

Plant growth-promoting bacteria optimize lettuce seedling production

Bactérias promotoras do crescimento vegetal otimizam a produção de mudas de alface

Las bacterias promotoras del crecimiento vegetal optimizan la producción de plántulas de lechuga

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Matheus Aparecido Pereira Cipriano¹

ORCID: <https://orcid.org/0000-0002-1259-741X>

São Paulo State University, Brazil

E-mail: matheus.cipriano@unesp.br

Claudio Marcelo Gonçalves de Oliveira²

ORCID: <https://orcid.org/0000-0002-1677-6853>

Instituto Biológico, Centro Experimental Central; Laboratório de Nematologia, Brazil

E-mail: claudiomarcelo.oliveira@sp.gov.br

Luis Felipe Villani Purquério³

ORCID: <https://orcid.org/0000-0002-2962-4517>

Instituto Agronômico de Campinas, Brazil

E-mail: felipe.purquerio@sp.gov.br

Adriana Parada Dias da Silveira⁴

ORCID: <https://orcid.org/0000-0003-3741-5798>

Instituto Agronômico de Campinas, Brazil

E-mail: adriana.silveira@sp.gov.br

Flávia Rodrigues Alves Patrício⁵

ORCID: <https://orcid.org/0000-0003-0447-7503>

Instituto Biológico, Centro Experimental Central; Laboratório de Fitopatologia, Brazil

E-mail: flavia.patricio@sp.gov.br

Abstract

The consumption of higher-quality, sustainably produced food is a growing demand of the consumer market and represents an essential strategy for preserving natural resources and maintaining soil quality. This sustainable paradigm has driven the expansion of the bio-input market, such as inoculants based on beneficial microorganisms, among which plant growth-promoting bacteria (PGPB) stand out. Among the PGPB, those of *Pseudomonas* genus show potential to promote plant growth even in the seedling stage, providing greater protection and resilience against plausible practices and diseases present in the soil, as distributed in lettuce cultivation. Lettuce, in turn, is the most commercially traded leafy vegetable in Brazil, and its cultivation is in a constant process of innovation. Despite the economic and agronomic relevance of lettuce, studies demonstrating the positive effects of PGPB of *Pseudomonas* genus on the production of seedlings are still scarce. This study evaluated the effect of 21 *Pseudomonas* strains on lettuce seedling production, as well as the potential of these strains to synthesize metabolites associated with plant development. The 21 strains tested, 78 % stimulated greater shoot and root growth, while at least 71 % produced at least one metabolite capable of promoting plant growth. This study characterized and selected *Pseudomonas* strains for potential use in bioprospecting bacteria to produce bio-inputs for more sustainable agriculture.

Keywords: Rhizobacteria; Bioinputs; Microbial inoculants.

Resumo

O consumo de alimentos mais saudáveis e produzidos de forma sustentável constitui uma exigência crescente do mercado consumidor e representa uma estratégia essencial para a preservação dos recursos naturais e a manutenção da qualidade do solo. Esse paradigma sustentável impulsionou a expansão do mercado de bioinsumos, como os inoculantes à base de microrganismos benéficos, entre os quais se destacam as bactérias promotoras do crescimento de plantas (BPCPs). Entre as BPCPs, as do gênero *Pseudomonas* apresentam potencial para promover o crescimento vegetal ainda na fase de mudas, conferindo maior proteção e capacidade de enfrentamento contra pragas e doenças presentes no solo, como observado na cultura da alface. A alface, por sua vez, é a hortaliça folhosa mais comercializada no Brasil, e seu cultivo encontra-se em constante processo de inovação. Apesar da relevância

¹ Department of Plant Protection, School of Agricultural Sciences, São Paulo State University (UNESP), 18610-034, Botucatu, São Paulo, Brazil.

² Instituto Biológico, Centro Experimental Central; Laboratório de Nematologia, Rodovia Heitor Penteado, km 3, 13092-543, Campinas, SP, Brazil.

³ Instituto Agronômico de Campinas, Campinas, Brazil.

⁴ Centro de Solos e Recursos Agroambientais, Instituto Agronômico (IAC), Campinas, São Paulo 13020-902, Brazil.

⁵ Instituto Biológico, Centro Experimental Central; Laboratório de Fitopatologia, Rodovia Heitor Penteado, km 3, 13092-543, Campinas, SP, Brazil.

econômica e agrônômica da alface, ainda são escassos os estudos que demonstram os efeitos positivos das PGPB do gênero *Pseudomonas* na produção de mudas dessa hortaliça. O presente estudo avaliou o efeito de 21 isolados de *Pseudomonas* na produção de mudas de alface, bem como o potencial desses isolados em sintetizar metabólitos associados ao desenvolvimento vegetal. Dos 21 isolados testados 78 % estimularam maior crescimento da parte aérea e das raízes, enquanto pelo menos 71 % produziram ao menos um metabólito capaz de favorecer o crescimento das plantas. Este estudo caracterizou e selecionou isolados de *Pseudomonas* como potencial uso em programas de bioprospecção de bactérias para a produção de bioinsumos para a agricultura mais sustentável.

