Agrogenesis Journal of Sustainable Agriculture and Innovation. 2026. 2(1); 66-74

AGROGENESIS
Journal of Sustainable Agriculture and Innovation
www.agrogenesis.umi.ac.id

Optimization of Plant Growth Promoting Rhizobacteria (PGPR) Concentration for Enhanced Growth and Biomass of Pakcoy *Brassica rapa* L.) in Wick System Hydroponic Cultivation

Dian Nita[1]*, Aminah[1], Hidrawati[1]

[1] Agrotechnology Study Program, Faculty of Agriculture and Mine Land Bioremediation, Universitas Muslim Indonesia Jl. Urip Sumoharjo No. km. 5, Panaikang, Panakkukang District, Makassar City, South Sulawesi 90231, Indonesia

ARTICLE INFO

Keywords:
Rhizobacteria
Pakcoy
Hydroponics
Concentration
Growth

Article History:
Received:
Accepted:

*) Corresponding author:
E-mail: diannitaamir@gmail.com

ABSTRACT

This study aimed to determine the effect of Plant Growth Promoting Rhizobacteria (PGPR) concentrations on the growth of pakcoy *Brassica rapa* L.) cultivated hydroponically. The experiment was conducted in Toabo Village, Papalang Subdistrict, Mamuju Regency, West Sulawesi Province, from March to April 2024. The research employed a Randomized Block Design with five PGPR concentration treatments: control (no PGPR), 15 ml/L, 20 ml/L, 25 ml/L, and 30 ml/L, each replicated three times. The observed parameters included plant height, number of leaves, edible weight, root weight, and total plant weight. The results showed that PGPR application significantly affected plant height, root weight, and total plant weight, but had no significant effect on the number of leaves and edible weight. The best treatment was obtained with 30 ml/L PGPR, yielding an average plant height of 27.83 cm, root weight of 22.06 g, and total plant weight of 76.67 g. This study recommends the application of 30 ml/L PGPR to improve the growth and yield of hydroponically grown pakcoy.

INTRODUCTION

Optimization of Plant Growth Promoting Rhizobacteria (PGPR) concentration is crucial to maximize the growth and biomass yield of Pakcoy (*Brassica rapa* L.) cultivated in a wick hydroponic system (Putra et al., 2022). PGPR are beneficial soil microorganisms known to enhance plant growth by facilitating nutrient solubilization and uptake, synthesizing phytohormones, and increasing plant tolerance to abiotic stress. While research on PGPR in soil-based agriculture has been extensive, their effective application in hydroponic systems, particularly wick systems, has not been widely studied (Bhardwaj et al., 2024). This gap highlights the need to determine the appropriate PGPR concentration to ensure optimal interaction with the hydroponic environment, thereby enhancing plant performance without causing side effects (Akhtar et al., 2020).

The wick hydroponic system is a soilless cultivation technique that delivers nutrients to plants via capillary wicks, ensuring efficient water and nutrient supply while minimizing resource waste. Its simplicity and low operating costs make this system suitable for urban and small-scale agriculture (Syahputra et al., 2023). However, the unique nutrient delivery mechanism in the wick system can affect the behavior and effectiveness of PGPR differently compared to soil or other hydroponic methods (Singh et al., 2026). Therefore, understanding the interaction between PGPR concentration and nutrient dynamics in the wick system is crucial for optimizing nutrient bioavailability and uptake, which directly impacts the growth parameters and biomass accumulation of Pakcoy (Das et al., 2024).

In addition to enhancing plant growth, the use of PGPR in hydroponic cultivation offers an environmentally friendly alternative to conventional chemical fertilizers. Chemical fertilizers, although effective, often contribute to environmental pollution and soil degradation if used excessively(Bisht & Singh Chauhan,

ISSN: 3090-2657
DOI: https://doi.org/10.33096/agrogenesis.v2i1.1100

2021). Application of PGPR can reduce dependence on these inputs by promoting natural nutrient cycling and increasing nutrient use efficiency by plants (Bhandari et al., 2025). Optimization of PGPR concentration in wick hydroponic systems aligns with the goals of sustainable agriculture by supporting environmentally friendly practices that meet the rising demand for high-quality vegetables such as Pakcoy, while minimizing ecological footprint and preserving environmental health (Jain et al., 2022).

