**Bioeksperimen: Jurnal Penelitian Biologi**
**Volume 12, Issue 2, September 2026, pp. 253-260**
**p-ISSN: 2460-1365, e-ISSN: 2527-2799**
https://journals2.ums.ac.id/bioeksperimen

# Colonization of *Streptomyces enissocaesilis* on the root system of *Zea mays* var ceratina

**Velma Agtavia*, Yuliana Retnowati**, Novri Youla Kandowangko, Jusna Ahmad, Abubakar Sidik Katili**
[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Jl. Prof. Bj. Habibie, Bone Bolango Regency, Gorontalo, Indonesia. 96119 tel./fax +62-822-92424007

*Corresponding e-mail: *Email: velmaagtavia@gmail.com; **Email: yuliana.retnowati@ung.ac.id

**How to cite:**
Agtavia, V., Retnowati, Y., Kandowangko, N. Y., Ahmad, J., & Katili, A. S. (2026). Colonization of Streptomyces enissocaesilis on the Root System of Zea mays var ceratina. *Bioeksperimen: Jurnal Penelitian Biologi*, *12*(2), 262–269. https://doi.org/10.23917/bioeksperimen.v12i2.17484.

**Article info**

**Article History:**
Received: 12 May 2026, Revised: 01 July 2026, Available Online: 28 September 2026

**Keywords:**
Root colonization, metabolites, plant growth, *Streptomyces enissocaesilis*, *Zea mays* var. ceratina



**Abstract**

*Streptomyces enissocaesilis* is a microorganism with diverse biological activities; it is capable of colonizing plant root systems by forming mycelium and adhering to root surfaces.. This study aimed to analyze the colonization of *Streptomyces enissocaesilis* in the root system of *Zea mays* var ceratina based on root infection ability, metabolite profiles in growth media, and plant vegetative growth. *Zea mays var ceratina* was grown hydroponically using the *Deep Flow Technique* (DFT) for 30 days with inoculation ($1.1 \times 10^8$ CFU/g) and without inoculation of *Streptomyces enissocaesilis* as a control. Plant growth was monitored at 7-day intervals, while infectivity and metabolite profiles were assessed at the end of the growth period; metabolite screening in the growth medium was performed using LC-MS.The results showed that *Streptomyces enissocaesilis* was able to infect plant root tissue, as well as interact on the root surface, as indicated by filamentous structures resembling hyphae on the epidermis of treated plant roots. Analysis of the metabolite profile in growth media inoculated with *Streptomyces enissocaesilis* using LC-MS revealed peaks detected at retention times of 0.72 and 1.18 minutes. Inoculation of *Streptomyces enissocaesilis* during the vegetative growth of *Zea mays* var ceratina, based on plant height and root length data, showed significantly higher values compared to the control; however, no significant differences were observed for the parameters of leaf number, dry weight, and root-to-shoot ratio. Based on these data, inoculation with *Streptomyces enissocaesilis* has the potential to function as a *Plant Growth Promoting Rhizobacteria* (PGPR). Based on the research findings, *Streptomyces enissocaesilis* has the potential to be developed as a plant growth promoter. However, its effectiveness in increasing biomass and overall plant growth still requires further study.

## Introduction

The root system, or rhizosphere, is the zone surrounding plant roots that consists of various components, such as microorganisms, soil, and roots. The root system serves as the site where plant roots absorb water and nutrients and interact with microorganisms (Viana *et al.,* 2022). The presence of microorganisms in the root system is strongly influenced by the soil's physicochemical properties and the plant's biological activity in the form of chemical signals, namely root exudates (Haldar & Sengupta, 2015). Microorganisms in the rhizosphere are not always beneficial; pathogenic microorganisms can dominate and transform mutualistic interactions into harmful ones for the plant (Chauhan et al., 2023). Pathogenic fungal groups such as *Phytophthora* spp. and *Fusarium* spp. can cause root rot and stem rot in plants (Xie *et al.,* 2022). These fungal infections typically occur during the plant's vegetative phase, approximately 21 days after planting (Rampersad, 2020). The presence of pathogenic fungi in the rhizosphere can adversely affect plant

growth, leading farmers to frequently use synthetic fungicides to control these pathogens (Muslim & Suwandi, 2023).

