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Biocontrol Potential of *Streptomyces* sp. from the *Avicennia marina* Rhizosphere against *Sclerotium rolfsii* in Bird's Eye Chili (*Capsicum frutescens* L.)

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Abstract: This study aimed to evaluate the potential of *Streptomyces* sp. isolated from the rhizosphere of the mangrove *Avicennia marina* as a biological control agent against *Sclerotium rolfsii*, the causal agent of basal stem rot in bird's eye chili (*Capsicum frutescens* L.). The study was conducted using a non-factorial completely randomized design consisting of a control treatment and root-soaking treatments in a *Streptomyces* sp. suspension for different durations: 15, 30, and 45 minutes. Observational data were analyzed using ANOVA at the 5% significance level with IBM SPSS Statistics version 27. The results showed that *Streptomyces* sp. inhibited the growth of *S. rolfsii* on artificial medium by up to 52.33%, indicating strong antagonistic activity. The in vivo assay further demonstrated that the 45-minute root-soaking treatment (SW3) delayed disease incubation until the final day of observation, prevented the development of disease symptoms throughout the observation period, and enhanced vegetative growth in bird's eye chili plants. These findings suggest that *Streptomyces* sp. from the rhizosphere of *A. marina* has promising potential as a biological control agent for managing basal stem rot caused by *S. rolfsii* in bird's eye chili.
Keywords: *Streptomyces* sp.; *Sclerotium rolfsii*; biological control; antagonist

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INTRODUCTION

Bird's eye chili (*Capsicum frutescens* L.) is an important horticultural crop with relatively comprehensive nutritional content and high economic value. In addition to its extensive use in household consumption and the food and beverage processing industries, bird's eye chili is also utilized in the manufacture of pharmaceutical and cosmetic products (Wisnujati & Siswati, 2021). Consequently, bird's eye chili is considered one of the nine basic necessities in Indonesia, and market demand continues to increase in line with population growth and the expansion of food and non-food industries (Pratiwi, 2021). However, according to data from Badan Pusat Statistika (2023), bird's eye chili production has declined by up to 8.09% over the past five years.

One of the main factors contributing to the decline in bird's eye chili productivity is the incidence of plant-disturbing organisms, particularly pathogens (Inaya et al., 2022). Among the various pathogens that cause diseases in bird's eye chili, *Sclerotium rolfsii* is a fungal pathogen responsible for collar rot, wilt, and damping-off disease (Hutauruk, 2018). Yield losses caused by this fungus can reach 80%, and under environmental conditions favorable for fungal development, losses may increase to 100% (Hidayat et al., 2015). Chili seedlings affected by damping-off disease have only a 10% chance of survival (Majeed et al., 2018). *S. rolfsii* exhibits high adaptive capacity by forming sclerotia in soil, manure, and infected plant residues (Sumartini, 2012).

Synthetic pesticides remain the primary option used by farmers to control *S. rolfsii*. However, their continued use can adversely affect the environment because many contain persistent active ingredients and may promote the emergence of resistant pathogen strains. The use of antagonistic microorganisms, such as *Streptomyces* sp., represents an alternative strategy for controlling *S. rolfsii*. *Streptomyces* sp. is a Gram-positive bacterium belonging to the Actinomycetes group, characterized by high adaptability and a filamentous morphology that microscopically resembles fungi (Procópio et al., 2012). This rhizosphere bacterium is capable of producing approximately 75% of commercially available antibiotics by synthesizing a wide range of active compounds as secondary metabolites in large quantities (Thepbandit and Athinuwat, 2024). *Streptomyces* sp. can inhibit the growth of fungal pathogens through antibiosis, hyperparasitism, and overgrowth mechanisms (Sahriyanor et al., 2024). It is also classified as a plant growth-promoting rhizobacterium (PGPR), with the ability to facilitate the uptake of various soil nutrients and to synthesize and regulate the concentrations of growth-promoting phytohormones (Lehar et al., 2018).

The exploration of *Streptomyces* sp. from extreme ecosystems, such as mangrove areas, has attracted increasing attention because of its distinctive biological characteristics. The *Streptomyces* sp. isolate used in this study was obtained from the rhizosphere of *Avicennia marina* in the Surabaya Mangrove Botanical Garden, an environment known for its high adaptive capacity to various abiotic and biotic stresses. The superior characteristics of mangrove-derived *Streptomyces* sp. are supported by Abo-Zaid et al. (2021), who reported that this bacterium inhibited the mycelial growth of *S. rolfsii* by up to 98.7% in vitro. Furthermore, Qiu et al. (2024) evaluated the antagonistic activity of *Streptomyces* sp. against *S. rolfsii* in bird's eye chili and reported a control efficiency of 70.42%, along with improved vegetative growth and chlorophyll production through its PGPR activity.

Although the potential of *Streptomyces* sp. has been widely investigated, information on *Streptomyces* sp. derived from the rhizosphere of *A. marina* and its direct application to bird's eye chili seedlings, particularly through root immersion treatment for the control of *S. rolfsii*, remains limited. Early protection during the seedling stage is considered one of the most effective approaches for reducing disease incidence and severity in the field (Rahayu et al., 2021). In addition, the duration of seedling root immersion is presumed to play an important role in optimizing bacterial colonization by *Streptomyces* sp. and enhancing its ability to suppress pathogen development. Therefore, this study aimed to evaluate the potential of *Streptomyces* sp. isolates derived from the mangrove rhizosphere of *A. marina* in suppressing the development of *S. rolfsii*, to determine the most effective seedling root immersion duration for inhibiting collar rot disease, and to assess the PGPR-mediated effects of the isolate on the vegetative growth of bird's eye chili plants.