This study makes a significant contribution to the scientific understanding of plant-microbe interactions in hydroponic cultivation, a field that remains less explored compared to conventional soil-based agriculture. By identifying the optimal concentration of PGPR for Pakcoy grown in a wick system, this study provides practical insights for agronomists and farmers aiming to enhance crop productivity and sustainability. These findings are expected to serve as a valuable reference for the development of hydroponic technology applications, support food security initiatives, and encourage the adoption of biofertilization techniques in modern resource-efficient agricultural systems (Ikiz et al., 2024)

MATERIALS AND METHOD

This study was conducted in Toabo Village, Papalang Subdistrict, Mamuju Regency, West Sulawesi Province, from March to April 2024. The materials included Nauli F1 pakcoy seeds, rockwool, AB mix nutrient solution, plant growth-promoting rhizobacteria (PGPR), and water. Equipment comprised seedling trays, nutrient solution containers, netpots, flannel cloth wicks, measuring cups, Total Dissolved Solids (TDS) and pH meters, rulers, writing tools and a camera.

A Randomized Complete Block Design (RCBD) was employed to evaluate the effect of different PGPR concentrations on pakcoy growth. Five treatments were established based on PGPR concentration in the nutrient solution: P0 (control, no PGPR), P1 (15 ml PGPR per liter of water), P2 (20 ml PGPR per liter of water), P3 (25 ml PGPR per liter of water), and P4 (30 ml PGPR per liter of water). Each treatment was replicated three times, resulting in 15 experimental units. Each experimental unit consisted of six planting holes, totaling 90 plants.

The experimental procedure involved sowing Nauli F1 pakcoy seeds directly onto rockwool medium placed in seedling trays. Each experimental unit received AB mix nutrient solution, prepared according to manufacturer instructions, and supplemented with the assigned PGPR concentration per treatment group. Nutrient solution quality was monitored every two days by measuring Total Dissolved Solids (TDS) and pH using calibrated meters to ensure optimal growing conditions.

Growth parameters, including plant height, number of leaves, and leaf length, were measured weekly using a standard ruler. Photographic documentation was performed at each measurement interval using a digital camera to visually record plant development. All data were systematically recorded in field notebooks for subsequent analysis.

Data were analyzed using Analysis of Variance (ANOVA) to determine the significance of treatment effects on growth parameters. When significant differences were detected ($p < 0.05$), mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level. This statistical approach allowed for rigorous evaluation of the influence of varying PGPR concentrations on pakcoy growth under controlled hydroponic conditions.

This methodology provides a clear, replicable framework with detailed descriptions of materials, experimental design, treatment application, monitoring, measurement, and statistical analysis to ensure scientific rigor and transparency.

RESULTS AND DISCUSSION

1. Plant Height

The analysis results showed that the concentration of PGPR application had a significant effect on the growth in height of pakcoy plants at 30 days after planting. The results of the mean test can be seen in Table 1.

Table 1. Mean Plant Height (cm) of Pakcoy at various PGPR concentrations

Treatment	Average	LSD 5%
P0 = Control (no treatment)	23.33^{b}	
P1 = 15 ml PGPR per 1 liter of water	23.50^{b}	
P2 = 20 ml PGPR per 1 liter of water	26.00^{ab}	2.30
P3 = 25 ml PGPR per 1 liter of water	25.33^{b}	
P4 = 30 ml PGPR per 1 liter of water	28.10^{a}	

Note: Numbers followed by different letters (a, b) indicate statistically significant differences based on the LSD 5% test.

