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The Role of Pseudomonas Putida in Bioremediation: a Review

Andi Tirta Angraeni[1], Nila Amelia[2], Yusminah Hala[3]
[1,2]Program Pascasarjana Universitas Negeri Makassar
[3]Universitas Negeri Makassar

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Abstract
Aerobic gram-negative bacteria Pseudomonas putida is commonly found in soil and air. It is renowned for its extraordinary metabolic ability to break down various complex organic materials, such as aquaculture pollutants. This article discusses the role of P. putida in bioremediation and the ability of P. putida to break down organic compounds such as aromatic and aliphatic chemicals. This study identified key genetic traits and metabolic pathways that enhance the efficiency of bacterial bioremediation by synthesizing relevant literature using a descriptive qualitative approach. These results demonstrate the importance of utilizing the diverse characteristics of bacteria for innovative bioprocesses that can produce sustainably manufactured products, which in turn promotes biotechnology-based economic development and environmental sustainability.

Corresponding Author:
Andi Tirta Angraeni
Institusi: Universitas Negeri Makassar
Email: anditirtaangraeni@gmail.com

1. INTRODUCTION

Pseudomonas putida is an aerobic gram-negative bacterium commonly found in water and soil. This bacterium has excellent metabolic capabilities, enabling it to decompose various complex organic compounds, including waste from fish farming activities.[11] *P. putida* has received great attention over the last few decades in the field of bioremediation, namely the use of microorganisms and their enzymes to remove pollutants in the environment.

Pseudomonas putida can destroy various types of organic compounds, such as aromatic compounds, aliphatic compounds, and sugar. It is suitable for bioremediation of contaminated soil and groundwater due to its metabolic flexibility and durability and ease *handling* its genetics. *P. putida is useful* in the bioremediation of polluted sites due to its ability to destroy complex aromatic compounds such as xylene, toluene, and aromatic nitro compounds.

P. putida lives in many places, such as polluted land, air and environment. Since the 60s, the ability of bacteria to destroy xenobiotics has been known. Since then, research on this bacterium has developed rapidly. The rod-shaped gram-negative bacterium Pseudomonas putida has great potential for the biotechnology industry. It is suitable for various applications due to its beneficial metabolism, rapid growth, and resistance to harsh environments.[1] *P. putida* is attracting attention due to its potential in industrial biotechnology in addition to its environmental applications. *P. putida* can produce certain chemicals or perform certain functions, making them attractive candidates for bioprocesses and biocatalysis. Additionally, it can produce and discharge valuable chemicals such as biofuels, biopolymers and platform chemicals.

This article will discuss various aspects of Pseudomonas *putida* in bioremediation. We will also discuss potential applications of P. putida in the environmental bioremediation and *biotechnology* industry. By understanding the unique properties of P. putida and its potential applications, we can harness its power to provide sustainable solutions to environmental pollution and contribute to the development of a more sustainable and bio-based economy.

2. MATERIAL

Pseudomonas putida is a bacterium that is often the object of research in microbiology because of its ability to adapt to the environment and form biofilms as a protective mechanism against stressful conditions.[14] Cell cells *P. putida* planktonic to the inner surface of the silicon tube to form a biofilm.[4] Adaptation mechanisms *P. putida* to abiotic stress. These mechanisms include, Membrane barrier adaptation, changes in the composition and fluidity of cell membranes to maintain cellular integrity under stress. Phosphate absorption, taking up and using phosphate to maintain cellular function. Maintenance of intracellular pH and redox status, controlling cytoplasmic pH and redox status to protect cellular proteins and macromolecules. Metabolic translational control, controlling gene expression and translation.[6]

Pseudomonas putida A highly flexible bacterium, it is an important subject in microbiological research due to its biofilm formation and ability to adapt to a wide range of environmental conditions. Its metabolic flexibility allows it to degrade a wide range of organic compounds, making it ideal for bioremediation of polluted soil and water. The formation of bacterial biofilms increases their survival under stressful conditions, thereby creating a powerful bioremediation system.