Palavras-chave: Rizobactérias; Bioinsumos; Inoculantes microbianos.

Resumen

El consumo de alimentos más saludables y producidos de forma sostenible es una demanda creciente del mercado de consumo y representa una estrategia esencial para la preservación de los recursos naturales y el mantenimiento de la calidad del suelo. Este paradigma sostenible ha impulsado la expansión del mercado de bioinsumos, como los inoculantes basados en microorganismos beneficiosos, entre los que destacan las bacterias promotoras del crecimiento vegetal (BPCV). Entre las BPCV, las del género *Pseudomonas* muestran potencial para promover el crecimiento de las plantas en la etapa de plántula, proporcionando mayor protección contra plagas y enfermedades presentes en el suelo, como se observa en el cultivo de lechuga. La lechuga es la hortaliza de hoja más comercializada en Brasil, y su cultivo se encuentra en constante innovación. A pesar de la relevancia económica y agronómica de la lechuga, los estudios que demuestran los efectos positivos de *Pseudomonas* en la producción de plántulas de lechuga aún son escasos. Este estudio evaluó el efecto de 21 aislamientos de *Pseudomonas* en la producción de plántulas de lechuga y el potencial de estos aislamientos para sintetizar metabolitos asociados con el desarrollo de la planta. De los 21 aislados analizados, el 78% estimuló un mayor crecimiento de brotes y raíces, mientras que al menos el 71% produjo al menos un metabolito capaz de promover el crecimiento vegetal. Este estudio caracterizó y seleccionó aislados de *Pseudomonas* para su posible uso en programas de bioprospección de bacterias destinadas a la producción de bioinsumos para una agricultura más sostenible.

Palabras clave: Rizobactérias; Bioinsumos; Inoculantes microbianos.

1. Introduction

The consumption of organic foods or foods produced with lower input, such as agrochemicals, has increased worldwide, including in Brazil. This sustainable concept has opened the market for inoculants, which include beneficial microorganisms (BM) that can completely or partially replace chemical fertilizers, as well as fungicides or nematicides. Among these microorganisms, bacteria that colonize the rhizosphere of plants can stimulate the development of the host crop, when they are called plant growth-promoting rhizobacteria (PGPR). These microorganisms can be applied relatively easily during the seedling production phase and, in this way, promote their growth and greater root development, taking them to the field with a greater capacity to face challenges and diseases presented in the soil. Rhizobacteria inoculation in seedlings, promoting their growth and enrichment, can also meet market demands for more sustainable products, produced with less environmental impact. Studies show a positive effect of endophytic bacteria and rhizobacteria on the development of several crops of agricultural interest, such as lettuce, sugarcane, coffee, cotton, among others, with increases in biomass production, due to the optimization of photosynthesis and nitrogen metabolism (Cipriano et al., 2016; Rossetto et al., 2021, Souza et al., 2025, Zonta et al., 2026).

The beneficial effect triggered by rhizobacteria may be related to the nutritional status improvement of the plant, promoted by biological nitrogen fixation (BNF), phosphate solubilization, production of siderophores and hormones (such as indoleacetic acid - IAA), production of exopolysaccharides (EPS), and 1-aminocyclopropane-1- carboxylate (ACC) deaminase among others (Otieno et al., 2015; Naing et al., 2021; Timofeeva et al., 2022). The production of compounds with biological control properties, such as the production of hydrocyanic acid (HCN) and various antagonistic substances, is capable of inhibiting the growth of phytopathogens (Olanrewaju et al., 2017; Subedi et al., 2020).

The lettuce (*Lactuca sativa L.*), a leafy vegetables, is the most produced and consumed in Brazil. Its production is mainly concentrated in the states of São Paulo, Minas Gerais, and Rio de Janeiro. The São Paulo green belt accounts for more than 80% of the vegetables sold at CEAGESP (São Paulo's wholesale market). Lettuce cultivation occurs in organic,

hydroponic, protected cultivation, and open-field systems, the latter being the most widely used. Most lettuce production in Brazil has been practiced in soil, in open fields, despite the numerous losses and limitations that occur in summer cultivation (Sala & Costa, 2012). However, the consumption of leafy vegetables has increased mainly due to the increase in the population's purchasing power and the growing concern for a healthier and lower-calorie diet (Martins et al., 2009). Therefore, it is necessary for producers to produce in quantity, with quality, and throughout the year to meet consumer market demand. To overcome this challenge, it is necessary to use high-productivity farming systems (Furlani & Purquerio, 2010).