Table 1 presents the average plant height (cm) of Pakcoy treated with various concentrations of Plant Growth-Promoting Rhizobacteria (PGPR). The results show that plant height varies significantly among treatments, as determined by the LSD 5% test. The control group (P0), which did not receive PGPR treatment, showed an average height of 23.33 cm, statistically similar to the P1 treatment (15 ml PGPR per liter) with a height of 23.50 cm. The P2 treatment (20 ml PGPR per liter) produced an average height of 26.00 cm, indicating a moderate increase but statistically overlapping with both lower and higher treatments. The P3 treatment (25 ml PGPR per liter) had an average height of 25.33 cm, not significantly different from the control or P1. The highest plant height was observed in the P4 treatment (30 ml PGPR per liter), with an average of 28.10 cm, which was significantly greater compared to the control and lower PGPR concentrations. These findings indicate that increasing PGPR concentration up to 30 ml per liter positively affects Pakcoy growth, with the highest concentration yielding the most pronounced effect on plant height.

The increase in Pakcoy plant height observed in the PGPR treatment indicates that the presence of these microorganisms has a positive effect on plant growth. PGPR play a role in enhancing the availability of nutrients, particularly nitrogen and phosphorus, which are essential for plant development. At a concentration of 30 ml per liter (P4), the significant increase in plant height may be attributed to the optimal activity of PGPR in stimulating nutrient uptake and the production of growth hormones such as cytokinins and auxins, thereby accelerating cell division and elongation in plant tissues (Chakraborty & Chakraborty, 2022).

The non-significant difference between treatments P0, P1, and P3 indicates that PGPR concentrations at low to medium levels have not yet been sufficient to produce a strong or consistent effect on increasing plant height (Purnima & Singh, 2023). This may be due to the lack of an active microbial population capable of effectively interacting with plant roots at those doses. In addition, the possibility of a threshold concentration of PGPR that must be reached for its promotive effect to become evident is also an important factor in interpreting these results (Vanamala et al., 2021).

The non-linear increase in plant height in treatments P2 and P3 indicates that the plant's response to PGPR depends not only on dosage, but also on the balance of microorganisms and environmental conditions in the growth medium (Zhang et al., 2024). The statistically overlapping effects between these treatments show that, despite the upward trend, biological variability and other factors such as microbial competition or the physiological condition of the plant may influence the final outcome (Waller et al., 2024). Therefore, a dosage of 30 ml per liter is the most effective concentration in this study for maximizing Pakcoy plant height growth.

2. Number of Leaves

The results of observations of the number of leaves and variance analysis show that the concentration of PGPR application did not have a significant effect on the number of leaves of pakcoy plants at 30 days after planting. The results of the mean test can be seen in Figure 1.

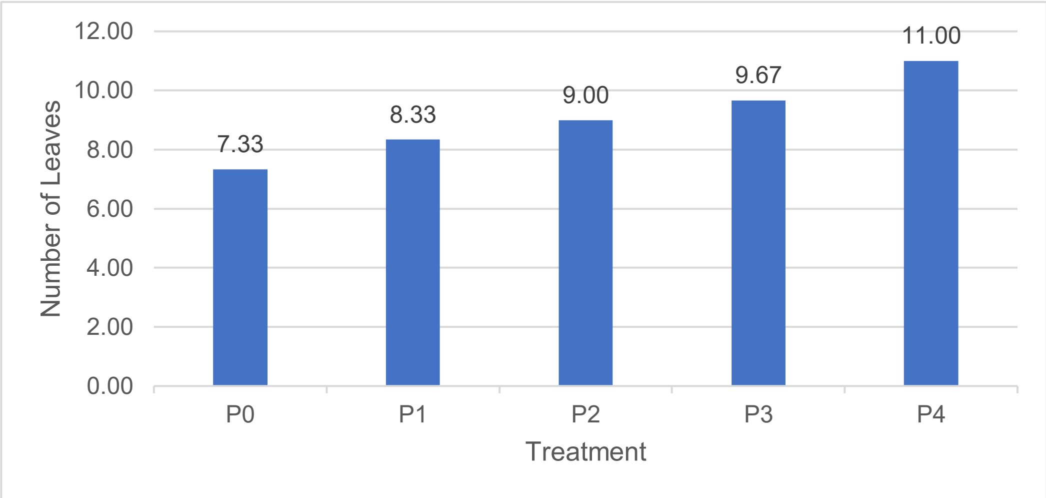

Figure 1. Mean number of leaves (pieces) of pakcoy plants treated with PGPR at different concentrations

Figure 1 shows that the P4 treatment with PGPR application resulted in the highest average number of leaves, namely 11.00 leaves, while the P0 treatment without PGPR application had the lowest number of leaves, namely 7.33 leaves. However, although there was a numerical increase in the number of leaves in the P4 treatment, statistical analysis showed that this difference was not significant compared to the other treatments. This indicates that the application of PGPR in this study did not have a significant effect on the number of pakcoy leaves.