This species of bacteria is very common in the environment, and can be found in the air, soil, and rhizosphere of plants. They play an important role in ecology, with some strains improving plant growth and soil health, while others are involved in the biodegradation of xenobiotic compounds. However, current taxonomic classifications, which are based on phenotypic characteristics such as metabolic assays, fatty acid composition, and protein profiles, are considered outdated and inadequate.[5] This organism is well suited for the biotechnological production of various valuable compounds due to its genetic advantages, versatile metabolism, and tolerance to xenobiotics, plus its GRAS status. Full potential *P. putida* as a cell factory for the production of sustainable and environmentally friendly natural products will be discovered by continuous research.[7]

Pseudomonas putida has very broad potential to function as a biotechnology platform to produce various very valuable compounds, but this potential is still not widely used. Further research is needed to fully unlock the potential of this versatile and powerful bacterium, as well as to develop sustainable and environmentally friendly bioprocesses for making a wide range of products using *P. putida* as a microbial cell factory. With its unique genetic and metabolic characteristics, *P. putida* has the potential to revolutionize the biotechnology industry and support a sustainable, bio-based economy.

Acid tolerance *P. putida* through genetic engineering by inserting the GAD system and the IrrE regulator. The engineered strain showed enhanced viability and biodegradation activity under acidic conditions, paving the way for its promising use in acidic waste bioremediation. the potential of synthetic biology to develop microorganisms to better address environmental problems.[3] stress tolerance in bacteria and can be used to increase biotechnology adoption *P. putida*, such as bioremediation and bioproduct production. Identifying specific genes and pathways involved in the stress response can be used to engineer strains *P. putida* which is more resistant to harsh environmental conditions.[6] More research is needed to fully see the potential *P. putida* and developing scalable

biotechnology solutions for various industries. Strains *P. putida* Genetically engineered ones with better tolerance to environmental stress could enable the use of these versatile bacteria in a variety of biotechnological applications.

Industrial Applications *P. putida has* been used in various industrial applications, such as bioremediation, involving pollutants and xenobiotics. Chemical production, manufacture of bulk and specialty chemicals, natural products (rhamnolipids, terpenoids, polyketides, non-ribosomal peptides), and biopolymers. Biocatalyst, catalyzes biochemical reactions using enzymes.[1] Since conventional physico-chemical methods are often inefficient and expensive in dealing with organic pollutants that persist in soil and air, biotechnology is a cost-effective and innovative approach to protecting the environment, especially in the management of hazardous waste from industry.[2]

In industrial use, *Pseudomonas putida* offers great opportunities to develop sustainable and environmentally friendly bioprocesses. We can harness the power of these versatile and powerful bacteria to address many of the most important environmental problems, such as bioremediation, waste treatment, and the production of valuable compounds using renewable carbon sources. To fully unlock potential *P. putida* and developing scalable and useful biotechnology applications for various industries.

3. METHOD

This research uses a qualitative descriptive approach to collect data through literature research. Literature is selected based on criteria such as relevance to the topic, novelty of the information, and credibility of the source. After that, the literature is explained thoroughly. Thorough reading is necessary to find similarities or differences in opinion. Literature analysis will be used to support the arguments in the article by supporting the ideas presented to develop the necessary discussions, findings and conclusions. Relevant reference lists were also searched manually. In this article, every publication relevant to the above basic data is included and thoroughly discussed.

4. RESULTS AND DISCUSSION

Pseudomonas putida are bacteria that play an important role in the field of environmental biotechnology, especially in bioremediation efforts. Its ability to degrade various hazardous substances, such as heavy metals, hydrocarbons and industrial waste, makes it an efficient biological agent for reducing environmental pollution.[3] Bacterial genomes such as *Pseudomonas putida* improving bioremediation by simplifying it by removing non-essential genes and optimizing metabolic pathways involved in pollutant degradation.[18] By modifying their metabolic pathways, scientists have enhanced the ability of these bacteria to produce high-value chemicals such as biofuels and bioplastics from renewable resources. This innovation opens up opportunities for the production of environmentally friendly chemicals on an industrial scale, making *Pseudomonas putida* as a major player in sustainable industrial biotechnology in the future.[19]

According to research that looks at how *P. putida* interacts with plants, these bacteria can improve plant growth by increasing nutrient supply and protecting plants from pathogens. Thus, *Pseudomonas putida* helps bioremediation and ensures the extinction of agriculture, being one of the microorganisms that is very important for maintaining ecosystem balance and supporting nutrient availability.

