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Streptomyces spp. as biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum*-induced soft rot in potato

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Abstract

The study aimed to evaluate the biocontrol efficacy of native *Streptomyces* spp. isolates against *Pectobacterium carotovorum* subsp. *carotovorum* (Pcc), the causal agent of potato soft rot. Nine *Pectobacterium carotovorum* subsp. *carotovorum* isolates were obtained from potato tubers exhibiting typical symptoms of soft rot and were identified based on morphological and biochemical characteristics. The pathogenicity of these isolates was assessed, and the most virulent isolate, Pcc6, was identified through PCR amplification and sequencing of the 16S rRNA gene. Additionally, sixteen actinomycete isolates were identified as *Streptomyces* spp. based on thorough assessment of their physiological and biochemical characteristics. *In vitro* antagonism tests revealed significant variation in the inhibitory effect of *Streptomyces* spp. isolates on the growth of Pcc6, with isolates 1, 3, 4, 5, 6, 7, 8, 9, 10, and 12 demonstrating strong inhibitory activity and were selected for further experiments. Furthermore, *in vivo* tuber inoculation tests and pots experiments demonstrated the biocontrol efficacy of selected *Streptomyces* spp. isolates against Pcc6 in potato tubers, with isolate 4 exhibiting the highest bioagent efficiency, completely preventing the soft rot lesion *in vivo* tuber inoculation test and reducing the disease severity by 93.94% in the pots experiment. The findings of this study underscore the promising role of *Streptomyces* spp. isolates as biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum*, providing valuable insights for the development of sustainable disease management strategies in potato production.

Keywords: *Streptomyces* spp., *Solanum tuberosum*, *Pectobacterium carotovorum*, biological control, potato soft rot.

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1. Introduction

Potato (*Solanum tuberosum* L.) is a vital component of global food security, with a production about 375 million tons in 2022 (FAO, 2022). However, the potato industry faces significant challenges, particularly from bacterial soft rot, a highly destructive disease caused by pectinolytic bacteria, notably *Pectobacterium carotovorum* subsp. *carotovorum* (formerly *Erwinia carotovora* subsp. *carotovora*) (Scherr *et al*., 2012). This disease inflicts extensive damage to potato tubers, leading to tissue maceration, foul odor, and substantial yield loss (Mwalukasa, 2013). The management of bacterial soft rot is further complicated by the wide host range, genetic diversity, and environmental adaptability of *Pectobacterium carotovorum*, rendering the use of resistant cultivars and chemical bactericides ineffective (Giannini *et al*., 2017). Consequently, there is an urgent need for alternative and sustainable strategies to control bacterial soft rot in potatoes. Biological control, involving the use of living organisms or their products to suppress plant pathogens, emerges as a promising approach for disease management (Abid *et al*., 2015). Notably, bacteria in the genus *Streptomyces* have garnered attention due to their antagonistic activity against a wide range of plant pathogens and the production of bioactive compounds (Lakenarine *et al*., 2020). The use of *Streptomyces* spp. as a biocontrol agent against *Pectobacterium carotovorum* causing soft rot in potatoes has been a subject of significant research interest. Investigated the efficacy of four bioagents, including *Streptomyces* spp., in vitro and in vivo against pathogenic isolates of *Pectobacterium carotovorum* subsp. *carotovorum*, demonstrating the potential of *Streptomyces* spp. in controlling potato soft rot (Salem and El-Shafea, 2018). Additionally, Trung *et al*. (2021) showed that *Streptomyces* spp. exhibited strong effects against *Pectobacterium carotovorum* causing soft rot disease on potato, further supporting its biocontrol potential. Furthermore, Rahman *et al*. (2017) demonstrated the bactericidal activity of certain chemicals, including *Streptomyces* spp., against *Pectobacterium carotovorum*, a pathogen causing potato soft rot, highlighting the diverse strategies for disease management. These studies collectively underscore the promising role of *Streptomyces* spp. as a biocontrol agent against *Pectobacterium carotovorum*, offering valuable insights for the development of sustainable strategies to mitigate soft rot in potato production. This study aims to evaluate the biocontrol efficacy of native *Streptomyces* spp. isolates against *Pectobacterium carotovorum* subsp. *carotovorum* causing soft rot in potatoes. The specific objectives include isolating and identifying streptomycetes from potato rhizosphere and tuber tissues, screening their antagonistic activity against *Pectobacterium carotovorum* subsp. *carotovorum*, and assessing their *in vivo* biocontrol activity in potato tubers.