The lack of significant effect of PGPR on leaf number can be explained by several external factors that influence leaf growth, such as light intensity, temperature, and nitrogen availability in the hydroponic solution (Andrade et al., 2023). Nitrogen is an essential nutrient that plays a key role in leaf formation and development, so nitrogen limitation can restrict leaf growth response even when PGPR is applied (Al-Falih, 2023). In addition, suboptimal environmental conditions can affect the effectiveness of PGPR in stimulating vegetative growth, particularly in leaf organs whose response tends to vary depending on plant species and growing environment (Mitra et al., 2024).

PGPR are known to enhance vegetative growth in plants; however, specific responses in leaf number are highly dependent on the interaction between treatment and environmental as well as nutritional factors. Previous studies have shown that although PGPR can improve chlorophyll quality and plant health, their effect on leaf number is not always significant without adequate nutritional and environmental conditions (Utami et al., 2024). Therefore, although the P4 treatment showed a trend of increasing leaf number, factors such as nitrogen availability and light conditions must be considered as important variables influencing the final outcome of pakcoy leaf growth.

3. Consumption Weight (g)

The results of consumption weight observations (grams) and variance analysis presented show that the concentration of PGPR administration has no significant effect on the consumption weight (grams) of pakcoy plants at 30 days after planting. The results of the average test can be as sho wn in Figure 2.

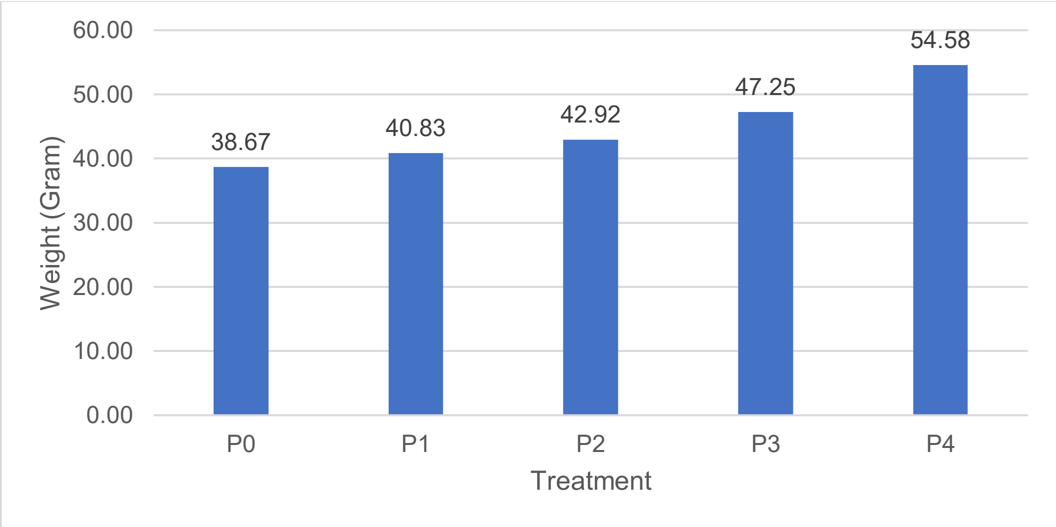

Figure 2. Diagram of average weight consumption (grams) of pakcoy plants at various concentrations of PGPR administration.

Figure 2 shows the results of the analysis of variance, indicating that the application of various PGPR concentrations did not have a significant effect on the consumable weight of pak choi plants at 30 days after planting (DAP). However, the mean values show a trend of increasing consumable weight with higher PGPR concentrations. The lowest consumable weight was recorded in the control treatment (P0) at 38.67 g, followed by P1 (40.83 g) and P2 (42.92 g). Higher consumable weights were observed in P3 (47.25 g), while the highest consumable weight was obtained in the P4 treatment, with an average of 54.58 g. Although statistical analysis showed that these differences were not significant, the numerical trend indicates that increasing PGPR concentration tends to enhance the consumable biomass of pak choi plants.