METHOD

Time and Location of the Study

This study was conducted from July 2025 to January 2026 at the Plant Health Laboratory 1, Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Jawa Timur. The in vivo antagonism assay was conducted in Keputih, Surabaya, East Java, Indonesia.

Biological Materials and Isolates

The biological material used in this study consisted of cayenne pepper seeds (*Capsicum frutescens* L.) cv. Dewata 43 F1, which were required for the in vivo

antagonism assay. The seeds were sown in a planting medium consisting of sterilized soil and compost at a ratio of 1:1. Seedlings were maintained until 14 days after sowing, or until they had developed three to four true leaves, before root-soaking treatment was applied.

The *Streptomyces* sp. isolate used in this study was obtained from the collection of the Plant Health Laboratory, UPN "Veteran" Jawa Timur. The isolate had previously been isolated from the rhizosphere or root zone of mangrove plants at the Mangrove Botanical Garden, Gunung Anyar, Surabaya, East Java. The fungal pathogen *Sclerotium rolfsii* was obtained through exploration of cayenne pepper plantations in Kampungbaru, Kediri, East Java.

Experimental Design

The in vivo antagonism assay was arranged in a non-factorial completely randomized design (CRD), with root-soaking duration of cayenne pepper seedlings as the treatment factor. Six treatments, including controls, were tested with three replications per treatment. Each replication consisted of six cayenne pepper plants, resulting in a total of 108 experimental plants. The treatments were as follows:

KS : *Streptomyces* isolate only, without *Sclerotium rolfsii* inoculation (positive control)
KSr : *Sclerotium rolfsii* isolate only, without *Streptomyces* treatment (negative control)
KN : Without *Streptomyces* sp. and *Sclerotium rolfsii*
SW_1 : *S. rolfsii* inoculation and root soaking in *Streptomyces* sp. suspension for 15 min
SW_2 : *S. rolfsii* inoculation and root soaking in *Streptomyces* sp. suspension for 30 min
SW_3 : *S. rolfsii* inoculation and root soaking in *Streptomyces* sp. suspension for 45 min

Media Preparation

The media used in this study consisted of potato dextrose agar (PDA), glucose nitrate agar (GNA), and potato sugar extract medium (EKG). PDA was used as the growth medium for *S. rolfsii* and was prepared using 39 g of instant PDA medium (Merck) dissolved in 1,000 mL of sterile distilled water. GNA was used as the growth medium for *Streptomyces* sp. and consisted of 1 g glucose, 0.85 g $NaNO_3$, 1.75 g KH_2PO_4, 0.75 g KCl, 2.5 g $MgSO_4 \cdot 7H_2O$, 25 g agar, and 1,000 mL sterile distilled water. EKG medium was used for preparing the *Streptomyces* sp. suspension and consisted of 250 g potato, 20 g sugar, and 1,000 mL distilled water.

Rejuvenation of *Streptomyces* sp. Isolate and Propagation of *Sclerotium rolfsii*

The rejuvenation of the *Streptomyces* sp. isolate was performed to activate the bacterial culture and optimize its growth. The *Streptomyces* sp. isolate was obtained from the collection of the Plant Health Laboratory, UPN "Veteran" Jawa Timur, and had previously been isolated from the rhizosphere or root zone of mangrove plants at the Mangrove Botanical Garden, Gunung Anyar, Surabaya, East Java. Rejuvenation was conducted by transferring the *Streptomyces* sp. isolate to fresh GNA medium, followed by incubation for 14 days at room temperature.

Propagation of *S. rolfsii* was carried out to obtain a pure culture free from contamination by other microorganisms following isolation from symptomatic cayenne pepper plants. Before propagation, the fungal colonies were observed macroscopically and microscopically to confirm that they were *S. rolfsii*. Propagation was conducted by transferring the target fungal colony using an inoculating loop onto fresh PDA medium, followed by incubation at room temperature for 7 days.

In Vitro Antagonism Assay of *Streptomyces* sp. Against *S. rolfsii*

The in vitro antagonistic activity was evaluated using the dual-culture method, in which *Streptomyces* sp. and *S. rolfsii* isolates were placed in the same Petri dish to

observe the antagonistic response. A 9-cm-diameter Petri dish containing PDA medium was prepared. The *Streptomyces* sp. colony was inoculated by streaking it on one side of the Petri dish, 3 cm from the edge. On the opposite side, a 5-mm-diameter plug of *S. rolfsii* colony was inoculated at the same distance, 3 cm from the edge of the Petri dish. The assay was conducted with three replications.

Preparation of *Streptomyces* sp. Suspension

The *Streptomyces* sp. suspension was used to soak cayenne pepper seedling roots before transplanting as part of the antagonism assay treatment. The suspension used for root soaking had a colony density of 10^8 CFU/mL. The *Streptomyces* sp. suspension was prepared using liquid EKG medium by collecting 40 plugs of pure isolate colonies, each 5 mm in diameter, using a cork borer. The plugs were then transferred into an Erlenmeyer flask containing 400 mL of EKG medium. The suspension was homogenized using a rotary shaker at 60 rpm for 72 h at room temperature (Fitriana et al., 2020).