The use of biological agents is a promising approach for controlling plant pathogens (Seep *et al.,* 2021). One potential biological agent in maintaining soil ecosystem balance is Steptomycetes, a member of the actinomycetes group that holds great potential in supporting agricultural systems through biocontrol and biofertilization mechanisms (Widiantini, 2024). Research conducted by Retnowati *et al.* (2024) supports this finding, having successfully isolated three actinomycetes isolates. These actinomycetes isolates demonstrated the potential to enhance plant growth, as indicated by their phosphate-solubilizing activity and production of indole-3-acetic acid

The ability of *Streptomyces* to support plant health depends heavily on its ability to colonize the root system. *Streptomyces* colonization of the root system increases nutrient availability, stimulates lateral root formation, and enhances plant resistance to biotic and abiotic stresses (Vurukonda *et al*., 2018). *Zea mays* var. ceratina was selected as the appropriate host to test the effectiveness of *Streptomyces* colonization. Corn has a rhizosphere rich in growth-promoting and biocontrol microbes, such as *Streptomyces*, which solubilize phosphate, produce siderophores, and increase corn biomass (Ríos-Ruiz *et al.,* 2024). Corn is adaptable, drought-tolerant, pest-resistant, and popular with the public (Kandowangko, 2019).

Although the potential of *Streptomyces* to enhance plant growth has been widely reported, research on *Streptomyces enissocaesilis* remains very limited. Therefore, this study is necessary to determine the colonization ability of *Streptomyces enissocaesilis* in plant root systems.

## Materials and methods

The research was conducted at the Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Gorontalo State University. Meanwhile, the plant testing was carried out in the greenhouse located at the Department of Biology, Faculty of Mathematics and Natural Sciences, Gorontalo State University.

### 1. Materials

*Streptomyces anissocaesilis* isolates obtained from previous research that have potential as *Plant Growth-Promoting Rhizobacteria* (PGPR), *Streptomyces anissocaesilis* mycelium culture medium, Starch Casein Agar (SCA), *Zea mays* var. ceratina seeds, Nystatin, Ringer's solution).

### 2. Method

The colonization of *Streptomyces anissocaesilis* on the roots of *Zea mays* var ceratina was analyzed based on three parameters: the infection capability of *Streptomyces anissocaesilis* on root tissue, the metabolite profile in the growth medium, and plant growth over a 30-day growing period.

a. The Infection capability of *Streptomyces enissocaesilis* on the Roots tissue

The roots of 30-day-old plants were washed with sterile distilled water, then cut transversely and examined directly under a light microscope using fuchsin stain at 400x magnification. Infection by *Streptomyces anissocaesilis* in root tissue is indicated by filamentous structures and spores in the root tissue (Lanti *et al.,* 2025). Microscopic observations were also conducted on the root surface without fuchsin stain to determine the presence of interactions on the root surface (Toma *et al.,* 2024).

b. Analysis of metabolite profiles in growth media

Metabolite profiling of the growth medium was performed using LC-MS at the UGM LPPT in accordance with standard methods. The chromatograms were analyzed to identify specific peaks appearing in the growth medium samples inoculated with *Streptomyces anissocaesilis* compared to growth medium samples without *Streptomyces anissocaesilis* inoculation (Theowidavitya *et al.,* 2019).

c. Analysis of the vegetative growth of *Zea mays* var ceratina

*Zea mays* var. ceratina seeds were grown hydroponically using the Deep Flow Technique (DFT) system, with treatments involving inoculation with *Streptomyces enissocaesilis* ($1.1 \times 10^8$ CFU/gram) and without inoculation, in 10 liters of sterile distilled water as the growing medium, with three replicates. Chemical analysis of the growing medium water was conducted to determine the $NO_3^-$ and $PO_4^{3-}$ content. The vegetative growth of *Zea mays* var. ceratina was observed for 30 days at 7-day intervals, including

measurements of plant height, number of leaves, root length, plant dry weight, and root-to-shoot ratio. Plant height was measured from the surface of the growing medium to the highest point of the plant. (Arinong, A. R., *et al.* 2021). The leaves counted are those that have fully developed and are growing normally on the sample plants. Root length is measured from the base to the tip of the root. To determine dry weight, the plants are cleaned of debris, dried in an oven at 70°C for 48 hours, and then weighed using an analytical balance. The root-to-shoot ratio is obtained by comparing the dry weights of the roots and shoots using the formula:RPAdry weight of the rootdry weight pupus×100%.