2. Materials and methods

2.1 Pectobacterium carotovorum subsp. carotovorum isolation and identification

Pectobacterium carotovorum isolates were obtained from potato tubers exhibiting characteristic symptoms of soft rot, including water soaking, tissue maceration, and foul odor (Pérombelon, 2002; Toth *et al*., 2001). The infected tubers were sourced from diverse potato fields in Assiut and Sohag governorates, Egypt. The isolation process involved the excision of small pieces of diseased tissue, which were then streaked onto crystal violet pectate (CVP) agar plates and subsequently incubated at 28 °C for 24–48 hours (Hyman *et al*., 2001; Saarilahti *et al*., 1990). The identification of *Pectobacterium carotovorum* colonies was based on their morphological attributes, such as white, mucoid, convex, and circular appearance, as well as their capacity to generate a clear zone of pectin degradation on CVP agar (Hyman *et al*., 2001; Saarilahti *et al*., 1990). Furthermore, the identity of the isolates was confirmed through a series of biochemical tests, including Gram staining, catalase, oxidase, indole, methyl red, Voges-Proskauer, citrate utilization, and carbohydrate fermentation including acid production ability from α-methylglucoside, d-sorbitol, d-arabitol, palatinose, and inulin (Schaad *et al*., 2001; Toth *et al*., 2001; Yap *et al*., 2004). Subsequently, the isolates were preserved at 4 °C on slanted CVP tubes until further use (Hyman *et al*., 2001; Saarilahti *et al*., 1990).

2.2 Pathogenicity test of Pectobacterium carotovorum subsp. carotovorum isolates

The pathogenicity of *Pectobacterium carotovorum* subsp. *carotovorum* isolates was tested on potato tubers (Pérombelon, 2002). Healthy potato tubers of Kara cultivar were surface-sterilized with 70% ethanol and 0.5% sodium hypochlorite, rinsed with sterile water and air-dried (Moreau *et al*., 2005). A 5 mm deep wound was made on each tuber using a sterile cork borer (Smid *et al*., 1993). The wound was inoculated with 20 µL of *Pectobacterium carotovorum* subsp. *carotovorum* (10^8 CFU/ml) or sterile water (control) (Costa and Loper, 1994). The inoculated tubers were wrapped with moist filter paper and placed in plastic bags. The bags were incubated at 28 °C for 10 days (Rashid *et al*., 2013). The disease severity was measured as percentage based on the diameter of the soft rot lesion on the tuber surface (Pérombelon, 2002) using formula: The disease severity percentage = [Average diameter of the soft rot lesion (mm) / Average diameter of tuber (mm)] × 100. The experiment was repeated twice with 5 tubers for each isolate.

2.3 Molecular identification of Pectobacterium carotovorum subsp. carotovorum isolate

To confirm the identification the selected *Pectobacterium carotovorum* subsp.

carotovorum isolate, PCR amplification and sequencing of the 16S rRNA gene using universal primers were performed. The universal primers 799F (5'-AACMGGATTAGATACCCKG-3') and 1107R (5'-AGGGTTGCGCTCGTTG-3') were designed to specifically target the bacterial 16S rRNA gene and avoid co-amplification of plant organellar DNA (Chen *et al*., 2022). The PCR reaction mixture contained 12.5 µl of 2 × Taq Master Mix, 1 µl of each primer (10 µM), 2 µl of template DNA, and 8.5 µl of nuclease-free water. The PCR program consisted of an initial denaturation at 94°C for 5 min, followed by 35 cycles of 94°C for 30 s, 55°C for 30 s, and 72°C for 1 min, and a final extension at 72°C for 10 min. The PCR products were verified by electrophoresis on a 1.5% agarose gel and sent for Sanger sequencing. The obtained sequences were compared with the GenBank database using the BLASTn algorithm to identify the bacterial species.