Lettuce cultivation in Brazil is constantly innovating and rapidly incorporating new techniques in the areas of crop science and genetic improvement (Sala & Costa, 2012). The varietal types produced in Brazil are smooth, curly, mimosa, iceberg, romaine, red/purple, and mini-lettuce (Sala & Costa 2008). The curly type leads the market and accounts for approximately 60% of the total production area.

The demand for microorganisms that can promote growth and improve the quality of lettuce heads produced in conventional, organic, and even hydroponic systems is increasing. Studies show that beneficial bacteria, including rhizobacteria, especially of the genus *Pseudomonas*, can promote growth and increase the fresh and dry biomass of lettuce plants in both hydroponic and conventional cultivation in raised beds (Cipriano et al., 2013, Cipriano et al., 2016, Venancio et al., 2019), in addition to improving the physical and chemical conditions of the soil (Araújo Neto et al., 2012). Furthermore, *Pseudomonas*-based inoculants have already shown positive aspects in the concept that include not only lettuce productivity, related to biomass production, but also the capacity for biological control, maintaining the plants' nutritional status adequately and ensuring more sustainable management (Passera et al., 2020).

The bioprospecting of beneficial microorganisms, such as PGPR, that can be used as microbial inoculants to increase seedling production is ongoing and in line with initiatives for more sustainable food production methods. Therefore, the aims of this study were to select *Pseudomonas* rhizobacteria strains that promote greater growth of lettuce seedlings and to characterize these strains regarding their capacity to produce metabolites related to plant growth promotion.

2. Methodology

An experimental, laboratory-based study was conducted, using a qualitative and quantitative approach (Pereira et al., 2018; Risemberg et al., 2026) and employing statistical analysis (Vieira, 2021; Costa Neto & Bekman, 2009).

2.1 Rhizobacteria strains

In the present study we evaluated 21 *Pseudomonas* spp. strains from the Beneficial Microorganisms collection of the Microbiology Laboratory, Department of Plant Protection, São Paulo State University, School of Agronomic Sciences, Botucatu, São Paulo, Brazil. The microorganisms, preserved in King B culture medium (BK) (King et al., 1954) with mineral oil at 4 °C, were subcultured and multiplied in solid and liquid BK culture medium, according to the purpose of each test.

2.2 Characterization of metabolites produced by rhizobacteria

a) Indoleacetic acid (IAA) - the bacterial strains were grown in culture medium with L-tryptophan, the precursor of IAA, covered with a nitrocellulose membrane and incubated at 28 °C in the dark for 24 h (Bric, Bostock and Silverston 1991). After this time, the nitrocellulose membrane were immersed in Salkowski's solution and incubated at room temperature for up to 4 h. The red-purplish color halo around the colonies indicated IAA production. Each strains was tested in three replicates.

b) ACC deaminase - to evaluate the ACC deaminase activity the strains were cultured and incubated for 4 days at 28 °C, and growth indicated ACC deaminase production with ACC deaminase as the sole nitrogen source, according Penrose and Glick (2003) method. Each strain was tested in three replicates

c) Siderophore - production was assessed using the method proposed by Schwyn and Neilands (1987). The strains were grown on nutrient broth at 28 °C for 48 h with constant agitation, followed by centrifugation at 12 000 g for 10 min. The resuspension phase (100 µL) from each strain was transferred to a microtiter plate, to which 100 µL of Chromoblu S (CAS-Merck ®) indicator solution was added. Strains that changed color from blue to yellow were considered positive for siderophore production. The test was conducted with three biological replicates.

2.3 Effect of rhizobacteria on lettuce seedlings production

a) Preparation of bacterial inocula

The preparation of the bacterial strains suspension was carried out by culturing the strains in BK culture medium. The rhizobacteria were first cultured in 120 mL of this liquid medium, then centrifuged and transferred to a 0.01 mol.L⁻¹ MgSO₄.7H₂O solution. An estimative of the bacterial cells concentration was done by counting the number of colony-forming units (CFU), performed in Petri dishes with BK culture medium. The inoculum concentration used for all strains was 10⁸ CFU/mL.

b) Screening of rhizobacteria strains on lettuce seedlings

Pelleted seeds of curly lettuce (cv. Veronica) were sown in trays with 200 cells, with commercial substrate (Tropstrato HA Vegetables). After seed emergence, 3 mL of bacterial suspension of rhizobacteria strains was inoculated into each cell, and after 7 and 15 days the seedlings were treated with a nutrient solution adapted and formulated according to the recommendation of Furlani et al. (1999). The harvest of the first experiment was carried out 45 days after sowing and in the second experiment the harvest was carried out 25 days after sowing. In the second experiment the bacteria *Pseudomonas fluorescens* IAC-Beca141 (Cipriano et al., 2021) and *Pantoea dispersa* IAC-BEca128 (Silveira et al., 2018) were tested as a positive control, since they were selected as plant growth promoting bacteria (PGPB).