The increase in consumption weight observed at higher PGPR concentrations is likely due to the beneficial activity of plant growth-promoting rhizobacteria in the rhizosphere (Suresh et al., 2020). PGPR are known to enhance nutrient availability through mechanisms such as biological nitrogen fixation, phosphate solubilization, and the production of phytohormones, including auxins, gibberellins, and cytokinins. These processes stimulate root development and increase the efficiency of water and nutrient uptake, thereby promoting greater vegetative growth (Sinha et al., 2021). As a result, plants exposed to higher PGPR concentrations, particularly P4, tend to develop larger and thicker leaves, which contribute to the increased fresh weight of the harvested yield (Purnima & Singh, 2023). Nevertheless, the absence of significant differences among treatments suggests that the beneficial effects of PGPR are not sufficient to exceed experimental variability, or that environmental factors, including soil fertility, water availability, and climatic conditions, exert a greater influence on biomass accumulation than PGPR concentration itself (Maryam et al., 2025).

Consumption weight is an important yield parameter as it directly reflects the marketable portion of the plant leaves. In this study, the gradual increase in consumption weight from P0 to P4 indicates that PGPR application can enhance crop productivity, although the response was not statistically significant (Malik et al., 2022). These findings suggest that PGPR has the potential to increase pakcoy production when integrated with optimal cultivation practices, including balanced fertilization, proper irrigation, and favorable growing conditions (Andrade et al., 2023). Therefore, although the current results do not show a statistically significant effect, the consistently higher consumption weight at the highest PGPR concentration indicates a positive biological response that warrants further investigation under different environmental conditions or with higher replication to obtain a more accurate depiction of the treatment effect.

4. Root Weight

The results of the variance analysis showed that the concentration of PGPR application had a significant effect on root weight growth of pakcoy plants at 30 days after planting. The mean test results can be seen in Table 2.

Table 2. Mean Root Weight (g) of Pakcoy at various PGPR concentrations

Treatment	Average	LSD 5%
P0 = Control (no treatment)	16.67^{c}	
P1 = 15 ml PGPR per 1 liter of water	17.17^{b}	
P2 = 20 ml PGPR per 1 liter of water	19.08^{b}	2.30
P3 = 25 ml PGPR per 1 liter of water	18.67^{b}	
P4 = 30 ml PGPR per 1 liter of water	22.06^{a}	

Note: Numbers followed by different letters (a, b) are significantly different based on the LSD 5% test.

Table 2 presents the mean root weight of Pakcoy plants treated with different concentrations of Plant Growth Promoting Rhizobacteria (PGPR). The data reveal a significant increase in root biomass with increasing PGPR concentration, particularly at the highest dose of 30 ml per liter (P4), which produced an average root weight of 22.06 g. This value is statistically distinct from all other treatments, including the control (P0) with 16.67 g, and the intermediate concentrations P1 (17.17 g), P2 (19.08 g), and P3 (18.67 g), which share a similar statistical grouping but are significantly lower than P4 according to the LSD 5% test.

The significant enhancement in root weight observed at the P4 treatment can be attributed to the multifaceted role of PGPR in promoting root development (Larrabee & Nelson, 2021). PGPR facilitate nutrient solubilization, particularly phosphorus and potassium, which are critical for root growth and function. Additionally, these microorganisms stimulate root exudate production and expansion of the root system, thereby improving nutrient absorption efficiency (Salman & Avinash, 2025). The findings align with previous studies indicating that PGPR can increase root length and volume, contributing to a more robust root architecture that supports better plant growth in hydroponic systems (Vamerali et al., 2021).

The results underscore the effectiveness of PGPR as a biofertilizer in hydroponic cultivation by significantly boosting root biomass at an optimal concentration of 30 ml per liter (Rana et al., 2025). This improvement in root growth not only enhances nutrient uptake but also contributes to overall plant vigor and productivity. These insights provide practical guidance for optimizing PGPR application in wick hydroponic systems to maximize Pakcoy growth and yield.