### 3. Data analysis

Data on the infectivity of Streptomyces enissocaesilis in root tissue and the metabolite profile in the growth medium were analysed using quantitative descriptive methods. The data are presented in the form of figures. Data on the growth of Zea mays var. ceratina were analysed quantitatively using one-way ANOVA (Analysis of Variance) at a significance level (α) of 0.05 and presented in tabular form.

## Results and discussion

### 1. The ability of *Streptomyces enissocaesilis* to infect the root system of *Zea mays* var ceratina

The *Streptomyces enissocaesilis* isolate was tested for its ability to infect the root tissue of *Zea mays* var ceratina. The results of the observations showed that the *Streptomyces enissocaesilis* isolate was capable of infecting the root tissue of corn plants, as indicated by the presence of filamentous structures resembling hyphae that penetrated the plant's epidermal cells, followed by the formation of specific colonization patterns and spore formation, whereas in the control treatment, such structures were not found, indicating the absence of interaction between the root system and filamentous microbes during the plant's growth period (Figure 1). Morphological observations of the root surface of *Zea mays* var ceratina plants in the treatment inoculated with *Streptomyces enissocaesilis* revealed the presence of spots that are suspected to result from the interaction between *Streptomyces enissocaesilis* and the root system on the root epidermis, whereas no such structures were found in the control treatment. This morphological difference indicates that *Streptomyces enissocaesilis* inoculation affects the physical condition of *Zea mays* var ceratina roots (Figure 2).

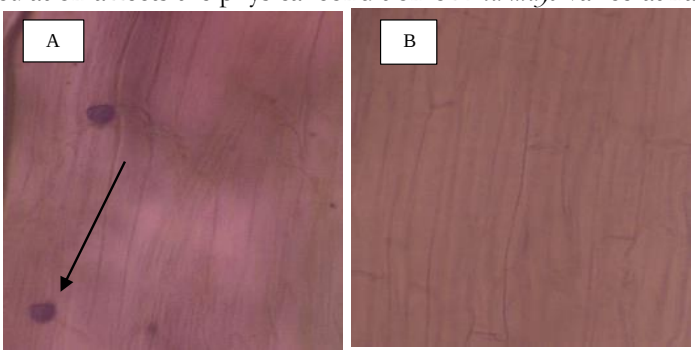


**Figure 1. The colonization ability of *Streptomyces enissocaesilis* on plant root tissue. (A) *Streptomyces enissocaesilis* treatment on *Zea mays* var ceratina roots; (B) *Zea mays var ceratina* control**

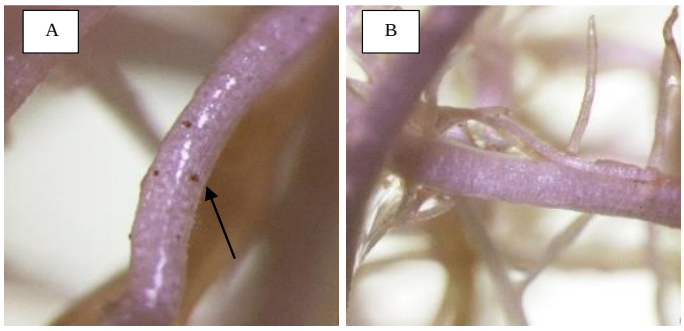


**Figure 2. The ability of Streptomyces enissocaesilis to colonize plant root surfaces. (A) Streptomyces enissocaesilis treatment on Zea mays var ceratina roots, (B) Zea mays var ceratina control**