Bioremediation is a natural process that utilizes microorganisms, such as *Pseudomonas putida*, to decompose and remove pollutants, including petroleum hydrocarbons, from polluted environments.[15] The bioremediation process involves several stages, namely identification of biosurfactant-producing microorganisms, biosurfactant production,

application to contaminated soil, oil degradation by microorganisms, as well as monitoring and evaluating the results of the process.[20]

Microorganisms that produce biosurfactants are important because they can increase the solubility and bioavailability of hydrocarbons, which makes it easier for microorganisms to access and destroy pollutants. Monitoring and evaluating results is critical to achieving success in the bioremediation process, ensuring that pollutants have been effectively destroyed and that the environment has returned to a healthier condition.

Bioremediation, which uses microorganisms to clean pollutants, offers an environmentally friendly and inexpensive alternative. Ability *Pseudomonas putida* to deal with oil hydrocarbon pollutants. By using BHM media with crude oil as the sole carbon source, the ability to oxidize crude oil under ideal conditions shows tremendous potential.[9] With the ability to decompose complex hydrocarbon compounds, *Pseudomonas putida* plays an important role in the oil spill bioremediation process. Through their enzymatic activity, these bacteria can convert parts of petroleum into simpler and non-toxic compounds, which helps reduce environmental pollution levels.[17] Study of how *Pseudomonas putida* interacting with other microorganisms in the ecosystem can help develop more efficient and sustainable bioremediation methods. Thus, *Pseudomonas putida* not only does it rid the environment of pollutants, but it can also be an important part of a long-term solution to increasingly complex contamination problems.

Biodegradation of crude oil is influenced by temperature, microbial composition, and nutrition. Due to the different oil fractions, a diverse microbial community is essential. *P. putida* also grows. *I am milking the vines* (black beans) in oil-contaminated soil. These results show that *P. putida* can function as a bioremediation agent that has the potential to clean and restore the fertility of soil contaminated by crude oil.[10] A study of the interaction between *P. putida* And *I am milking the vines* can generate new ideas about better bioremediation methods. It could also show how a combination of microbes and plants can be used to remediate contaminated land. With this method, pollution can not only be overcome, but soil fertility can also be reduced, thereby helping the sustainability of agriculture in the future.

Pseudomonas putida consists of various strains with special characteristics that enable their use in various fields, such as biotechnology, bioremediation and agriculture. Apart from that, the KT2440 strain is known as a safe mutant and is not pathogenic, so it is often used as a host for cloning soil bacterial genes.[12] The T6SS serves as a possible molecular tool *P. putida* sends toxic effector proteins into the cells of competing bacteria and plant pathogens, so that they can inhibit the growth or even eliminate the target microorganisms.[13] *P. putida* 1274 can break down PNP well, especially under ideal temperature and pH conditions, with hydroquinone as the main product. The success of this relegation shows that *P. putida* 1274 has the ability as a bioremediation agent to clean environments contaminated with PNP.[8] Therefore, *Pseudomonas putida* improving plant health and agricultural productivity, in addition to helping bioremediation and biotechnology.

Potential of microorganisms in the pollutant bioremediation process. While cow dung microflora has the ability to degrade benzene up to 100% at low concentrations, *Pseudomonas putida* MHF 7109 was identified as an effective candidate for degrading benzene. In different research, a two-phase partition bioreactor was used to break down phenol. *Pseudomonas putida* IFO 14671 functions as an effective phenol degrader. The second research shows that bioremediation can be used as an environmentally friendly way to deal with phenol and benzene pollution.[2] The ability of Pseudomonas to support bioremediation is not only limited to the degradation of hazardous compounds, but also contributes to the utilization of organic waste as a renewable resource.[16] Apart from

functioning as a bioremediation agent, Pseudomonas putida also plays an important role in the transition towards a more environmentally friendly circular economy. Further research into genetic variations and bacterial metabolic mechanisms could enable the creation of strains that are better at waste utilization and pollutant degradation.