Preparation of *S. rolfsii* Inoculum

Pathogen inoculation of the test plants was conducted using barley seed inoculum containing *S. rolfsii* mycelia. Before use as inoculum, the barley seeds were sterilized in an oven at 65°C for 50 min.

Pathogen inoculation was performed using *Rhizoctonia solani* inoculum propagated on 150 g of a sterile rice and rice husk substrate at a ratio of 3:1 in plastic bags. The substrate was sterilized using an autoclave at 121°C for 15 min, inoculated with 5 mm² pieces of *R. solani* culture, and incubated for two weeks at room temperature (Djaenuddin et al., 2017). The application of *R. solani* to the soil followed the method of Ali et al. (2025), in which the rice and rice husk substrate containing *R. solani* inoculum was mixed with the planting medium at a ratio of 15 g mycelial culture per kilogram of soil.

In Vivo Antagonism Assay of *Streptomyces* sp. Against *S. rolfsii*

The in vivo antagonism assay of *Streptomyces* sp. began with the preparation of the planting medium and inoculation with *S. rolfsii*. *S. rolfsii* inoculation was carried out 7 days before transplanting by placing four barley seed inocula in four different directions or corners. Each barley seed was positioned approximately 2 cm from the stem of the cayenne pepper plant (Qiu et al., 2024).

Transplanting was conducted when cayenne pepper seedlings were 18–21 days old or had developed three to four true leaves. Before transplanting, the seedlings were subjected to root-soaking treatment. Root soaking was performed using 100 mL of *Streptomyces* sp. suspension with a density of 10^8 CFU/mL for each treatment, corresponding to approximately 18 experimental plants. The roots of cayenne pepper seedlings were soaked for 15 min (W_1), 30 min (W_2), or 45 min (W_3). The positive control treatment received only the antagonistic bacterial treatment, applied for the longest soaking duration of 45 min.

Observation Parameters

1. Inhibition zone

The inhibition zone was defined as the clear area formed around the antagonistic agent on the medium, representing the inhibition of the target microorganism's growth. The percentage of inhibition zone formation was calculated using the following formula (Pandey et al., 2018):

$$\mathbf{I = [(r_1 - r_2) / r_1] \times 100\%}$$

Note:
I = percentage of inhibition (%)
r_1 = radius of the *S. rolfsii* colony growing away from *Streptomyces* sp. (cm)
r_2 = radius of the *S. rolfsii* colony growing toward *Streptomyces* sp. (cm)
The ability to inhibit the growth of *S. rolfsii* was classified into five categories based on the percentage of inhibition.

Table 1. Categories of inhibition of *S. rolfsii* fungal growth

Percentage of inhibition (I)	Inhibition category
I = 0%	No activity
0% < I ≤ 25%	Weak
25% < I ≤ 50%	Moderate
50% < I ≤ 75%	Strong
I > 75%	Very strong

2. Incubation Period

The incubation period was defined as the period from pathogen inoculation to the appearance of the first disease symptoms. Initial symptoms were characterized by softening of the outer tissue at the stem base, accompanied by a pale brown discoloration. Observation of the incubation period began after transplanting and continued until the first symptoms appeared. The incubation period was calculated using the following formula:

$$M = \Sigma(Z \times Y) / \Sigma X$$

Note:
Z = number of infected plants on day Y
Y = day of infection
X = total number of infected plants

3. Disease Intensity

Disease intensity refers to the severity of disease attack in a plant population or specific plant unit, based on the area or proportion of symptomatic plant tissue relative to the total tissue area. Disease intensity was observed for 28 days at 7-day intervals, starting after transplanting. Disease intensity after *S. rolfsii* inoculation was calculated using the following formula (Pratami et al., 2025):

$$I = [\Sigma(n \times v) / (Z \times N)] \times 100\%$$

Note:
I = disease intensity
n = number of diseased plants in each category
v = score value assigned to each diseased plant category
Z = highest score value
N = total number of observed plants

The disease severity scale used to calculate the intensity of *S. rolfsii* infection followed Yusnita et al. (2005), with the following scores:
0 = no symptoms
1 = necrosis affecting less than 50% of the stem circumference
2 = necrosis affecting 50%–75% of the stem circumference
3 = necrosis completely encircling the infected stem

4 = necrosis completely encircling the infected stem, with the infected stem beginning to bend and several leaves beginning to wilt
5 = dead plant

4. Plant Growth

Plant growth parameters consisted of plant height and number of leaves. Plant height was measured from the stem base to the highest growing point, whereas the number of leaves was counted based on fully expanded leaves.

5. Data Analysis

Observation data were analyzed using analysis of variance (ANOVA) with IBM SPSS Statistics version 27.0 to determine the effect of each treatment. The significance of treatment effects was determined based on the P-value. A P-value greater than 0.05 indicated a non-significant effect, whereas a P-value less than 0.05 indicated that the treatment had a significant effect or differed significantly. When the analysis showed significant differences among treatments, a post hoc test was conducted to identify which treatments produced the most significant effects using Tukey's honestly significant difference test, locally referred to as Beda Nyata Jujur (BNJ), at the 5% significance level.

RESULTS AND DISCUSSION

In Vitro Antagonism of *Streptomyces* sp. against *S. rolfsii*

The in vitro antagonism assay conducted using the dual-culture method showed that *Streptomyces* sp. was able to inhibit the growth of *S. rolfsii*. Differences in colony diameter between the two sides of the culture indicated the effectiveness of *Streptomyces* sp. in suppressing the growth rate of *S. rolfsii* (Figure 1).