*Streptomyces* is a filamentous bacterium resembling fungal hyphae, which facilitates its adaptation and attachment to plant root surfaces. The colonization process begins with a response to root exudates containing compounds such as sugars, amino acids, and organic acids, which serve as both chemical signals and nutrient sources. These compounds attract the bacteria to approach the roots via chemotaxis and activate genes involved in colonization. Subsequently, the bacteria attach to the root surface (rhizoplane) and form initial colonies through the growth of branching vegetative mycelium, thereby strengthening interactions with the plant and increasing the likelihood of penetration into root tissues (Compant *et al.,* 2025) The results of the observations indicate that *Streptomyces enissocaesilis* can infect root tissues through the penetration of filamentous structures (hyphae) into the epidermis and specific colonization leading to sporulation, suggesting a complex mutualistic interaction. These results align with the theory proposed by (El-Akshar *et al.*, 2022) that *Streptomyces* is capable of colonizing internal root tissues and sporulating on the surface layer. *Streptomyces* lives in the rhizosphere and endosphere of roots, forming mycelium and secreting bioactive metabolites, stimulating plant responses and combating other microbes. Liu *et al.* (2024) state that *Streptomyces* colonization of roots begins with chemical interactions between root exudates and soil microbes. Roots release organic compounds that serve as a nutrient source and chemotactic signals for rhizosphere bacteria, triggering the movement of *Streptomyces* to the rhizoplane and attachment to the epidermis. Colonization mechanisms include chemotaxis, adhesion, and adaptation to plant immunity.

## 2. Metabolite profile in the growth medium

Metabolite analysis of *Zea mays* var ceratina growth media was performed using LC-MS on growth media with and without *Streptomyces enissocaesilis* inoculation. The results showed that the chromatogram of the water sample with the inoculation treatment detected 12 major peaks at retention times ranging from 0.57 to 19.33 minutes, while the control sample detected 9 major peaks at retention times ranging from 0.57 to 19.33 minutes. This indicates the presence of specific metabolites produced as a result of the interaction between *Streptomyces enissocaesilis* and the root system of *Zea mays* var ceratina, which were detected at retention times of 0.72 and 1.18 minutes (Figure 3).

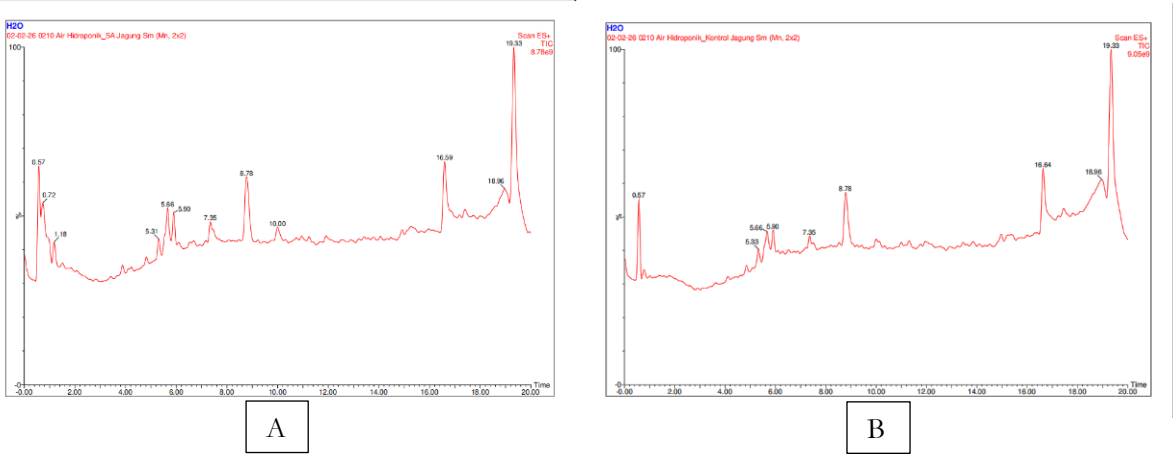


**Figure 3. Results of metabolomic chromatogram analysis of the root system of *Zea mays* var ceratina: (A) Treatment with *Streptomyces enissocaesilis*, (B) Control *Zea mays* var ceratina**

*Streptomyces* are soil bacteria capable of producing various bioactive secondary metabolites. These metabolites are not directly involved in primary growth but play a crucial role in ecological interactions, such as competition with other microorganisms and protection against pathogens. The production of these metabolites is regulated by biosynthetic gene clusters (BGCs), which are abundant in the *Streptomyces* genome. The presence of BGCs enables *Streptomyces* to produce bioactive compounds that play a role in microbial competition in the soil environment, particularly in inhibiting pathogen growth (Van der Heul *et al.*, 2018). Interactions between plants and microbes in the rhizosphere begin with the secretion of root exudates by plants, which attract microbes to the rhizosphere. Microbial colonization in the rhizosphere causes changes in the physical and chemical properties of the soil, which affect plant growth. Plant roots also form mutualistic symbioses, expand the root system, and enhance nutrient uptake. Additionally, microbes in the rhizosphere release compounds known as plant growth regulators (Widyati, 2013). The