5. Total Weight (g)

The results of the analysis of variance showed that the concentration of PGPR application had a significant effect on the total plant weight growth of pakcoy at 30 days after planting. The average test results are shown in Table 3.

Table 3. Average Total Weight (g) of Pakcoy at PGPR application of various concentrations

Treatment	Average	LSD 5%
P0 = Control (no treatment)	55.33^{c}	
P1 = 15 ml PGPR per 1 liter of water	58.00^{c}	
P2 = 20 ml PGPR per 1 liter of water	62.00^{b}	2.30
P3 = 25 ml PGPR per 1 liter of water	65.92^{b}	
P4 = 30 ml PGPR per 1 liter of water	76.67^{a}	

Note: Numbers followed by different letters (a,b) indicate significant differences based on the LSD5% test.

Table 3 presents the average total weight (in grams) of Pakcoy plants treated with different concentrations of Plant Growth-Promoting Rhizobacteria (PGPR). The treatments range from P0 (control) to P4 (highest concentration), and the results show a trend of increasing plant weight with higher PGPR concentrations (Sukul et al., 2021). The LSD 5% test was used to determine significant differences between treatments, with different letters (a, b, c) indicating statistically distinct groups.

Data show that the control treatment (P0) produced the lowest average weight, namely 55.33 g, which was significantly different from the highest concentration treatment (P4), which produced 76.67 g. This indicates that PGPR application has a positive effect on Pakcoy biomass accumulation. The increase in weight from P0 to P4 suggests that PGPR enhances plant growth, possibly by improving nutrient uptake, stimulating root development, or producing growth hormones (Aarti et al., 2024).

P1 and P2 treatments, with average weights of 58.00 g and 62.00 g respectively, showed gradual increases compared to the control, indicating no significant difference at the 5% level. However, starting from P2, the increase in weight became statistically significant, suggesting that a threshold concentration of PGPR is required to elicit a measurable growth response in Pakcoy (Sherly et al., 2025).

Further increases in PGPR concentration in P3 (65.92 g) and P4 (76.67 g) continued to show significant improvements, with P4 standing out as the most effective treatment. This dose-dependent response underscores the importance of optimizing PGPR concentration to maximize plant growth benefits (Purnima & Singh, 2023). The significant difference between P4 and all lower concentrations highlights the potential of higher PGPR levels to substantially increase crop yield (Nagrale et al., 2023).

The application of PGPR at varying concentrations has a positive and significant effect on the total weight of Pakcoy plants. The results emphasize that higher PGPR concentrations, particularly at P4, significantly boost plant biomass compared to the control and lower concentrations (Prisa & Jamal, 2025). These findings support the use of PGPR as a sustainable agricultural practice to improve vegetable crop productivity through biological means.

CONCLUSIONS

Based on the results of research that has been conducted on the effect of administering concentrations (PGPR) on the growth of hydroponic pakcoy plants, it is concluded that administering 30ml/l PGPR water is the concentration that yield optimal results and only has a significant effect on plant height, root weight, and total plant weight. Meanwhile, it does not have a significant effect on the number of leaves and consumption weight.

REFERENCES

Aarti, A., Sujata, S., Parmar, S., & Kumar*, A. (2024). Plant Growth Promoting Rhizobacteria: Their potential in sustainable Agriculture. *Journal of Science Innovations and Nature of Earth*, *4*(2), 40–46. https://doi.org/10.59436/jsianev4i2/270

Akhtar, T., Kumar, S., Kumar, S., & Meena, M. R. (2020). Importance of plant growth promoting rhizobacteria (PGPR) in agriculture: A Review. *Bhartiya Krishi Anusandhan Patrika*, *35*(1–2). https://doi.org/10.18805/bkap200

Al-Falih, A. M. (2023). The Mechanism of PGPR on the Photosynthesis System, Plant Resistance and Biofertilizers. *Environmental Analysis & Ecology Studies*, *11*(4). https://doi.org/10.31031/eaes.2023.11.000769

Andrade, L. A. D., Santos, C. H. B., Frezarin, E. T., Sales, L. R., & Rigobelo, E. C. (2023). Plant Growth-Promoting Rhizobacteria for Sustainable Agricultural Production. *Microorganisms*, *11*(4), 1088. https://doi.org/10.3390/microorganisms11041088