2.4 Isolation and identification of Actinomycetes

Actinomycetes were isolated from the rhizosphere and tuber tissues of healthy potato plants grown in a field in Assiut and Sohag governorates, Egypt. The rhizosphere soil samples were collected from the root zone of potato plants at the flowering stage. The tuber tissue samples were collected from the peel and flesh of healthy potato tubers at harvest. The soil and tissue samples were processed according to the method described by Vurukonda *et al*. (2018), respectively. Briefly, the soil samples were air-dried, sieved and serially diluted in sterile water. The tissue samples were surface-sterilized with 70% ethanol and 0.5% sodium hypochlorite, rinsed with sterile water and cut into small pieces. The soil and tissue suspensions were plated on starch casein agar (SCA) supplemented with 50 mg/l of cycloheximide and 25 mg/l of nalidixic acid to inhibit the growth of fungi and non-streptomycetes bacteria. The plates were incubated at 28 °C for 7–10 days. The streptomycetes colonies were identified based on morphological, cultural, physiological and biochemical characteristics as described by Shirling and Gottlieb (1966), and Lechevalier and Lechevalier (1970). The isolates were purified by repeated streaking on fresh SCA plates and stored at 4 °C.

2.5 Effect of Streptomyces spp. isolates on potato soft rot caused by Pectobacterium carotovorum subsp. carotovorum

2.5.1 In vitro antagonism test

The *in vitro* antagonism test was conducted to assess the inhibitory effect of *Streptomyces* spp. isolates on the growth of *Pectobacterium carotovorum subsp. carotovorum* on solid media. The methodology, adapted from El-Tarabily *et al*. (2000) with specific modifications, involved spreading a 100 µl of *Pectobacterium carotovorum* Pcc6 (10^8 CFU/ml) on the surface of potato dextrose agar (PDA) media in petri dishes using a sterilized L-shaped glass rod spreader.

Subsequently, a 5 mm diameter agar disk, cut from the margin of a culture grown in a plate on which the *Streptomyces* spp. isolates had been grown for 7 days at 28 °C, was placed at the center of each plate. The plates were then incubated at 28 °C for 5 days, and the inhibition zone was measured. To ensure the reliability of the findings, the experiment was repeated twice with three replicates for each isolate (Pliego *et al*., 2010).

2.5.2 In vivo tuber inoculation test

The *in vivo* tuber inoculation test was performed to evaluate the biocontrol efficacy of the selected *Streptomyces* spp. isolates against *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 in potato tubers. The test was conducted according to the method described by Reiter *et al*. (2002). Briefly, healthy potato tubers of Spunta cultivar were surface-sterilized with 70% ethanol and 0.5% sodium hypochlorite, rinsed with sterile water and air-dried. A 5 mm deep wound was made on each tuber using a sterile cork borer. The wound was inoculated with 100 µl of each *Streptomyces* spp. isolate (10^8 CFU/ml) and *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 (10^8 CFU/ml). The control tubers were inoculated with sterile water and *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 (10^8 CFU/ml). The inoculated tubers were wrapped with moist filter paper and placed in plastic bags. The bags were incubated at 28 °C for 10 days. The disease severity and bioagent efficiency percentages were assessed at the end of the incubation period. The disease severity was measured as the diameter of the soft rot lesion on the tuber surface and the disease severity percentage were calculated using the formula: The disease severity (%) = [Average diameter of the soft rot lesion (mm) / Average diameter of tuber (mm)] × 100. The bioagent efficiency percentage was calculated according to the formula: Bioagent efficiency percentage = [(Disease severity of untreated plants - Disease severity of treated plants) / Disease severity of untreated plants] × 100. The experiment was repeated twice with 5 tubers for each treatment.