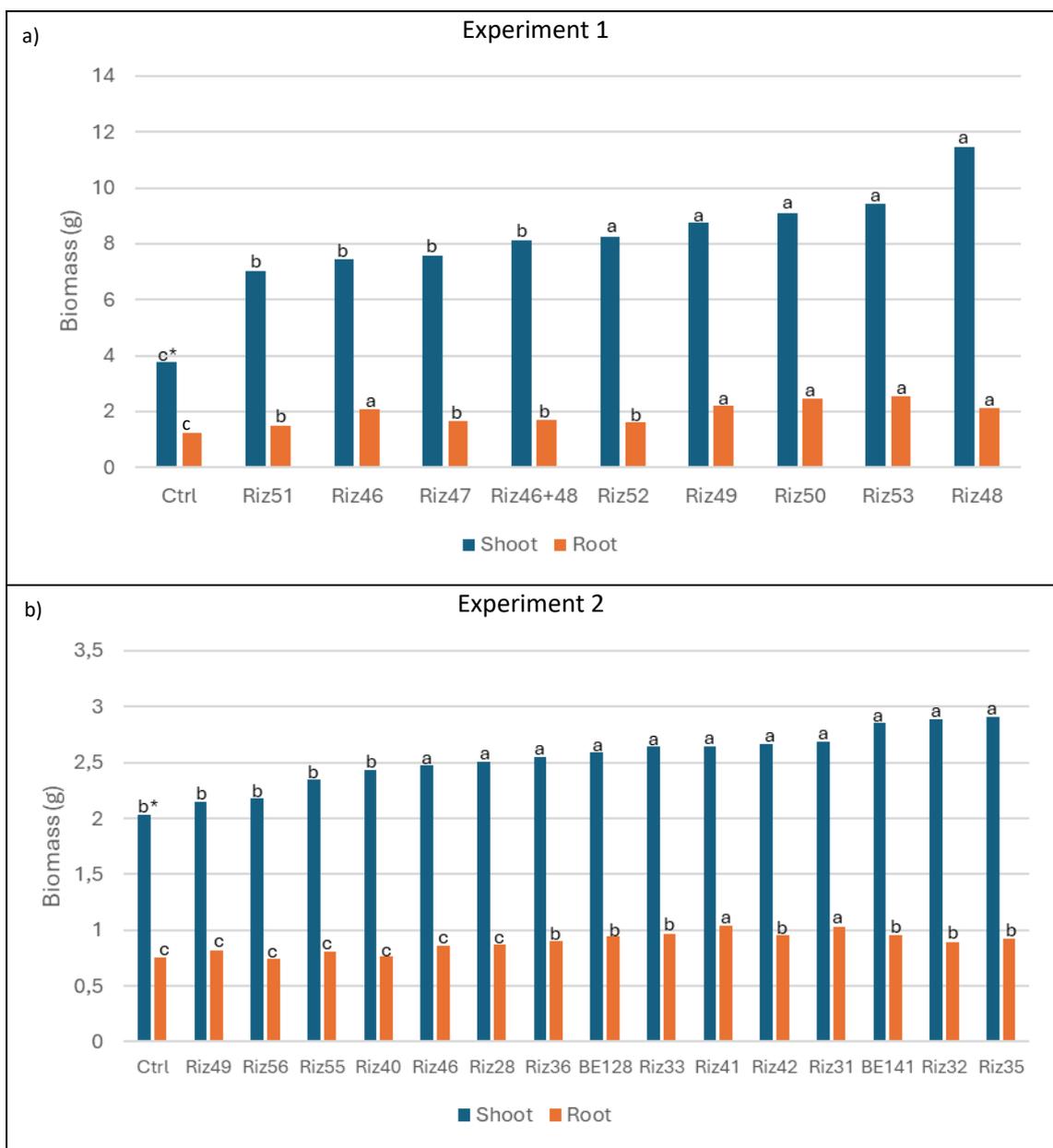
At the time of harvest, the roots were separated from the shoots, washed and all the material was kept in an oven at 70 °C for drying. Then the plant parts were weighed to obtain dry matter mass. Each treatment consisted of four replicates, with each reproduction consisting of four seedlings. All experiments were randomized. The data were analyzed by ANOVA using the Scott-Knott test at a 5% probability.

