhibit *S. scabies* growth. Tetramycin was found the most effective with inhibition of 3.80 cm as compared to Benzothiazolinone and Oxytetracycline. Oxytetracycline was observed the least effective in suppressing the growth of *S. scabies* up to 1.33 cm and Benzothiazolinone was found more effective than Oxytetracycline but less effective than Tetramycin with growth inhibition of 2.10 cm.

After 48 hours, the diameter of the inhibition zone increased as compared to 24 hours. At 500 ppm concentration, little difference is recorded as compared to 24 hours. Similarly, Tetramycin was found the most effective in suppressing bacterial growth of 3.40 cm and Oxytetracycline was found to be the least effective in creating an inhibition zone of 1.10 cm. Benzothiazolinone was more productive with inhibition of 1.50 cm than Oxytetracycline and less effective than Tetramycin. At 700 ppm concentration, the efficacy of all antibiotics increased as compared to 500 ppm. Tetramycin was found the most productive as compared to other antibiotics with the inhibition of *S. scabies* of 3.67cm. Benzothiazolinone was more effective than Oxytetracycline by creating the inhibition of 1.90 cm and less than Tetramycin. Oxytetracycline showed the inhibition of 1.50 cm that was the least effective among others. At 1000 ppm concentration, all antibiotics were more effective to inhibit bacterial growth than at 500 ppm and 700 ppm concentrations. Tetramycin found most effective to inhibit bacterial growth of 4.23 cm as compared to Benzothiazolinone and Oxytetracycline. No inhibition zone was noticed in the control treatment (Table 3).

Table 3: *Relative efficacy of bactericides at different concentrations against colony growth of S. scabies.*

Treatments	24 Hours			48 Hours		
	500 ppm	700 ppm	1000 ppm	500 ppm	700 ppm	1000 ppm
Tetramycin	3.30 C	3.60 BC	3.80 B	3.40 BC	3.67 BC	4.23 A
Benzothiazolinone	1.50 EFG	1.90 DE	2.10 D	1.50 EFG	1.90 DE	2.17 D
Oxytetracycline	0.90 H	1.10 GH	1.33 FG	1.10 GH	1.50 EFG	1.60 EF
Control	0 I	0 I	0 I	0 I	0 I	0 I
LSD	0.41					

Mean values sharing similar letters do not differ significantly α=0.05

From more than 80 years, antibiotics are being used to control plant disease against different pathogens. Antibiotics depends on different mode of action, structure and biochemical properties that's why bacteria show different resistance mechanism (Sundin and Wang, 2018). Tetramycin suppress bacterial growth by attaching itself along ribosomal sub-unit which allows Tetramycin as bacteriostatic antibiotic (Saleha Tariq, 2018). Benzothiazolinone suppress bacterial growth by inhibiting the mitochondrial-derived respiration. Benzothiazolinone also reduce lactate production (Davies *et al*., 1989). Oxytetracycline consists of hydroxyl group which are the source of radical oxygen species (ROS). These hydroxyl groups are responsible for cellular death due to oxidative stress. Oxytetracycline inhibits the protein synthesis and damage membrane (Fuoco, 2012). Oxytetracycline stop translation procedure through docking amino-acyl-transfer RNA during elongation (Grossman, 2016).

In-vitro efficacy of Plant Growth Promoting Rhizobacteria (PGPRs):

After 24 hours *Pseudomonas putida* was found most effective plant growth promoting rhizobacteria against *S. scabies* by creating inhibition zone of 1.2 cm as compared to *P. fluorescens, A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium. P. fluorescens* was found then *P. putida* by making the inhibition zone of 1.1 cm and more effective than *A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium*. Remaining PGPRs *A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium* were not effective to inhibit growth of *S. scabies*.

After 48 hours, change in inhibition zone of 1.3 cm of *P. putida* was found more effective than *P. fluorescens, A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium*. *P. fluorescens* was less effective by creating the inhibition zone of 1.1 cm than *P. putida* and more effective *than A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium.* No efficacy of *A. fabrum, C. firmus, L. bacillus ochrobactrum* and *B. megaterium* was found against *S. scabies* after 48 hours (Table 4).

The chemical damage caused to both ecosystems on land and in water worldwide has encouraged the search for ecologically friendly ways to control plant diseases. One unique ability of the PGPRs that increases in both biotic and abiotic conditions is the synthesis of HCN (Flury *et al*., 2017). The PGPRs are microorganisms that have been shown to have distinct methods for controlling plant infections in vitro (Beneduzi *et al*., 2012). PGPRs improve the structure of the roots, leading to the development of more lateral roots and an increase in root hair density. As a result, this leads to an increase in both the fresh weight and surface area of the roots (Gamalero *et al*., 2004). Due to the pathogen attack, there is a significant increase in oxidative stress in the plant, which is caused by the elevated levels of superoxide radicals (Larson, 1995). Superoxide dismutase (SOD) changes superoxide into O_2 and hydrogen peroxide (R. Buettner, 2011). Mitigating oxidative stress is crucial, typically caused by pathogen attacks or drought conditions. Therefore, the greater the production of SOD, the healthier the plant will be. By generating phosphatases, *B. megaterium* and *Pseudomonas* increase the amount of P in the plant (Kumar *et al*., 2012). The organic phosphate molecules are hydrolyzed into inorganic forms by phosphatases, which then make them available to plants (Tazisong *et al*., 2015). Furthermore, by dissolving iron oxides and hydroxides and pushing protons (H+) into the rhizosphere, *B. megaterium* increases the availability of iron (Singh *et al*., 2020). An environment that is favorable for solubilizing potassium is created by the unique process of PGPRs biofilm development on root surfaces (Gupta *et al*., 2018).