2.5.3 Pots experiment

To conduct the experiment, sterilized pots with a diameter of 30 cm were filled with sterilized soil and arranged in a complete randomized design. *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 bacteria were prepared by culturing them in nutrient agar media plates and maintaining them at 28°C for 48 hours. Similarly, *Streptomyces* spp. isolates were prepared by cultivating in conical flask containing a sterilized starch nitrate liquid medium and maintaining them at 28°C for a week. Ten tubers of potato (cv. Spunta) per treatment were washed with water and then sterilized with 70% ethyl alcohol. The actinomycetes isolates (10^8 CFU/ml) were combined with 1% (W/V) gum Arabic to enhance adhesion for 1 hour. Subsequently, the potato tubers were immersed in this mixture for 1 hour. The

potato tubers were then left to dry in jars overnight before being planted in the soil infested with 200 µl of *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 (10^8 CFU/ml) per pot. Each pot accommodated two potato tubers, and five pots were used for each treatment. The pots were placed in an open field at 26° 15' 47.2" N 31° 56' 21.8" E in El-Balyana, Sohag governorate, Egypt, during the summer growing season (February – May 2022). At the conclusion of the experiment, the number of infected potato tubers and the disease severity were assessed using the method outlined by Chastanger and Ogawa (1979). The infected potato tubers were categorized based on the extent of decay as follow: 0 = no rot, 1 = 1-24% of the surface decayed, 2 = 25-49% of the surface decayed, 3 = 50-74% of the surface decayed, 4 = 75% or more of the surface decayed, and the severity of infection percentage was calculated using the formula: Severity of infection (%) = [∑(number of potato tubers per category × category number) / (Total number of potato tubers × highest category number)] × 100.

2.6 Statistical analysis

The data were analyzed using analysis of variance (ANOVA) with the statistical package CoStat 6.41. Post hoc comparisons of means were conducted employing Fisher's protected least significant difference (LSD) test at a significance level of $p \leq 0.05$ (Gomez and Gomez, 1984). Additionally, the standard error of the mean (SEM) was computed for each treatment.

3. Results

3.1 Pectobacterium carotovorum subsp. carotovorum isolation and identification

Nine isolates of *Pectobacterium carotovorum* subsp. *carotovorum* (Pcc) were isolated and identified from potato tubers showed typical symptoms of soft rot collected from different fields in Assiut and Sohag governorates, Egypt. The morphological characterization of the Pcc colonies, including their white, mucoid, convex, and circular appearance, was consistent with previous descriptions of Pcc (Toth *et al*., 2001). Additionally, the ability of the isolates to produce a clear zone of pectin degradation on CVP agar confirmed their pectinolytic activity, a characteristic trait of Pcc. Furthermore, the confirmation of the isolates using a set of biochemical tests, including Gram staining, catalase, oxidase, indole, methyl red, Voges-Proskauer, citrate utilization, and carbohydrate fermentation including acid production ability from α-methylglucoside, d-sorbitol, d-arabitol, palatinose, and inulin, provided a robust basis for their identification. The isolates were stored at 4 °C on slanted CVP tubes for further experiments.

3.2 Pathogenicity of Pectobacterium carotovorum subsp. carotovorum isolates

The results of pathogenicity test showed significant variation in pathogenicity

among the nine *Pectobacterium carotovorum* subsp. *carotovorum* isolates, as measured by the percentage of disease severity on potato tubers cv. Spunta. The highest disease severity was observed for Pcc6 (93.18%), followed by Pc 5 (87.5%) and Pcc7 (81.67%). The lowest disease severity was recorded for Pcc4 (18.33%), followed by Pc 1 (30.83%) and Pcc9 (48.15%). The control tubers showed no infection. The LSD value at the 0.05 level was 10.42, indicating significant differences among the isolates (Table 1). Based on these results, Pcc6 was selected as the most virulent isolate for further experiments.