3. Results

3.1 Plant growth promoting effect due rhizobacterial treatment

In the first experiment, all the strains evaluated improved the shoot biomass and seedlings inoculated with the strains Riz52, Riz49, Riz50, Riz53 and Riz48 exhibited highest shoot promotion (Figure 1a). The strains Riz49, Riz50, 53 and Riz48 improved the root growth. The mixture of Riz46 and Riz48 did not improved the plant biomass production.

Figure 1 - Shoot and root dry mass (g/plant) of lettuce seedlings treated with bacterial strains.



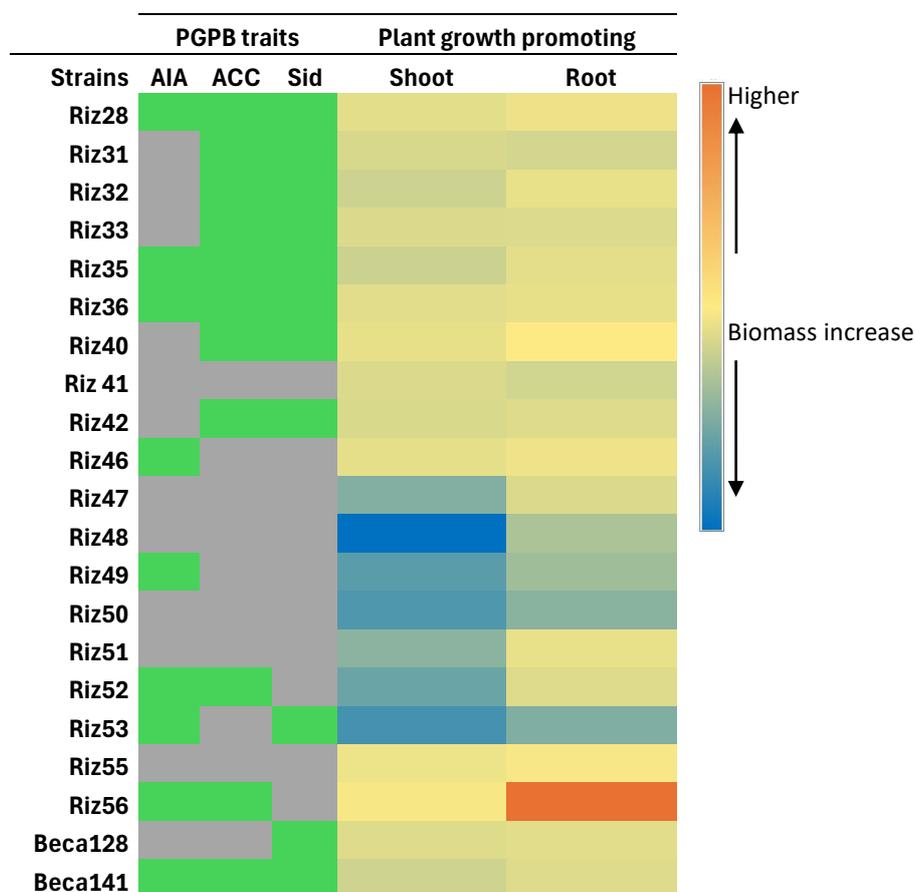
*Means followed by the same letters do not differ from each other using the Scott-Knott test ($P < 0.05$). Source: Authors.

In the second experiment, ten strains evaluated were able to improve the shoot biomass (Riz46, Riz28, Riz36, BE128, Riz33, Riz41, Riz42, Riz31, BE141, Riz32 and Riz35 (Figure 1b). Part of these strains (Riz36, BE128, Riz33, Riz41, Riz42, Riz31, BE141, Riz32 and Riz35) yielded the highest values for root dry mass. The other strains did not impacted the root biomass.

3.2 Rhizobacterial traits for plant growth-promoting

From all strains evaluated 71% produced at least one of the metabolites evaluated (Table 1). Regarding the AIA production, 42% of the strains (Riz48, Riz35, Riz36, Riz46, Riz49, Riz52, Riz53, Riz56 and BE141) were able to produce this phytohormone. Part of the strains (52%) were able to produce ACC deaminase and 47% of the strains produced siderophore.

Table 1 - Summary about the bacteria strains metabolites production and plant growth promotion on lettuce seedlings. IAA:indole-acetid acid; ACC:1-aminocyclopropane-1-carboxylate deaminase; Sid:siderophore.



Green: metabolites production and plant growth improvement.
 Grey: absence of effect. Source: Authors.

4. Discussion

The beneficial effect of plant growth-promoting bacteria (PGPBs), such as those of the genera *Azospirillum*, *Bacillus*, *Pseudomonas*, among others, is reported in different perennial and semi-perennial crops such as coffee and sugarcane, respectively (de Souza et al. 2025, Jakubowska et al., 2025, da Silva et al 2026). Nowadays, the use of PGPB has expanded to other crops, such as vegetables (Menezes et al., 2024; Lorenz et al., 2025).