results of the observations indicate that metabolite analysis of *Zea mays* var ceratina plants revealed that the chromatogram of the water samples from the inoculated treatment group showed 12 major peaks, whereas the control group showed 9 major peaks. This indicates the presence of specific metabolites produced as a result of the interaction between *Streptomyces enissocaesilis* and the root system of *Zea mays* var ceratina, detected at retention times of 0.72 and 1.18 minutes. These results align with the theory proposed by Ullah *et al.* (2021), which states that the production of secondary metabolites requires a sufficiently long incubation period and becomes active only in the stationary phase. In the early phase, *Streptomyces* focuses on vegetative growth, where cellular metabolism is still centered on cell division and expansion, rather than on the production of secondary metabolites (Baltz, 2016). Additionally, research by Ding *et al.* (2019) indicates that the transition from primary to secondary metabolism is dynamic and highly influenced by environmental conditions and growth media. Strain variability also affects metabolite biosynthesis, making the optimization of incubation time and environmental conditions crucial (Prudence *et al.*, 2020).

## 3. Growth of *Zea mays* var Ceretana

The effect of *Streptomyces enissocaesilis* from the maize rhizosphere on the growth of *Zea mays* var. ceratina was tested over a 30-day period, using the following parameters: plant height, number of leaves, root length, dry weight, and root-to-shoot ratio. The results showed that the plant height of the *Streptomyces enissocaesilis*-inoculated plants was 8.16 cm higher than that of the control. The number of leaves was the same, namely 4; root length with *Streptomyces enissocaesilis* was 7.33 cm longer than the control. Dry weight with *Streptomyces enissocaesilis* was 0.24 g, not significantly different from the control. The root-to-shoot ratio with *Streptomyces enissocaesilis* was 291 g higher than the control. Statistical analysis showed significant differences in plant height and root length, but no significant differences in the number of leaves, dry weight, and root-to-shoot ratio. This indicates that *Streptomyces enissocaesilis* has the potential to serve as a plant growth-promoting microorganism (PGPM) (Table 1) (Figure 4).

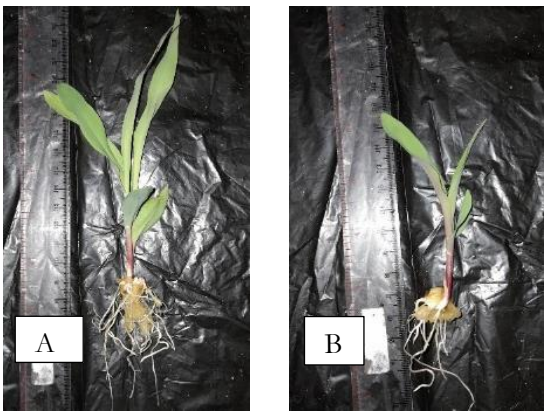


**Figure 4. Vegetative growth of *Zea mays* var. ceratina: (A) Treatment with *Streptomyces enissocaesilis*, (B) Control (*Zea mays* var. ceratina)**

**Table 1. The ability of Streptomyces enissocaesilis to induce the growth of Zea mays var ceratina**

| Treatment | *Zea mays* var ceratina | | | | |
|---|---|---|---|---|---|
| | Plant height (cm) | Number of leaves (pieces) | Root length (cm) | Dry weight (g) | Root rot ratio (g) |
| *Streptomyces* enssocaesilis | 32.58 | 4 | 18.98 | 1.05 | 415 |
| control | 24.42 | 4 | 11.65 | 0.81 | 124 |

The genus *Streptomyces* is known for its ability to produce phosphate-solubilizing enzymes and antibacterial compounds, as well as to form biofilms that enhance interactions between microbes and plant roots. These activities enhance the efficiency of nutrient and water uptake, which contributes to plant growth (Jog et al. 2014). Changes in metabolite dynamics are thought to influence plant vegetative growth because variations in *compounds* in the rhizosphere affect root physiological activity and canopy development. Based on the observation results, *Streptomyces enissocaesilis* had varying effects on the growth