Table (1): Disease severity of potato tubers cv. Spunta inoculated with different *Pectobacterium carotovorum* subsp. *carotovorum* (Pcc) isolates.

Isolate ID	Disease Severity (%)
Pcc1	30.83 ^{e}
Pcc2	69.44 ^{c}
Pcc3	69.84 ^{c}
Pcc4	18.33 ^{f}
Pcc5	87.5 ^{ab}
Pcc6	93.18 ^{a}
Pcc7	81.67 ^{b}
Pcc8	62.5 ^{c}
Pcc9	48.15 ^{d}
Control	0 ^{g}
LSD 0.05	10.42

Different letters in superscript denote significant differences (LSD, $p \leq 0.05$).

3.3 Molecular identification of Pectobacterium carotovorum subsp. carotovorum isolate

The identification of the selected isolate was carried out through PCR amplification of the 16S rRNA gene, followed by a BLASTn analysis. The BLASTn analysis revealed that the sequence had a 99.9% identity and 100% query coverage with the 16S rRNA gene of *Pectobacterium carotovorum* subsp. *carotovorum* strains from various sources, confirming the identification of the isolate. A phylogenetic tree based on the 16S rRNA gene sequences of the isolate and other *Pectobacterium carotovorum* subsp. *carotovorum* strains was constructed using the neighbor-joining method (Figure 1). The tree showed that the isolate clustered with other strains of the same subspecies, indicating a close genetic relationship and similarity. The isolate was designated as *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6.

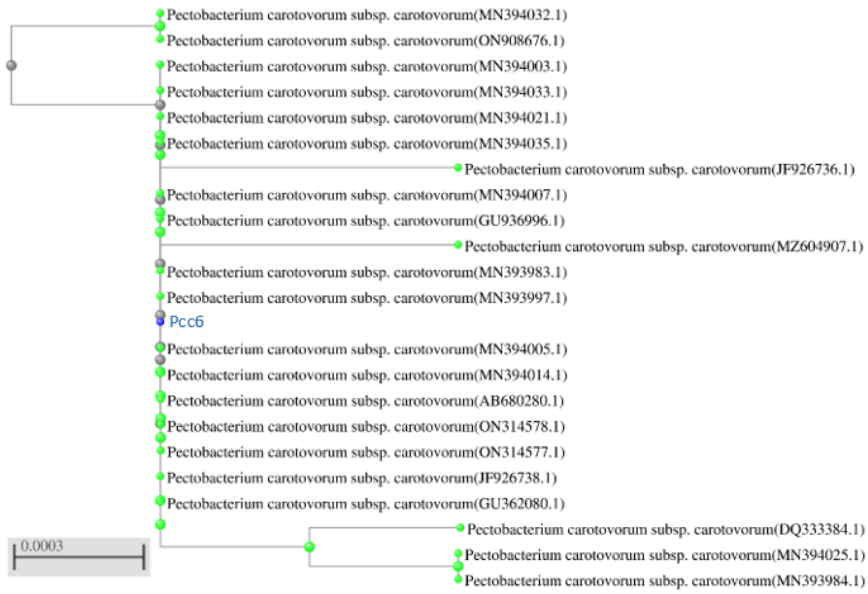

Figure (1): Phylogenetic tree of *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 isolate based on 16S rRNA gene sequences.

3.4 Isolation and identification of Actinomycetes

Sixteen isolates of *Actinomycetes* were isolated from the rhizosphere soil and tuber tissues of healthy potato plants grown in Assiut and Sohag governorates, Egypt. The *Actinomycetes* colonies were identified by their morphological, cultural, physiological and biochemical characteristics, as *Streptomyces* spp., as described by Shirling and Gottlieb (1966), and Lechevalier and Lechevalier (1970). The morphological characteristics of the isolates, including spore morphology, colony color, spore color, spore ornamentation, spore chain morphology, and other physiological traits such as temperature, pH, melanin production, and carbon utilization, were thoroughly assessed (Saha *et al*., 2022). Additionally, the physiological and biochemical characteristics of the isolates, including chitinase, phosphatase, siderophore production, and utilization of specific sugars, were investigated (Hastuti *et al*., 2012; Trussell *et al*., 1947). Subsequently, all isolates were confirmed to be *Streptomyces* spp. and were stored at 4 °C on SCA media for further use.