The results obtained in the present study point to promising and unprecedented data on bacteria that are candidates for inoculants for the production of lettuce seedlings, in accordance with the proposed objectives. The search for PGPB strains is constant because some microorganisms may lose viability and consequent beneficial effect on the crop, and new strains may be more efficient than others. For example, strains BE128 (*Pantoea dispersa*) and BE141 (*Pseudomonas fluorescens*), with proven effects as PGPB in sugarcane cultivation (Silveira et al., 2018, Cipriano et al. 2021), showed good results in the present study, now in lettuce (Experiment 2 – Figure 1b). However, strains Riz32 and Riz35 were able to stimulate greater shoot growth than the previous strains. This shows that the bioprospecting of new strains with the potential to increase biomass, aiming at more sustainable agricultural production, is ongoing.

In the first experiment, all strains stimulated greater shoot growth, and some of these strains were also able to stimulate root growth. In this experiment, the consortium between Riz46 and Riz48 was evaluated, demonstrating a superior beneficial effect compared to inoculation with the single strain Riz46. However, the effect of the single strain RZ48 was greater than the tested consortium (Figure 1a), regarding the shoot biomass improvement. Surprisingly, this consortium did not have

the best effect on root development when compared to single inoculation of these strains. Nevertheless, a greater increase on root biomass was observed compared to the control (without rhizobacteria). Other studies show that consortia between *Pseudomonas* strains can improve the development of lettuce seedlings (Cipriano et al., 2016) or have a beneficial effect on the target crop when this consortium occurs between different genera such as *Pseudomonas* and *Azotobacter* (Dobrzyński et al., 2025). The results about the PGPB consortium presented in this study show the promising effect of combining *Pseudomonas* strains for lettuce seedling production.

In general, the rhizobacteria strains tested had a greater growth effect on the plants shoots, compared to roots (Table 2). One hypothesis for this result is that the seedling production system, in trays, may limit the greater proliferation of seedling roots in this environment. However, in the later phase, on field condition, the roots development can be better, due the soil exploration and the PGPB inoculation (Cipriano et al., 2016).

The results of the metabolite analysis (Table 2) show that most strains produce at least one metabolite that favors plant development. IAA is a phytohormone, produced by microorganisms such as PGPB, that stimulates expansion, division, and elongation of plant cells (Duca et al., 2014; Goswamia et al., 2015). The production of ACC deaminase and siderophores by rhizobacteria are desirable characteristics in PGPB, as these metabolites help plants cope better with stress, increase iron availability for the plant, and act in the control of phytopathogens (Compant et al., 2005; Naing et al., 2021). The study presented here shows that some of the metabolites produced may have benefited the plant growth of lettuce seedlings. However, it is noteworthy that some strains, such as Riz47, Riz48, Riz50, and Rz51, did not produce any of the analyzed metabolites and yet stimulated greater seedling growth. Studies show that PGPB can trigger a beneficial effect due other mechanisms, which we did not investigate in this study, such as the phytohormones production, like gibberellins, exopolysaccharide (EPS) production, hydrocyanic acid, biological nitrogen fixation, among other mechanisms (Roslan et al., 2020; Hasan et al., 2024).

5. Conclusion

The rhizobacteria strains, from *Pseudomonas* genus, were able to improve the lettuce seedling growth (Figure 2) in the experiments conducted in this study. This rhizobacteria group is extended studied aiming to improve the more sustainable growth of different plant species since from perennial plants to annuals, and short-cycle plants like vegetables. The results obtained in this study point to new and promising data on the strains as candidate for inoculants in the production of lettuce seedlings, in accordance with the proposed objectives. These results meet the need of the seedlings producers to produce more robust seedlings, due to the greater production of biomass, which can guarantee greater success in field development, as well as accelerate the production process, obtaining more production cycles per year.

Figure 2 - Lettuce seedlings without (a) or with rhizobacteria inoculation (b).



Source: Authors.