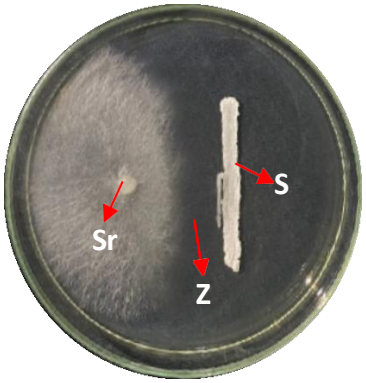

Figure 1. In vitro antagonism assay of *Streptomyces* sp. against *S. rolfsii*; Sr: *S. rolfsii* fungus, Z: inhibition zone, S: *Streptomyces* sp. bacterium.

The antagonistic activity of *Streptomyces* sp. against *S. rolfsii* was classified as strong, with an inhibition percentage of up to 52.33%, as indicated by the formation of a clear inhibition zone. The inhibitory mechanism likely occurred because *Streptomyces* sp. naturally synthesizes antibiotics in the form of secondary metabolites, which then diffuse into the growth medium and inhibit fungal growth without direct contact (Nurhidayati and Wisanggeni, 2025). This was supported by microscopic observations showing that the mycelia of *S. rolfsii* located near the inhibition zone exhibited abnormal hyphal growth. Under normal conditions, hyphae appear straight, intact, and cylindrical, with regular branching. In contrast, the hyphae observed in this study showed morphological alterations, including swelling (Figure 2a), bending (Figure 2b), abnormal branching (Figure 2c), and collapse, in which the

hyphal wall appeared shrunken, damaged, or disrupted in several areas (Figure 2d). Similarly, Sailaja et al. (2024) reported that antagonistic interactions between *Streptomyces* sp. and *S. rolfsii* caused irregular distortions at the contact points and collapse of fungal hyphae, characterized by deformation, swelling, and structural collapse.

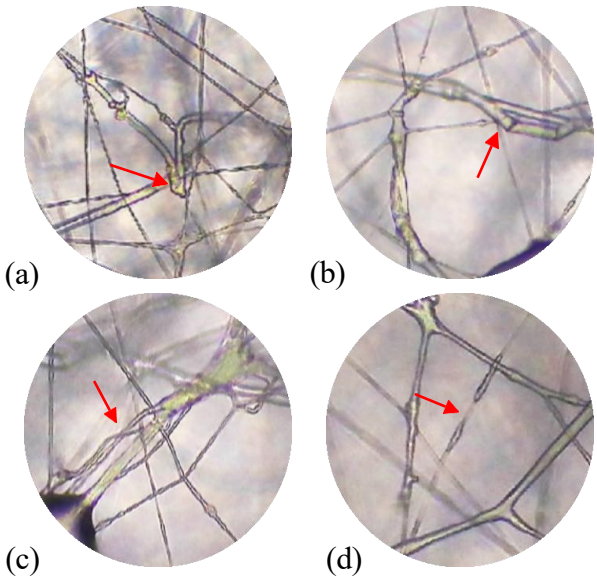

Figure 2. Microscopic observation of abnormal hyphal growth of *S. rolfsii* in the antagonism assay with *Streptomyces* sp.: (a) swelling; (b) abnormal branching; (c) hyphal bending; (d) collapse.

These morphological changes were attributed to the production of secondary metabolites and extracellular enzymes by *Streptomyces* sp., including fungal cell-wall-degrading enzymes such as cellulase, lipase, protease, and chitinase, which can cause structural damage to *S. rolfsii* cells (Piedra et al., 2026). These compounds diffuse into the culture medium, thereby inhibiting the growth of the pathogenic fungus without direct physical contact. Such damage not only slows fungal growth but may also disrupt the normal physiological function of the hyphae. The formation of an inhibition zone and the observed damage to hyphal structures indicate that the antagonistic interaction between *Streptomyces* sp. and *S. rolfsii* involved antibiosis or indirect mycoparasitism (Agustin et al., 2022).

In Vivo Antagonism of *Streptomyces* sp. against *S. rolfsii*

Incubation period

Root immersion in a suspension of *Streptomyces* sp. delayed the incubation period of stem rot disease caused by *S. rolfsii*. The shortest incubation period occurred in the KSr treatment, with initial symptoms appearing at an average of 7.61 days after transplanting. This rapid symptom development occurred because the pathogen was able to grow in the absence of an antagonistic agent, allowing the active inoculum in the planting medium to infect the plants immediately. In contrast, root immersion in the *Streptomyces* sp. suspension delayed symptom appearance. Initial symptoms appeared at 14.47 days after transplanting in the SW_1 treatment and at 25.16 days after transplanting in the SW_2 treatment. In the SW_3 treatment, no symptoms were observed until the final day of observation, namely 28 days after transplanting (Figure 3).