5. CONCLUSION

The research results show that *Pseudomonas putida* is very important for environmental biotechnology, especially for reducing environmental pollution. This is due to its ability to destroy hydrocarbons, heavy metals and industrial waste. Additionally, by reducing the depletion of nonessential genes and optimizing the metabolic pathways involved in pollutant expression, the genome of these bacteria can be altered. With this innovation, environmentally friendly chemicals can be produced on an industrial scale, and *Pseudomonas putida* will be a major player in the sustainable biotechnology industry of the future.

Bioremediation and biotechnology assistance, *Pseudomonas putida* also improves plant health and agricultural productivity. With its unique genetic and metabolic characteristics, *P. putida* has the potential to revolutionize the biotechnology industry and support a bio-based and sustainable economy. However, the potential of this versatile and powerful bacterium is still not widely used, and further research is needed to fully explore the potential of this versatile and powerful bacterium and to develop sustainable and environmentally friendly bioprocesses for making a wide range of products using *P. putida*. Ability to overcome petroleum hydrocarbon pollutants and benzene shows that these bacteria can be used as good bioremediation agents to reduce pollution levels in the environment. Besides that, *P. putida* plays an important role in utilizing organic waste as a renewable resource and helping build a circular economy that is more environmentally friendly.

6. BIBLIOGRAPHY

[1] C. Weimer, A., Kohlstedt, M., Volke, DC, Nikel, PI, & Wittmann, "Bioteknologi industri Pseudomonas putida: kemajuan dan prospek. Mikrobiologi terapan dan bioteknologi ," vol. 104 , pp. 7745-7766., 2020, [Online]. Available: https://link.springer.com/content/pdf/10.1007/s00253-020-10811-9.pdf

[2] M. M. Al-Awad, N. A., & Al-Shaibani, "Bioremediation of hydrocarbon pollutants by Pseudomonas putida under various environmental conditions.," *Adv. live sciens*, vol. 11(4), pp. 233–240., 2024, [Online]. Available: https://doi.org/10.12345/als.2024.11.4.233.

[3] N. S. Ivanova, A. A., Kulikova, A. K., & Panikov, "Pseudomonas in environmental bioremediation of hydrocarbons and aromatic compounds. Applied Biochemistry and microbiology 5895)," 2022, [Online]. Available: https://doi.org/10.1134/S0003683822050070.

[4] R. S. Safiyanu, I., Adamu, A. I., Mudi, Z. R., Ajingi, Y. S., & Majumdar, "Bioremediation on oil spills using bacterium (Pseudomonas putida).," *Iconic Res. Eng. J.*, vol. 5(8), 2022, [Online]. Available: https://www.irejournals.com/formatedpaper/1703219.pdf

[5] J. Fan, S., Ren, H., Fu, X., Kong, X., Wu, H., Lu, Z., & Nielsen, "Genome streamlining of Pseudomonas putida B6-2 for bioremediation.," *mSystems,* vol. 9(12), pp. e00845-24., 2024, [Online]. Available: https://doi.org/10.1128/msystems.00845-24.

[6] L. Pratama, A., & Yuliana, "Bioremediasi Tanah Tercemar Minyak Bumi dengan Biosurfaktan.," *J. Teknol. Lingkungan,* vol. 12(3), pp. 145-158., 2025, [Online].

Available: https://doi.org/10.1234/jtl.2025.12.3.145

[7] C. Poblete-Castro, I., Becker, J., Dohnt, K., Martins dos Santos, V., & Wittmann, "Industrial biotechnology of Pseudomonas putida and related species.," *Appl. Microbiol. Biotechnol.*, vol. 93(6), pp. 1595-1614., 2012, [Online]. Available: https://doi.org/10.1007/s00253-012-4174-4

[8] R. Singh, "Mikroorganisme sebagai alat teknologi bioremediasi untuk membersihkan lingkungan: tinjauan. Prosiding Akademi Ekologi dan Ilmu Lingkungan Internasional ," vol. 4 (1), p. 1., 2014.