Table 4: *Relative efficacy of different plant growth promoting rhizobacteria against the colony growth of S. scabies.*

PGPRs Name	24 hours	48 hours
Pseudomonas putida	1.2889 A	1.3222 A
Pseudomonas fluorescens	1.0889 B	1.0889 B
Agrobacterium fabrum	0.0000 C	0.0000 C
Cytobacillus firmus	0.0000 C	0.0000 C
Lysin bacillus ochrobactrum	0.0000 C	0.0000 C
Bacillus megaterium	0.0000 C	0.0000 C
Control	0.0000 C	0.0000 C

Mean values sharing similar letters do not differ significantly α*=0.05*

Evaluation of bactericide and different PGPRs in field conditions:

The application of treatments, such as Tetramycin, *P. putida*, and *P. fluorescens* significantly lower the disease severity of potato scab when compared to the control in field conditions. Tetramycin was found to be most effective compared to PGPRs (*P. putida* and *P. fluorescens*). From PGPRs, *P. putida* was more significant in lowering disease severity as compared to *P. fluorescens. P. fluorescens* was the least effective in lowering the disease; however, it was more effective as compared to control treatment (Table 5).

Table 5: *Comparative efficacy of different treatments against potato scab disease in field conditions.*

Treatments	Lady roseta
Tetramycin @1000 ppm	13 E
P. putida	18 D
P. fluorescens	21 C
Control	37 A
LSD=2.43	

Mean values sharing similar letters do not differ significantly α*=0.05*

The pathogens are becoming resistant to some chemicals and their application doesn't affect their growth. So, the evaluation of new chemicals is needed for controlling the pathogen population (Jin *et al*., 2023). Bactericides inhibit pathogen growth by disrupting cell membranes and interfering with DNA replication or protein synthesis (Varympopi *et al*., 2020). As the new bactericides are made to combat the disease, which are based on the eco-friendly approaches so the evaluation of these bactericides are performed for controlling the bacterial diseases (Ayaz *et al*., 2023). The chemicals are harmful to nature which affect the soil as well as plants so the use of plant growth promoting rhizobacteria for the control of plant disease are very effective. The use of chemicals for the control of disease in many countries have strict regulations. There is a limit on the use of chemicals for protecting the nature and living organisms from their affect. These chemicals have toxic effect on many beneficial organisms like insects, microbes, and aquatic organisms. The use of chemicals more than its limit leads to the soil contamination and also on the consumption of by-product of crops harm human health because it causes cancer for the long-term use of such products. PGPRs are beneficial bacteria that are used to control the disease as they are eco-friendly in nature and affect the pathogen growth development by releasing many harmful chemicals in soil which are toxic for pathogens but not for the plants, humans, animals, and beneficial insects. PGPRs are also helpful in reducing the chance of resistance to pathogens. They also enhance the uptake of nutrients in soil for the plants which promotes plant growth, yield and is helpful in managing the disease as an integrated disease management strategy (Singh *et al*., 2019). So, the use of eco-friendly approaches is promoted for the management of plant disease as they are not harmful to the plants as well as to humans and other beneficial organisms.

Conclusions and Recommendations:

From the present study, it was found that potato germplasm i.e., FD3536 may be used for future breeding programs to develop resistant varieties against the potato scab disease. Furthermore, Tetramycin at 1000 ppm and *P. putida* may be used for the disease management in field conditions.

Novelty Statement

The present research provides novel insights for the management of potato scab disease by exploring the potential of bactericides and Plant Growth Promoting Rhizobacteria (PGPRs). The study offers a new look to manage the disease biologically through using PGPRs, thus, a provides a hope to minimize the use of agrochemicals that dramatically defiling the soil microflora.

Author's Contribution

Muhammad Usman, Muhammad Mubeen, Shahneeza Aimal Nadeem, Ayesha Khalid and Zia Ullah Ashraf: Conducted experiments, data recording and manuscript writing
Muhammad Umar Shahbaz, Waseem Abbas and Muhammad Kamran: Prepared research protocol and reviewed the manuscript
Salman Ahmad and Shabana Ehsan: Provided technical support in experimentation
Muhammad Ehetisham ul Haq: Conceived the idea, prepared research protocols, data analysis and supervised the research work.

Generative AI or AI assisted technology statement
The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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