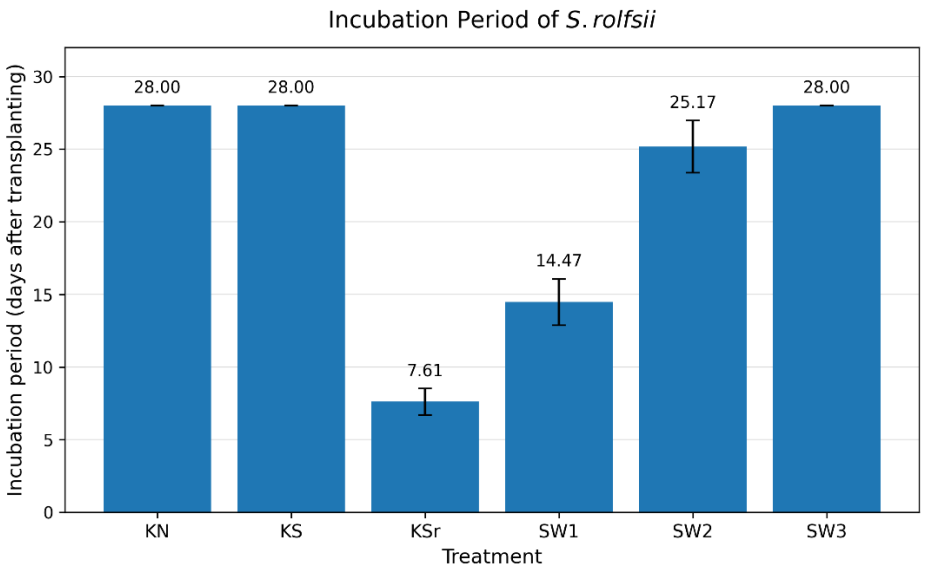

Figure 3. Histogram of the incubation period of *S. rolfsii* infection

These findings indicate that the incubation period was relatively short under environmental conditions favorable for pathogen development. However, root immersion in an antagonistic agent such as *Streptomyces* sp. effectively prolonged the incubation period. Longer root immersion durations appeared to influence the extent of *Streptomyces* sp. colonization on the root surface. Root colonization by *Streptomyces* sp. can trigger induced systemic resistance (ISR), a process in which microorganisms produce chemical signals in the form of secondary metabolites that are distributed throughout the plant. This process places the plant in a primed defensive state, enabling a faster and stronger defense response during pathogen attack (Santhoshinii et al., 2025).

Disease Intensity

The intensity of stem rot disease in cayenne pepper plants was influenced by the interaction among *S. rolfsii* as the pathogen, *Streptomyces* sp. as the antagonistic microorganism, and the host response of cayenne pepper. The symptoms observed included necrosis at the basal stem, leaf discoloration and wilting, followed by the appearance of white mycelia on decaying plant tissue. According to Lamichhane et al. (2017), infected cayenne pepper plants show symptoms such as soft, sunken, and girdled basal stem tissue near the soil surface. In addition, leaves turn yellow and wilt, while the infected basal stem becomes covered with white mycelial mats and dark brown to black sclerotia resembling mustard seeds. When dead plants are uprooted, clusters of sclerotia are often observed attached to the roots.

Disease intensity was assessed using a scoring method to determine disease severity. The results showed that different root immersion durations in *Streptomyces* sp. significantly reduced stem rot intensity caused by *S. rolfsii* at each observation time. At the final observation, the highest disease intensity occurred in the KSr treatment, reaching 93.33%, because the pathogen developed optimally without inhibition by an antagonistic agent. The root immersion treatments still showed disease incidence, but with lower intensity than KSr. The SW1 treatment showed disease intensity of 43.33%, whereas SW2 showed very low disease intensity of only 5.55%. Meanwhile, SW3 continued to suppress disease incidence until the final observation (Table 1).

Table 1. Disease intensity of stem rot in cayenne pepper plants

Treatment	Day 7	Day 14	Day 21	Day 28
KN	0.00 a	0.00 a	0.00 a	0.00 a
KS	0.00 a	0.00 a	0.00 a	0.00 a
KSr	20.00 b	50.00 c	77.77 c	93.33 c
SW1	0.00 a	12.22 b	27.77 b	43.33 b
SW2	0.00 a	0.00 a	0.00 a	5.55 a
HSD value at 5%	3.73	6.81	8.88	13.63

Note: Mean values followed by the same letter within the same column are not significantly different according to the HSD test at 5%.

The high disease intensity observed in the KSr treatment was associated with the highly aggressive pathogenicity of *S. rolfsii* and the timing of inoculation, which supported pathogen development before transplanting. *S. rolfsii* produces cellulase, pectinase, and hemicellulase enzymes that damage basal stem tissues, leading to stem rot symptoms (Ayed et al., 2025). In addition to the aggressive pathogenicity of *S. rolfsii*, early inoculation contributed to the high disease intensity observed. Pathogen inoculation was conducted before transplanting; therefore, the inoculum had already germinated, and fungal mycelia had colonized the rhizosphere zone. When plant roots came into contact with actively contaminated soil, the likelihood of infection increased immediately because these conditions facilitated direct pathogen attack on the host without inhibition. This finding is consistent with the study by Meena et al. (2024), which showed that the presence of *S. rolfsii* inoculum in the planting medium before the early plant growth stage allows the pathogen to develop around the basal stem zone before infection occurs.

Early inoculation was also applied in the SW1, SW2, and SW3 treatments; however, the analysis showed significant differences compared with the KSr treatment. Relative to KSr, root immersion for 15 min in the SW1 treatment suppressed disease by 53.57%, immersion for 30 min in the SW2 treatment suppressed disease by 94.05%, and immersion for 45 min in the SW3 treatment suppressed disease by up to 100%. Longer immersion durations allowed the *Streptomyces* sp. isolate to remain in contact with the root surface for a longer period, thereby increasing the opportunity for microbial attachment, growth, and biofilm formation in the rhizosphere. Intensive colonization of the root zone enhances competition with the pathogen for space and nutrients and maximizes the secretion of antimicrobial metabolites that suppress *S. rolfsii* growth before root damage occurs. Raish et al. (2025) reported that the initial contact duration between a biological control agent and plant roots contributes to successful bacterial colonization in the rhizosphere, stimulates plant defense responses, and inhibits the development of surrounding fungal pathogens.