Bhandari, A., P, A., Bhanusree, M. R., Anandan, P., Pooja, K., K.Nivetha, K. N., & Kumar, K. R. (2025). Role of Plant Growth Promoting Rhizobacteria for Advanced Sustainable Agricultural Practices: A Review. *Asian Journal of Soil Science and Plant Nutrition*, *11*(2), 1–14. https://doi.org/10.9734/ajsspn/2025/v11i2506

Bhardwaj, T., Khanna, K., Sharma, P., Dhiman, S., Ibrahim, M., Arora, U., Sharma, P., Sharma, I., Arora, P., Sharma, A., Kaur, R., Ahmad Mir, B., Ohri, P., & Bhardwaj, R. (2024). *Plant Growth-Promoting Rhizobacteria (PGPR): A Credible Tool for Sustainable Agriculture* (pp. 211–250). Bentham Science. https://doi.org/10.2174/9789815179699124010011

Bisht, N., & Singh Chauhan, P. (2021). *Excessive and Disproportionate Use of Chemicals Cause Soil Contamination and Nutritional Stress*. Intechopen. https://doi.org/10.5772/intechopen.94593

Chakraborty, U., & Chakraborty, B. (2022). *Utilization of Plant Growth Promoting Rhizobacteria with Multiple Beneficial Traits in Agricultural Biotechnology for Crop Improvement* (pp. 131–172). Jenny Stanford. https://doi.org/10.1201/9781003313144-7

Ikiz, B., Dasgan, H. Y., & Gruda, N. S. (2024). Utilizing the power of plant growth promoting rhizobacteria on reducing mineral fertilizer, improved yield, and nutritional quality of Batavia lettuce in a floating culture. *Scientific Reports*, *14*(1), 1616. https://doi.org/10.1038/s41598-024-51818-w

Jain, P., Gupta, A., & Chandukar, P. (2022). Sustainable Agriculture with Rhizobacteria (PGPR). *Zenodo (CERN European Organization for Nuclear Research)*. https://doi.org/10.5281/zenodo.6602005

Larrabee, M. M., & Nelson, L. M. (2021). *The use of plant growth-promoting rhizobacteria (PGPR) to improve root function and crop nutrient use efficiency* (pp. 467–492). Burleigh Dodds Science. https://doi.org/10.19103/as.2020.0075.22

Malik, G., Chugh, S., & Madan, A. (2022). *The Potential of Plant Growth-Promoting Rhizobacteria (PGPR) as Biological Tools in Enhancing Agricultural Sustainability* (pp. 295–309). Springer. https://doi.org/10.1007/978-3-031-04805-0_14

Maryam, M., Bhatti, A., Suleman, H., Zeshan, K., Imtiaz, M., & Batool, R. (2025). Unlocking Soil Fertility and Enhancing Plant Health: The Vital Role of PGPR. *Journal of Biological and Allied Health Sciences*, *6*(1), 28–43. https://doi.org/10.56536/jbahs.v6i1.72

Mitra, D., Pellegrini, M., & Guerra-Sierra, B. E. (2024). Interaction between Plants and Growth-Promoting Rhizobacteria (PGPR) for Sustainable Development. *Bacteria*, *3*(3), 136–140. https://doi.org/10.3390/bacteria3030009

Nagrale, D. T., Chaurasia, A., Kumar, S., Gawande, S. P., Hiremani, N. S., Shankar, R., Gokte-Narkhedkar, N., Renu, R., & Prasad, Y. G. (2023). PGPR: the treasure of multifarious beneficial microorganisms for nutrient mobilization, pest biocontrol and plant growth promotion in field crops. *World Journal of Microbiology and Biotechnology*, *39*(4), 100. https://doi.org/10.1007/s11274-023-03536-0

Prisa, D., & Jamal, A. (2025). Potential and applications of plant growth promoting rhizobacteria (PGPR). *Multidisciplinary Reviews*, *8*(10), 2025317. https://doi.org/10.31893/multirev.2025317