of Zea mays var ceratin; the treatment inoculated with *Streptomyces enissocaesilis* showed higher growth compared to the control without *Streptomyces enissocaesilis* inoculation, particularly in plant height and root length. Meanwhile, the number of leaves, dry weight, and root-to-shoot ratio showed no significant differences between the treatment inoculated with *Streptomyces enissocaesilis* and the control without inoculation. According to Glick (2012), IAA production by rhizosphere bacteria plays a crucial role in stimulating cell elongation and tissue differentiation, particularly in roots and stems. This explains the increase in root length and plant height, which are responses to auxin hormone activity. Additionally, Lamuka et al. (2025) also state that *Streptomyces* has the potential to act as a phosphate solubilizer and an IAA producer. This highlights the potential of *Streptomyces* as a biofertilizer that plays a role in enhancing nutrient availability for plants. However, the lack of significance in the parameters of leaf number, dry weight, and root-to-shoot ratio can be explained through several plant physiological approaches. According to Taiz et al. (2015), leaf formation and dry biomass accumulation are more closely related to photosynthetic efficiency, accumulation of assimilation products, and sufficient growth time. Therefore, although there was an increase in morphological growth in terms of plant height and root length, more complex physiological processes such as leaf organ formation and biomass accumulation were not yet optimal. Furthermore, the root-to-shoot ratio serves as an indicator of the balance in the distribution of photosynthates between the upper and lower parts of the plant. According to Poorter *et al.* (2012), this ratio tends to remain stable during significant environmental changes or stress. Therefore, the absence of a significant difference in the root-to-shoot ratio indicates that *Streptomyces* inoculation has not significantly altered the plant's biomass allocation pattern, but rather only affects linear growth (elongation). Additionally, according to Bashan and de-Bashan (2010), the effects of PGPR are often more evident in the early stages of plant growth, whereas effects on total biomass and yield components require a longer time or specific environmental conditions to be detected significantly If colonization is successful, Streptomyces can produce a variety of bioactive compounds directly in the root zone, such as indole-3-acetic acid (IAA), siderophores, ACC deaminase, phosphate-solubilizing enzymes, as well as various antibiotics and hydrolytic enzymes. These compounds serve to stimulate root development, enhance nutrient uptake, suppress the growth of soil-borne pathogens, and trigger systemic plant resistance, or Induced Systemic Resistance. Thus, successful root colonization is a key factor in determining how effectively Streptomyces functions as a plant growth-promoting bacterium (Viaene *et al.,* 2016)

## Conclusion

*Streptomyces enissocaesilis* is capable of colonizing the tissues and root surfaces of *Zea mays* var. ceratina grown using the DFT hydroponic system. Inoculation increased the number and intensity of metabolites and promoted vegetative growth, as evidenced by increases in plant height, number of leaves, root length, dry weight, and root-to-shoot ratio. Thus, *Streptomyces enissocaesilis* has the potential to serve as a plant biofertilizer.

## Author Statements

**Acknowledgements and funding statements:** This research was funded by the Indonesian Ministry of Education, Culture, Research, and Technology (Project No. 063/E5/PG.02.00.PL/2024) and Contract No. 938/UN47.DI.1/PT.01.03/2024. Rector's Decision No. 733/UN47/HK.02/2024. We would like to thank the Ministry of Education, Culture, Research, and Technology for funding this research

**Competing of interest:** The authors declare no competing interests

**Author's contributions:** Velma Agtavia: conceptualization, analysis, manuscript writing; Yuliana Retnowati: conceptualization, manuscript writing methods; Jusna Ahmad: manuscript writing; Abubakar Sidik Katili: methods, analysis

**Generative AI:** The authors confirm that only DeepL was used in the preparation of this manuscript to translate and refine the text.

**Data availability:** The raw data underlying the conclusions of this article, including root infection observations, metabolite analyses, and measurements of plant height, number of leaves, root length, dry weight, and root-to-shoot ratio, will be provided by the authors

## References


Arinong, A. R., Nispasari, N., Wahab, A., & Nurcholis, J. (2021). Aplikasi Plant Growth Promoting Rhizobacteria (PGPR) Akar Tumbuhan Putri Malu Terhadap Pertumbuhan Dan Produksi Tanaman Kacang Panjang (*Vigna sinensis* L.): The Application of Plant Growth Promoting Rhizobacteria (PGPR) of Sensitive Plant Root Toward The Growth and Production of Long Bean (Vigna sinensis L.). *Jurnal Agrisistem*, *17*(1), 10-18.https://doi.org/10.52625/j-agr.v17i1.187