Streptomyces sp. has antagonistic capacity through the production of diverse secondary metabolites, including antibiotics, pathogen cell-wall-degrading enzymes such as chitinase, β-1,3-glucanase, protease, cellulase, hemicellulase, and pectinase, as well as siderophores. Collectively, these compounds enhance the competitive ability of *Streptomyces* sp. in the rhizosphere. Boukaew et al. (2025) stated that volatile compounds produced by *Streptomyces* sp. can kill the mycelia and sclerotia of *S. rolfsii* and provide a high level of protection to chili seedlings against this pathogen. The antagonistic mechanism becomes more effective when the microorganism has already attached to and colonized the root surface. Thus, when the pathogen enters or comes

into contact with the root, the metabolic activity of *Streptomyces* sp. can immediately inhibit the development of *S. rolfsii*.

Growth of Cayenne Pepper Plants

The use of *Streptomyces* sp. not only functioned as an antagonistic agent but also enhanced vegetative plant growth through its plant growth-promoting rhizobacteria (PGPR) properties. Analysis of variance for growth parameters showed significant differences between root immersion treatments and the control. This indicates that root immersion before transplanting had a significant effect on plant height and leaf number.

Observations showed no substantial differences among treatments in the early observation period, either in plant height increase or leaf number (Tables 2 and 3). This suggests that *Streptomyces* sp. colonizing the roots was still adapting to the rhizosphere environment. Differences among treatments became more apparent at 14 days after transplanting. This stage represents an active vegetative growth phase, characterized by intensive cell division and elongation. By the final week of observation, the KS treatment, which involved the longest immersion duration, consistently showed the highest increase in plant height and leaf number. Based on the post hoc test, plant height in the KS treatment reached 22.39 cm, with the highest leaf number of 58.05. In contrast, the control treatment without root immersion in *Streptomyces* sp. showed a plant height of only 12.95 cm and a leaf number of 22.44. Compared with the control, vegetative growth increased by 51.92%–115.80%.

The increase in plant height and leaf number in the root immersion treatments demonstrates that *Streptomyces* sp. possesses PGPR activity. This bacterium produces growth hormones such as indole-3-acetic acid (IAA), which stimulates cell division and elongation as well as lateral root formation. A more developed root system increases the surface area for water and nutrient uptake, thereby supporting stem growth and leaf formation (Omar et al., 2022). In addition, *Streptomyces* sp. can solubilize phosphate and produce siderophores, increasing the availability of phosphorus and iron in the rhizosphere. Phosphorus plays an important role in cell division and the formation of new tissues, whereas iron supports chlorophyll synthesis and photosynthetic efficiency. Improved nutrient availability is therefore directly associated with increased leaf number and plant height.

Table 2. Observation of cayenne pepper plant height

Treatment	Day 7	Day 14	Day 21	Day 28
KN	5.00 b	7.86 b	9.82 bc	12.95 c
KS	8.58 d	13.56 d	18.34 e	22.39 e
KSr	3.86 a	5.20 a	4.27 a	2.89 a
SW1	4.82 ab	6.28 a	8.12 b	6.84 b
SW2	5.65 bc	7.97 b	10.63 c	14.78 c
HSD value at 5%	1.00	1.27	1.71	3.15

Note: Mean values followed by the same letter within the same column are not significantly different according to the HSD test at 5%.

Table 3. Observation of leaf number in cayenne pepper plants

Treatment	Day 7	Day 14	Day 21	Day 28
KN	5.00 b	7.86 b	9.82 bc	12.95 c
KS	8.58 d	13.56 d	18.34 e	22.39 e

Treatment	Day 7	Day 14	Day 21	Day 28
KSr	3.86 a	5.20 a	4.27 a	2.89 a
SW1	4.82 ab	6.28 a	8.12 b	6.84 b
SW2	5.65 bc	7.97 b	10.63 c	14.78 c
HSD value at 5%	1.00	1.27	1.71	3.15

Note: Mean values followed by the same letter within the same column are not significantly different according to the HSD test at 5%.

The same immersion duration was also applied in the SW3 treatment; however, plant height and leaf number remained lower than those in the KS treatment. Nevertheless, these values were higher than those of the other treatments inoculated with the pathogen *S. rolfsii*. According to Abou Jaoudé et al. (2023), the application method and contact duration between *Streptomyces* sp. and the root system influence the success of bacterial colonization, establishment, and persistence on roots, as well as plant growth. *Streptomyces* sp. isolated from the mangrove rhizosphere may have a high adaptive capacity under extreme environmental conditions; therefore, its PGPR activity can remain effective even under pathogen pressure from *S. rolfsii* in the rhizosphere. Furthermore, rhizosphere bacteria originating from extreme environments such as mangroves tend to possess more diverse metabolite profiles and biological activities, contributing to environmental stress tolerance and antagonism against plant pathogens (Sakaroni et al., 2025).