Purnima, P., & Singh, P. (2023). Plant Growth Promoting- Rhizobacteria (PGPR): Their Potential as Biofertilizer and Biopesticide Agents: A Review. *Asian Journal of Advances in Agricultural Research*, *22*(1), 25–37. https://doi.org/10.9734/ajaar/2023/v22i1431

Putra, I. G. K. P., Rai, I. N., & Wijana, G. (2022). Aplikasi Plant Growth Promoting Rhizobacteria (PGPR) dan Limbah Air Kolam Lele dengan Sistem Irigasi Tetes terhadap Pertumbuhan dan Hasil Tanaman Pakcoy (Brassica rapa L.). *Agrotrop : Journal on Agriculture Science*, *12*(2), 175. https://doi.org/10.24843/ajoas.2022.v12.i02.p01

Rana, N., Ghabru, A., Chauhan, S., & Sharma, H. (2025). *PGPR-Biotechnological Interventions for Improvement of Crop Plants* (pp. 154–187). Crc. https://doi.org/10.1201/9781003625674-7

Salman, K., & Avinash, P. S. (2025). Direct mechanism of PGPR for promoting plant growth: Current perspective. *Plant Science Today*. https://doi.org/10.14719/pst.7748

Sherly, J., Shankar, R., & Sivasakthivelan, P. (2025). *Plant Growth-Promoting Rhizobacteria for Nutrient Mobilization and Enhancing Yield and Quality of Vegetable Crops* (pp. 188–206). Crc. https://doi.org/10.1201/9781003625674-8

Sinha, D., Mukherjee, S., & Mahapatra, D. (2021). *Multifaceted Potential of Plant Growth Promoting Rhizobacteria (PGPR)* (pp. 205–268). Igi Global. https://doi.org/10.4018/978-1-7998-7062-3.ch008

Sukul, P., Kumar, J., Rani, A., Mohamed Abdillahi, A., Balu Rakesh, R., & Harish Kumar, M. (2021). Functioning of Plant Growth Promoting Rhizobacteria (PGPR) and Their Mode of Actions: an Overview From Chemistry Point of View. *PLANT ARCHIVES*, *21*(Suppliment-1), 628–634. https://doi.org/10.51470/plantarchives.2021.v21.s1.096

Suresh, A., Sameera, P. M., Chapla, J., & Rajarao, P. (2020). *Plant Growth-Promoting Rhizobacteria (PGPR) Activity in Soil* (pp. 165–182). Crc. https://doi.org/10.1201/9781003057819-9

Utami, D. S., Setiawati, M. R., & Simarmata, T. (2024). Synergistic and Competence of Native Plant Growth Promoting Rhizobacteria on Direct Mechanism on Growth Plants: A Review. *International Journal of Life Science and Agriculture Research*, *03*(02). https://doi.org/10.55677/ijlsar/v03i2y2024-08

Vamerali, T., Panozzo, A., Visioli, G., & Dal Cortivo, C. (2021). *Root–microbe Interactions Influencing Water and Nutrient Acquisition Efficiency* (pp. 159–192). Wiley. https://doi.org/10.1002/9781119525417.ch6

Vanamala, P., Sultana, U., Sindhura, P., & Gul, M. Z. (2021). *Plant Growth-Promoting Rhizobacteria (PGPR)* (pp. 332–357). Igi Global. https://doi.org/10.4018/978-1-7998-7062-3.ch012

Waller, L. P., Allen, W. J., Black, A., Condron, L., Tonkin, J. D., Tylianakis, J. M., Wakelin, A., & Dickie, I. A. (2024). Asymmetric sharing of generalist pathogens between exotic and native plants correlates with exotic impact in communities. *Journal of Ecology*, *112*(10), 2264–2276. https://doi.org/10.1111/1365-2745.14392

Zhang, F., Huang, S., Yu, X., Han, H., Li, X., Bai, C., Zhou, Y., & Bi, S. (2024). Advances in Growth-Promoting Rhizobacteria Function on Plant Growth Facilitation and Their Mechanisms. *Scholars Journal of Engineering and Technology*, *12*(03), 114–117. https://doi.org/10.36347/sjet.2024.v12i03.002