References

- Araújo Neto, S. E., Silva, E. M. N. C., Ferreira, R. L. F., & Cecílio Filho, A. B. (2012). Rentabilidade da produção orgânica de alface em função do ambiente, preparo do solo e época de plantio. *Revista Ciência Agronômica*, 43, 783-791.
- Ates, O. (2015). Systems biology of microbial exopolysaccharides production. *Frontiers in Bioengineering and Biotechnology*, 3:200. doi: 10.3389/fbioe.2015.00200.
- Bric, J. M.; Bostock, R. M., & Silverstone, S. E. (1991). Rapid in situ assay for indole acetic acid production by bacteria immobilized on a nitrocellulose membrane. *Applied and Environmental Microbiology*, 57(2), 535-538.
- Cipriano, M. A. P., Patricio, F. R. A., & Freitas, S. S. (2013). Potencial de rizobactérias na promoção de crescimento e controle da podridão radicular em alface hidropônica. *Summa Phytopathologica (IMPRESSO)*, 39, 51-57, 2013.
- Cipriano, M.A.P., Lupatini M, Lopes-Santos, L. et al. (2016). Lettuce and rhizosphere microbiome responses to growth promoting *Pseudomonas* species under field conditions. *FEMS Microbiology Ecology*. Dec;92(12), fiw197. doi: 10.1093/femsec/fiw197. Epub 2016 Sep 21. PMID: 27660605.
- Cipriano, M. A. P., Freitas-Iório, R. D. P., Dimitrov, M. R., De Andrade, S. A. L., Kuramae, E. E., & Silveira, A. P. D. D. (2021). Plant-growth endophytic bacteria improve nutrient use efficiency and modulate foliar n-metabolites in sugarcane seedling. *Microorganisms* 9, 479. <https://doi.org/10.3390/microorganisms9030479>.
- Compant S., Duffy, B., Nowak, J., Clement, C., & Barka, E. A. (2005). Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Applied Environmental Microbiology*, 71, 4951-4959.
- Costa Neto, P. L. O. & Bekman, O. R. (2009). *Análise estatística da decisão*. (2ed). Editora Blucher.
- Da Silva, G. F., Santos, H. L., Carnietto, M. R. A., & Silva, M. A. (2026). Sugarcane nutrition under organomineral fertilizer, phosphate-solubilizing bacteria, and reduced phosphate doses. *Annals of Applied Biology*. DOI: 10.1111/aab.70095
- De Souza, M. P. P., Cipriano, M. A. P. C., Braghono, M. T., de Sousa, L. P., Mondego, J. M. C., Patrício, F. R. A. P., & Silveira, A. P. D. (2025). Beneficial bacteria improve seedling growth and nutrition and promote biological controle of coffee diseases. *Journal of Applied Microorganisms*, 136(3). <https://doi.org/10.1093/jambio/lxaf050>
- Dobrzyński, J., Kulkova I., & Jakubowska, Z. (2024). Non-native PGPB consortium altered the rhizobacterial community and slightly stimulated the growth of winter oilseed rape (*Brassica napus* L.) under field conditions. *Microbial Ecology*, 87, 168. <https://doi.org/10.1007/s00248-024-02471-3>
- Duca, D., Lorv, J., Patten, C. L., Rose, D., Glick, B. R. (2014). Indole-3-acetic acid in plant microbe interactions. *Antonie Van Leeuwenhoek*, 106, 85-125.
- Furlani, P.R.; Silveira, L.C.P.; Bolonhezi, D.; & Faquin, V. (1999). Cultivo hidropônico de plantas. *Boletim Técnico* 180, IAC, Campinas, 52p, 1999.
- Furlani, P. R., & Purquerio, L. F. V. (2010). Avanços e desafios na nutrição de hortaliças. In: Mello Prado, R., Cecílio Filho, A.B., Correia M.A.R., Puga, A.P. (Eds). *Nutrição de plantas: diagnose foliar em hortaliças*, 2010.
- Goswamia, D., Thakker, J. N., & Dhandhukia, P. C. (2015). Simultaneous detection and quantification of indole-3-acetic acid (IAA) and indole-3-butyric acid (IBA) produced by rhizobacteria from L-tryptophan (Trp) using HPTLC. *Journal of Microbiological Methods* 110, 7-14. <http://dx.doi.org/10.1016/j.mimet.2015.01.001> 0167-7012
- Hasan, A.; Tabassum, B.; Hashim, M.; & Khan, N. (2024). Role of Plant growth promoting rhizobacteria (pgpr) as a plant growth enhancer for sustainable agriculture: A Review. *Bacteria*, 3, 59–75. <https://doi.org/10.3390/bacteria3020005>
- Jakubowska, Z., Gradowski, M., & Dobrzyński, J. (2025). Role of plant growth-promoting bacteria (PGPB) in enhancing pphenolic compounds biosynthesis and its relevance to abiotic stress tolerance in plants: a review. *Antonie van Leeuwenhoek*, 118, 123, 2025. <https://doi.org/10.1007/s10482-025-02130-8>
- King, E. O.; Ward, M. K.; & Raney, D. E. (1954). Two simple media for the demonstration of pyocyanin and fluorescin. *Journal of Laboratory and Clinical Medicine*, 44(2), 301-307.
- Martins, C. M., Medeiros, J. F., Lopes, W. A. R., Braga, D. F., & Amorim, L. B. (2009). Curva de absorção de nutrientes de alface hidropônica. *Caatinga*, 22, 123-128.
- Naing, A. H., Maung T., & Kim, C.K. (2021). The ACC deaminase-producing plant growth-promoting bacteria: Influences of bacterial strains and ACC deaminase activities in plant tolerance to abiotic stress. *Physiology Plant*, 173, 1992–2012. <https://doi.org/10.1111/ppl.13545>
- Olanrewaju, O., Glick, B. R.; & Babalola, O. O. (2017). Mechanisms of action of plant growth promoting bacteria. *World Journal of Microbiology Biotechnology*. <https://doi.org/10.1007/s11274-017-2364-9>.
- Otieno N., Lally, R.D., Kiwanuka, S. et al. (2015). Plant growth promotion induced by phosphate solubilizing endophytic *Pseudomonas* isolates. *Frontiers in Microbiology*, 6, 745. doi:10.3389/fmicb.2015.00745
- Passera, A., Vacchini, V., Cocetta, G., Shahzad, G., Arpanahi, A. A., Casati, P., Ferrante, A., & Piazza, L. (2020). Towards nutrition-sensitive agriculture: an evaluation of biocontrol effects, nutritional value, and ecological impact of bacterial inoculants. *Science of the Total Environment*, 724, 138127, 2020.
- Penrose, D. M. & Glick B. R. (2003). Methods for isolating and characterizing ACC deaminase-containing plant growth-promoting rhizobacteria. *Physiologia Plantarum* 118, 10-15.
- Pereira, A. S. et al. (2018). *Metodologia da pesquisa científica*. [free ebook]. Santa Maria: Editora da UFSM.