3.5 Effect of Streptomyces spp. isolates on potato soft rot caused by Pectobacterium carotovorum subsp. carotovorum

3.5.1 In vitro antagonism test

The results of the *in vitro* antagonism test are shown in Table (2). The results indicated that the *Streptomyces* spp. isolates varied in their ability to inhibit the

growth of Pcc6 on PDA plates. The most effective isolate was isolate 4, which produced an inhibition zone of 40 mm, followed by isolate 12, which produced an inhibition zone of 33.33 mm. The least effective isolates were isolates 2, 13, 14, 15, and 16, which did not produce any inhibition zone. The control plates, inoculated with Pcc6 only, also did not show any inhibition zone. The differences among the isolates were statistically significant, with an LSD value of 4.39 at the 0.05 level. The isolates that showed significant inhibition of Pcc6 growth on PDA plates, namely isolates 1, 3, 4, 5, 6, 7, 8, 9, 10, and 12, were selected for further experiments to evaluate their biocontrol potential on potato tubers.

Table (2): *In vitro* antagonistic activity of *Streptomyces* spp. isolates against *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 on potato dextrose agar (PDA) plates.

Streptomyces spp. isolate No.	Inhibition zone (mm)
1	9 ^{def}
2	0 ^{i}
3	25 ^{c}
4	40 ^{a}
5	11.33 ^{d}
6	9.33 ^{de}
7	5.67 ^{fgh}
8	3.33 ^{hi}
9	2.67 ^{hi}
10	7.33 ^{efg}
11	4.67 ^{gh}
12	33.33 ^{b}
13	0 ^{i}
14	0 ^{i}
15	0 ^{i}
16	0 ^{i}
Control	0 ^{i}
LSD 0.05	4.39

Different letters in superscript denote significant differences (LSD, $p \leq 0.05$).

3.5.2 In vivo tuber inoculation test

The results of the *in vivo* tuber inoculation test are shown in Table (3). The results indicated that the *Streptomyces* spp. isolates significantly reduced the disease severity caused by *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 on potato tubers. The most effective isolate was isolate 4, which completely prevented the soft rot lesion, resulting in a bioagent efficiency of 100%. The other isolates also showed varying degrees of biocontrol efficacy, ranging from 20.37% (isolate 1) to 62.97% (isolate 12). The control tubers showed the highest disease severity of 90%. The differences among the treatments were statistically significant,

with an LSD value of 11.64 at the 0.05 level. Based on the biocontrol efficacy results, the isolate 4 and isolate 12 were selected for further experiments.

Table (3): Effect of *Streptomyces* spp. isolates on disease severity and bioagent efficiency against *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 in potato tubers cv. Spunta.

Streptomyces spp. isolate No.	Disease severity (%)	Bioagent efficiency (%)
1	71.67 ^{cd}	20.37
3	40.83 ^{ef}	54.63
4	0 ^{g}	100
5	66.67 ^{d}	25.92
6	50 ^{e}	44.44
7	78.33 ^{bc}	12.97
8	77.5 ^{cd}	13.89
9	82.5 ^{abc}	8.33
10	89.17 ^{ab}	0.92
12	33.33 ^{f}	62.97
Control	90 ^{a}	0
LSD 0.05	11.64	

Different letters in superscript denote significant differences (LSD, p ≤0.05).