CONCLUSION

Based on the research conducted, the *Streptomyces* sp. isolate obtained from the rhizosphere of the mangrove *Avicennia marina* was able to inhibit the growth of the pathogenic fungus *S. rolfsii* through an antibiosis-mediated inhibitory mechanism. The inhibition percentage reached 52.33%, which falls within the category of strong inhibition. Direct antagonistic testing on cayenne pepper plants showed that the duration of root immersion in the *Streptomyces* sp. suspension affected both the incubation period and disease intensity. The longest immersion duration, 45 minutes (SW3), produced the best result in extending the incubation period, as no initial symptoms were observed until the final week of observation. This treatment effectively suppressed disease intensity by up to 100%. In addition, longer immersion durations enhanced vegetative plant growth by 51.92–115.80% compared with the control treatment.

RECOMMENDATION

Further studies at the field scale are needed to comprehensively evaluate the antagonistic efficacy and stability of secondary metabolites produced by the mangrove rhizosphere isolate of *Streptomyces* sp. Such testing is essential to determine the ability of the isolate to suppress the growth of *Sclerotium rolfsii* under the influence of complex natural environmental factors. In addition, expanding antagonism assays to include various pathogens and other crop species is necessary to assess the spectrum of activity, consistency of effectiveness, and interaction patterns of the isolate as a potential biological control agent (BCA).

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REFERENCES

Abou Jaoudé, R., Luziatelli, F., Ficca, A. G., & Ruzzi, M. (2023). A plant's perception of growth-promoting bacteria and their metabolites. *Frontiers in Plant Science, 14*, 1–31. https://doi.org/10.3389/fpls.2023.1332864

Abo-Zaid, G., Abdelkhalek, A., Matar, S., Darwish, M., & Abdel-Gayed, M. (2021). Application of bio-friendly formulations of chitinase-producing *Streptomyces cellulosae* Actino 48 for controlling peanut soil-borne diseases caused by *Sclerotium rolfsii*. *Journal of Fungi, 7*(3), 1–24. https://doi.org/10.3390/jof7030167

Agustin, D. A., Abadi, A. L., & Aini, L. Q. (2022). Uji mekanisme antagonis rizobakteri terhadap *Sclerotium rolfsii* penyebab rebah semai pada tanaman kacang tanah. *Agropross: National Conference Proceedings of Agriculture*, 296–307. https://doi.org/10.25047/agropross.2022.300

Al Raish, S. M., Sourani, O. M., & Abu-Elsaoud, A. M. (2025). Plant growth-promoting microorganisms as biocontrol agents: Mechanisms, challenges, and future prospects. *Applied Microbiology (Switzerland), 5*(2), 1–20. https://doi.org/10.3390/applmicrobiol5020044

Ayed, F., Rania, A. B. A., Saoussen, B. K., & Hayfa, J.-K. (2025). Biocontrol of *Agroathelia rolfsii* associated with stem rot disease in tomato (*Solanum lycopersicum* L.) and growth promotion using compost-associated actinobacteria. *Brazilian Journal of Microbiology, 56*(2).

Boukaew, S., Yossan, S., Chumkaew, K., Punfujinda, C., Buatong, J., Boonlue, S., Chumthong, A., & Petlamul, W. (2025). Volatile organic compounds from *Streptomyces philanthi* RM-1-138: Biocontrol of *Sclerotium rolfsii* and their impact on chili pepper seed germination. *Journal of Agriculture and Food Research, 21*, 101899. https://doi.org/10.1016/j.jafr.2025.101899

de Lima Procópio, R. E., da Silva, I. R., Martins, M. K., de Azevedo, J. L., & de Araújo, J. M. (2012). Antibiotics produced by *Streptomyces*. *Brazilian Journal of Infectious Diseases, 16*(5), 466–471. https://doi.org/10.1016/j.bjid.2012.08.014

Fitriana, I. N., Suryaminarsih, P., Mindari, W., & Wiyatiningsih, S. (2020). Studi pertumbuhan multiantagonis *Trichoderma* sp. dan *Streptomyces* sp. dalam suspensi akar, humat cair, dan ekstrak kentang gula. *Berkala Ilmiah Agroteknologi - Plumula, 7*(1), 25–32. https://doi.org/10.33005/plumula.v7i1.19

Hidayat, T., Supriyadi, S., & Sarjiyah, S. (2015). Pengaruh pemberian ekstrak daun sirih (*Piper betle* L.) untuk mengendalikan damping-off pada tanaman cabai (*Capsicum annum*). *Planta Tropika: Journal of Agro Science, 3*(1), 60–66. https://doi.org/10.18196/pt.2015.040.60-66

Inaya, N., Meriem, S., & Masriany, M. (2022). Identifikasi morfologi penyakit tanaman cabai (*Capsicum* sp.) yang disebabkan oleh patogen dan serangan hama lingkup Kampus UIN Alauddin Makassar. *Filogeni: Jurnal Mahasiswa Biologi, 2*(1), 8–14. https://doi.org/10.24252/filogeni.v2i1.27092

Lamichhane, J. R., Dürr, C., Schwanck, A. A., Robin, M. H., Sarthou, J. P., Cellier, V., Messéan, A., & Aubertot, J. N. (2017). Integrated management of damping-off diseases: A review. *Agronomy for Sustainable Development, 37*(2). https://doi.org/10.1007/s13593-017-0417-y

Lehar, L., Arifin, Z., Sine, H. M. C., Lengkong, E. F., & Sumayku, B. R. A. (2018). Pemanfaatan plant growth promoting rhizobacteria (PGPR) dalam

meningkatakan pola pertumbuhan bawang merah lokal (*Allium ascalonicum* L.) Sabu Raijua NTT. *Politanikoe, 23*(1), 646–656.