Rossetto, L., Pierangeli, G. M. F., Kuramae, E. E., Xavier, M. A., Cipriano, M. A. P., & Silveira, A. P. D. (2021). Sugarcane pre-sprouted seedlings produced with beneficial bacteria and arbuscular mycorrhizal fungi. *Bragantia*, 80. <https://doi.org/10.1590/1678-4499.20200276>

Roslan M. A. M., Zulkifli, N. N., Sobri, Z. M., Zuan, A. T. K., Cheak, S.C., & Rahman, N.A. (2020) Seed biopriming with P- and K-solubilizing *Enterobacter hormaechei* sp. improves the early vegetative growth and the P and K uptake of okra (*Abelmoschus esculentus*) seedling. *PLoS ONE* 15(7), e0232860. <https://doi.org/10.1371/journal.pone.0232860>

Sala, F. C. & Costa C. P. (2012). Retrospectiva e tendência da alfacultura brasileira. *Horticultura Brasileira*, 30, 187-194.

Sala, F.C. & Costa, C.P. (2008). Gloriosa: Cultivar de alface americana tropicalizada. *Horticultura Brasileira*, 26, 409-410.

Schwyn, B. & Neilands, J. B. (1987). Universal assay for the detection and determination of siderophores. *Analytical Biochemistry*, 160(1), 47-56. doi: 10.1016/0003-2697(87)90612-9.160:47-56.

Silveira, A. P. D.; Iório, R. P. F.; Marcos, F. C. C. et al. (2018). Exploitation of new endophytic bacteria and their ability to promote sugarcane growth and nitrogen nutrition. *Antonie Leeuwenhoek*. doi:10.1007/s10482-018-1157-y, 2018.

Subedi, P., Gattoni, K., Liu, W., Lawrence K. S., & Park, S. W. (2020). Current utility of plant growth-promoting rhizobacteria as biological control agents towards plant-parasitic nematodes. *Plants* 9, 11, doi:10.3390/plants9091167.

Timofeeva, A. M.; Galyamova, M. R.; & Sedykh, S. E. (2022). Bacterial Siderophores: Classification, Biosynthesis, Perspectives of Use in Agriculture. *Plants*, 11, 3065. <https://doi.org/10.3390/plants11223065>

Venancio et al. (2019). Lettuce production under reduced levels of n-fertilizer in the presence of plant growth-promoting *Bacillus* spp. *Bacteria. Journal of Pure and Applied Microbiology*, 13(4), 1941-1952, 5910| <https://doi.org/10.22207/JPAM.13.4.06>.

Vieira, S. (2021). *Introdução à bioestatística*. Editora GEN/Guanabara Koogan.

Zonta, J. H., Rodrigues, J. I. S., & Zonta, J. B. (2026). *Bacilus aryabhatai* como mitigador do deficit hídrico no cultivo do algodoeiro. *Research, Society and Development*, 15(2), e5215250664, 2026 (CC BY 4.0) | ISSN 2525-3409 DOI: <http://dx.doi.org/10.33448/rsd-v15i2.50664>