Baltz, R. H. (2016). Genetic manipulation of secondary metabolite biosynthesis for improved production in Streptomyces and other actinomycetes. *Journal of Industrial Microbiology and Biotechnology*, *43*(2-3), 343-370. https://doi.org/10.1007/s10295-015-1682-x

Bashan, Y., & de-Bashan, L. E. (2010). How the plant growth-promoting bacterium Azospirillum promotes plant growth—a critical assessment. *Advances in agronomy*, *108*, 77-136. http://doi.org/10.1016/s0065-2113(10)08002-8

Chauhan, P., Sharma, N., Tapwal, A., Kumar, A., Verma, G. S., Meena, M., ... & Swapnil, P. (2023). Soil microbiome: diversity, benefits and interactions with plants. *Sustainability*, *15*(19), 14643. https://doi.org/10.3390/su151914643

Compant, S., Cassan, F., Kostić, T., Johnson, L., Brader, G., Trognitz, F., & Sessitsch, A. (2025). Harnessing the plant microbiome for sustainable crop production. *Nature Reviews Microbiology*, *23*(1), 9-23.

Ding, T., Yang, L. J., Zhang, W. D., & Shen, Y. H. (2019). The secondary metabolites of rare actinomycetes: chemistry and bioactivity. *RSC advances*, *9*(38), 21964-21988. http://doi.org/10.1039/c9ra03579f

El-Akshar, E. A., Elmeihy, R. M., Tewfike, T. A., & Abou-Aly, H. E. 2022. Endophytic *Streptomyces enissocaesilis* as a nematicidal and biostimulant agent. Egyptian Academic Journal of Biological Sciences, 14(2), 123–133. https://doi.org/10.21608/eajbsg.2022.262580

Glick, B. R. (2012). Plant growth-promoting bacteria: mechanisms and applications. *Scientifica*, *2012*(1), 963401. http://doi.org/10.6064/2012/963401

Haldar, S., & Sengupta, S. (2015). Plant-microbe cross-talk in the rhizosphere: insight and biotechnological potential. *The open microbiology journal*, *9*, 1.10.2174/1874285801509010001

Jog, R., Pandya, M., Nareshkumar, G., & Rajkumar, S. 2014. Mechanism of phosphate solubilization and antifungal activity of *Streptomyces* spp. isolated from wheat roots and rhizosphere and their application in improving plant growth. Microbiology, 160(4), 778-788. http://doi.org/10.1099/mic.0.074146-0

Kandowangko, N. Y. 2019. Solutions to Corn Drought (Utilization of Azospirillum Microorganisms and Arbuscular Mycorrhizae). Ideas Publishing.

Lamuka, A. P., Retnowati, Y., Katili, A. S., Kandowangko, N. Y., & Uno, W. D. (2025). Phosphate Soluting Actinomycetes in the Rhizosfer of Corn (Zea mays) in Gorontalo. *MIKHAYLA: Journal of Advanced Research*, *2*(1), 1-10. https://doi.org/10.61579/mikhayla.v2i1.282

Lanti, S., Retnowati, Y., Kandowangko, N. Y., Hasan, A. M., & Katili, A. S. 2025. Micromonospora Sp. Viability Test from the Rhizosphere of Plants in the Gorontalo Karst Ecosystem on Rice Growth Medium. MIKHAYLA: Journal of Advanced Research, 2(1), 29–34. http://doi.org/10.61579/mikhayla.v2i1.289

Liu, Y., *et al.* 2024. Root colonization by beneficial rhizobacteria. FEMS Microbiology Reviews, 48(1), fuad066. http://doi.org/10.1093/femsre/fuad066

Muslim, I. A., & Suwandi, I. (2023). PENGENDALIAN HAYATI PATOGEN TANAMAN DENGAN MIKROORGANISME ANTAGONIS EDISI REVISI I.

Poorter, H., Niklas, K. J., Reich, P. B., Oleksyn, J., Poot, P., & Mommer, L. 2012. Biomass allocation to leaves, stems and roots: meta-analyses of interspecific variation and environmental control. New phytologist, 193(1), 30-50.