Leiva-Piedra, J. L., Seclen-Pozo, Y. R., & Romero-Becerra, I. A. (2026). Potential of *Streptomyces* sp. strains isolated from fallow soils for the control of *Botrytis* sp. in blueberries. *Revista Brasileira de Meio Ambiente, 14*(2), 162–183.

Majeed, M., Hassan Mir, G., Hassan, M., Mohuiddin, F. A., Paswal, S., & Farooq, S. (2018). Damping off in chilli and its biological management: A review. *International Journal of Current Microbiology and Applied Sciences, 7*(4), 2175–2185. https://doi.org/10.20546/ijcmas.2018.704.247

Meena, P. N., Meena, A. K., Tiwari, R. K., Lal, M. K., & Kumar, R. (2024). Biological control of stem rot of groundnut induced by *Sclerotium rolfsii* Sacc. *Pathogens, 13*(8). https://doi.org/10.3390/pathogens13080632

Omar, A. F., Abdelmageed, A. H. A., Al-Turki, A., Abdelhameid, N. M., Sayyed, R. Z., & Rehan, M. (2022). Exploring the plant growth-promotion of four *Streptomyces* strains from rhizosphere soil to enhance cucumber growth and yield. *Plants, 11*(23), 1–19. https://doi.org/10.3390/plants11233316

Pandey, A., Malviya, M. K., & Trivedi, P. (2018). Chitinase and glucanase activities of antagonistic *Streptomyces* spp. isolated from fired plots under shifting cultivation in Northeast India. *Journal of Advanced Research in Biotechnology, 3*(1), 1–7. https://doi.org/10.15226/2475-4714/3/1/00130

Pratami, S., Hemon, A. F., & Haryanto, H. (2025). Respon beberapa genotipe kacang tanah yang terinfeksi *Sclerotium roflsii* Sacc. pada fase vegetatif dan generatif: Response of several peanut genotypes infected by *Sclerotium roflsii* Sacc. in vegetative and generative phases. *[Nama Jurnal Tidak Dicantumkan], 4*(3), 1002–1011.

Pratiwi, A. S. (2021). Barang kebutuhan pokok yang tidak dikenai pajak pertambahan nilai. *Journal of Law, Administration, and Social Science, 1*(1), 47–60. https://doi.org/10.54957/jolas.v1i1.78

Qiu, Z. L., Da Liu, S., Li, X. G., Zhong, J., & Zhu, J. Z. (2024). Identification and mechanism characterization of *Streptomyces griseoaurantiacus* XQ-29 with biocontrol ability against pepper southern blight caused by *Sclerotium rolfsii*. *Pesticide Biochemistry and Physiology, 202*, 105956. https://doi.org/10.1016/j.pestbp.2024.105956

Rahayu, D. R., Wiyatiningsih, S., & Suryaminarsih, P. (2021). Pengaruh perendaman bibit bawang merah dengan formulasi biopestisida untuk mengendalikan penyakit moler (*Fusarium oxysporum*). *Agritrop: Jurnal Ilmu-Ilmu Pertanian (Journal of Agricultural Science), 19*(2), 121–129. https://doi.org/10.32528/agritrop.v19i2.6337

Sahriyanor, A., Mariana, & Budi, I. S. (2024). Uji *Streptomyces* sp. isolat lahan rawa untuk menekan pertumbuhan *Colletotrichum* sp. asal cabai rawit varietas Hiyung secara in vitro. *Proteksi Tanaman Tropika, 7*(2), 922–933.

Sakaroni, R., Kusuma, A. S. H. M., & Adawiyah, M. R. (2025). Actinobacteria from mangrove rhizosphere as a source of biocontrol agents to support sustainable agriculture. *BIOEDUPAT: Pattimura Journal of Biology and Learning, 5*(2), 360–369. https://doi.org/10.30598/bioedupat.v5.i2.pp360-369

Santhoshinii, E., Jahagirdar, S., Krishnaraj, P. U., Kambrekar, D. N., & Hegde, G. (2025). Biocontrol potential of novel *Streptomyces* spp. in suppressing leaf curl complex of chilli (*Capsicum annuum* L.). *Biochemical and Cellular Archives, 25*(2), 1643–1651. https://doi.org/10.51470/bca.2025.25.2.1643

Sumartini. (2012). Penyakit tular tanah (*Sclerotium rolfsii* dan *Rhizoctonia solani*) pada tanaman kacang-kacangan dan umbi-umbian serta cara pengendaliannya. *Jurnal Litbang Pertanian, 31*(1), 27–34. http://pustaka.litbang.deptan.go.id/publikasi/p3311125.pdf

Thepbandit, W., & Athinuwat, D. (2024). Rhizosphere microorganisms supply availability of soil nutrients and induce plant defense. *Microorganisms, 12*(3), 1–23. https://doi.org/10.3390/microorganisms12030558

Yusnita, Widodo, & Sudarsono. (2005). In vitro selection of peanut somatic embryos on medium containing culture filtrate of *Sclerotium rolfsii* and plantlet regeneration. *HAYATI Journal of Biosciences, 12*(2), 50–56. https://doi.org/10.1016/S1978-3019(16)30324-2

Zahara, Wisnujati, A. D., N. S., & Siswati, E. (2021). Analisis produk dan produktifitas cabai rawit (*Capsicum frutescens* L.) di Indonesia. *Sosio Agribisnis, 21*(1), 18–29.