3.5.3 Pots experiment

The results of the pots experiment are shown in Table (4). The results indicated that the *Streptomyces* spp. isolates significantly reduced the disease severity and increased the bioagent efficiency against *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 in potato tubers cv. Spunta. The most effective isolate was isolate 4, which reduced the disease severity to 4% and increased the bioagent efficiency to 93.94%. The second most effective isolate was isolate 12, which reduced the disease severity to 20% and increased the bioagent efficiency to 69.70%. The control tubers showed the highest disease severity of 66% and no bioagent efficiency. The differences among the treatments were statistically significant, with an LSD value of 25.90 at the 0.05 level. These results demonstrate the potential of *Streptomyces* spp. isolates as biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum* in potato tubers under open field conditions.

Table (4): Effect of *Streptomyces* spp. isolates on disease severity and bioagent efficiency against *Pectobacterium carotovorum* subsp. *carotovorum* Pcc6 infected potato plants cv. Spunta under open field conditions.

Streptomyces spp. isolate No.	Infected tubers (%)	Severity of infection (%)	Bioagent efficiency (%)
4	10	4 ^{b}	93.94
12	30	20 ^{b}	69.70
Control	80	66 ^{a}	0
LSD 0.05		25.90	

Different letters in superscript denote significant differences (LSD, p ≤0.05).

4. Discussion

The results of this study provide valuable insights into the potential of Streptomyces spp. as biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum*, the causative agent of soft rot in potatoes. The pathogenicity test of *Pectobacterium carotovorum* subsp. *carotovorum* on potato tubers provided essential information about the virulence of different isolates, with Pcc6 identified as the most virulent isolate. This information was crucial for selecting an appropriate target pathogen for the subsequent biocontrol experiments (Shirling and Gottlieb, 1966). The molecular identification of the Pcc6 isolate using PCR amplification and sequencing of the 16S rRNA gene confirmed its identity as *Pectobacterium carotovorum* subsp. *carotovorum*, providing a robust basis for the pathogenicity and biocontrol assays (Toth *et al*., 2001). The isolation and identification of *Streptomyces* spp. from the rhizosphere and tuber tissues of healthy potato plants in Egypt demonstrate the presence of these biocontrol agents in the local agricultural environment (Lechevalier and Lechevalier, 1970). The *in vitro* antagonism test revealed significant variation in the inhibitory effect of *Streptomyces* spp. isolates on the growth of *Pectobacterium carotovorum* subsp. *carotovorum*, with some isolates demonstrating strong inhibitory activity (El-Tarabily *et al*., 2000). These findings are consistent with previous research highlighting the antagonistic activity of *Streptomyces* spp. against a wide range of plant pathogens (Vurukonda *et al*., 2018). Furthermore, the *in vivo* tuber inoculation test and the pots experiment demonstrated the biocontrol efficacy of selected *Streptomyces* spp. isolates against *Pectobacterium carotovorum* subsp. *carotovorum* in potato tubers. Isolate 4 exhibited the highest bioagent efficiency, completely preventing the soft rot lesion in the *in vivo* tuber inoculation test and significantly reducing disease severity in the pots experiment (Salem and El-Shafea, 2018). These results are in line with previous studies that have reported the biocontrol potential of *Streptomyces* spp. against various plant pathogens, indicating their promising role in disease management (Pliego *et al*., 2010). Overall, the results of this study support the promising role of *Streptomyces* spp. as biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum*, offering valuable insights for the development of sustainable strategies to mitigate soft rot in potato production. The findings contribute to the growing body of evidence on the potential of biological control, particularly involving *Streptomyces* spp., as a sustainable approach for disease management in agriculture (Mwalukasa, 2013). These results have significant implications for the development of alternative and sustainable strategies to control bacterial soft rot in potatoes, addressing the urgent need for effective disease management

approaches (Scherr *et al*., 2012). In conclusion, the findings of this study underscore the potential of native *Streptomyces* spp. isolates as effective biocontrol agents against *Pectobacterium carotovorum* subsp. *carotovorum*, providing a foundation for further research and development of sustainable disease management strategies in potato production.

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