Prudence, S., Addington, E., Castaño-Espriu, L., Mark, D., Pintor-Escobar, L., Russell, A., … & McLean, T. 2020. Advances in actinomycete research: an actinobase review of 2019. Microbiology, 166(8), 683-694. http://doi.org/10.1099/mic.0.000944

Rampersad, S. N. 2020. Pathogenomics and management of Fusarium diseases in plants. Pathogens, 9(5), 340. http://doi.org/10.3390/pathogens9050340

Retnowati, Y., Kandowangko, N. Y., Katili, A. S., & Pembengo, W. 2024. Diversity of actinomycetes on plant rhizosphere of karst ecosystem of Gorontalo, Indonesia. Biodiversitas Journal of Biological Diversity, 25(3). http://doi.org/10.13057/biodiv/d250301

Ríos-Ruiz, W. F., Casique-Huamanguli, R. D., Valdez-Nuñez, R. A., Rojas-García, J. C., Calixto-García, A. R., Ríos-Reátegui, F., … & Padilla-Santa-Cruz, E. 2024. Rhizospheric bacteria of cover legumes from acidic soils are capable of solubilizing different inorganic phosphates. Microorganisms, 12(6), 1101. https://doi.org/10.3390/microorganisms12061101

Seepe, H. A., Nxumalo, W., & Amoo, S. O. 2021. Natural products from medicinal plants against phytopathogenic Fusarium species: Current research endeavours, challenges and prospects. Molecules, 26(21), 6539.https://doi.org/10.3390/molecules26216539

Taiz, L., Zeiger, E., Møller, I., & Murphy, A. 2015. Plant physiology and development 6th ed Sinauer Associates Sunderland. MA, USA.

Theowidavitya, B., Muttaqin, M., & Tjahjoleksono, A. 2019. Metabolomic Analysis of the Interaction Between Rice and Bacteria. Journal of Biological Resources, 5(1), 18–24. https://doi.org/10.29244/jsdh.5.1.18-24

Toma, T., Kováč, J., & Ďurkovič, J. 2024. Fast, Easy, and Comprehensive Techniques for Microscopic Observations of Fungal and Oomycete Organisms Inside the Roots of Herbaceous and Woody Plants. Bio-protocol, 14(11), e5013. DOI:https://doi.org/10.21769/BioProtoc.5013

Ullah, S., Muhammad, Z., Jehan, S., Zia, S., Hussain, Z., Hussain, S., … & Ullah, H. 2021. Soil actinomycetes molecular characterization for secondary metabolites production. Journal of Advanced Biomedical and Pharmaceutical Sciences, 0(0), 40-44. https://doi.org/10.21608/jabps.2021.98256.1141

Van Der Heul, H. U., Bilyk, B. L., McDowall, K. J., Seipke, R. F., & Van Wezel, G. P. 2018. Regulation of antibiotic production in Actinobacteria: new perspectives from the post-genomic era. Natural product reports, 35(6), 575-604.

Viana, W., Scharwies, J. D., & Dinneny, J. R. 2022. Deconstructing the root system of grasses through an exploration of development, anatomy and function. Plant, Cell & Environment, 45(3), 602-619. https://doi.org/10.1111/pce.14270

Viaene, T., Langendries, S., Beirinckx, S., Maes, M., & Goormachtig, S. (2016). Streptomyces as a plant's best friend?. *FEMS microbiology ecology*, *92*(8), fiw119. https://doi.org/10.1093/femsec/fiw119

Vurukonda, S. S. K. P., Giovanardi, D., & Stefani, E. 2018. Plant growth promoting and biocontrol activity of *Streptomyces* spp. as endophytes. International journal of molecular sciences, 19(4), 952.

Widiantini, F., Syahnur, F., Hidayat, Y., & Yulia, E. 2024. Isolation of Potential Nitrogen-Fixing Phylloplane Bacteria and in Vitro Detection of Their Ability to Inhibit the Growth of Colletotrichum. Jurnal Fitopatologi Indonesia, 20(1), 34-46.

Widyati, E. (2013). Memahami interaksi tanaman–mikroba. Tekno Hutan Tanaman, 6(1), 13-20.

Xie, S., Jiang, L., Wu, Q., Wan, W., Gan, Y., Zhao, L., & Wen, J. 2022. Maize root exudates recruit Bacillus amyloliquefaciens OR2-30 to inhibit Fusarium graminearum infection. Phytopathology®, 112(9), 1886-1893. http://doi.org/10.1094/PHYTO-01-22-0028-R