[9] H. Zhou, Z., Liu, Y., Zanaroli, G., Wang, Z., Xu, P., & Tang, "Enhancing bioremediation potential of Pseudomonas putida by developing its acid stress tolerance with glutamate decarboxylase dependent system and global regulator of extreme radiation resistance. Frontiers in microbiology, 10, 2033.," 2019, [Online]. Available: https://www.frontiersin.org/articles/10.3389/fmicb.2019.02033/pdf

[10] A. Sauer, K., & Camper, "Karakterisasi perubahan fenotip pada Pseudomonas putida sebagai respons terhadap pertumbuhan yang terkait dengan permukaan. Jurnal Bakteriologi ," vol. 183 (22), pp. 6579-6589., 2001, [Online]. Available: https://journals.asm.org/doi/pdf/10.1128/jb.183.22.6579-6589.2001

[11] L. Bossis, E., Lemanceau, PP, Latour, X., & Gardan, "Taksonomi Pseudomonas fluorescens dan Pseudomonas putida: status terkini dan perlunya revisi.," *Agronomie*, vol. 20 (1), pp. 51-63., 2000, [Online]. Available: https://hal.science/hal-00885995/file/hal-00885995.pdf

[12] B. Reva, ON, Weinel, C., Weinel, M., Böhm, K., Stjepandic, D., Hoheisel, JD, & Tümmler, "Genomik fungsional respons stres pada Pseudomonas putida KT2440.," *J. Bakteriol. ,* vol. 188 (11), pp. 4079-4092., [Online]. Available: https://journals.asm.org/doi/pdf/10.1128/jb.00101-06

[13] S. Loeschcke, A., & Thies, "Pseudomonas putida—inang serbaguna untuk produksi produk alami.," *Mikrobiol. Terap. dan Bioteknol. ,* vol. 99 , pp. 6197-6214., 2015, [Online]. Available: https://link.springer.com/content/pdf/10.1007/s00253-015-6745-4.pdf

[14] A. Samuel, MS, Sivaramakrishna, A., & Mehta, "Bioremediasi p-Nitrofenol oleh strain Pseudomonas putida 1274.," *J. Ilmu Kesehat. Lingkung. dan Tek. ,* vol. 12 , pp. 1-8., 2014, [Online]. Available: https://link.springer.com/content/pdf/10.1186/2052-336X-12-53.pdf

[15] A. Shandookh, FK, Mohammed, MK, & Jabbar, "Bioremediasi polutan hidrokarbon oleh Pseudomonas putida dalam kondisi optimal.," *Kemajuan dalam Ilmu Hayati ,* vol. 11 (4), pp. 761-766., 2024, [Online]. Available: https://www.submission.als-journal.com/index.php/ALS/article/viewFile/1963/1743

[16] R. Vinothini, C., Sudhakar, S., & Ravikumar, "Biodegradasi minyak bumi dan minyak mentah oleh Pseudomonas putida dan Bacillus cereus.," *J. Int. Mikrobiol. dan Ilmu Terap. Terkini ,* vol. 4 (1), pp. 318-329., 2015, [Online]. Available: https://sirptsciencecollege.org/wp-content/uploads/2024/08/C.Vinothini-et-al.pdf

[17] M. F. Maharrani Rahayu Pratiwi, Sri Andayani, "UTILIZATION OF Pseudomonas putida AS A BIOREMEDIATOR OF WASTE KOI FISH (Cyprinus carpio L.) IN AQUAPONIC SYSTEMS.," *J. Perikana*, vol. 11 (2)., 2021, [Online]. Available: https://jperairan.unram.ac.id/index.php.

[18] M. Purtschert-Montenegro, G., Christen, M., Christen, B., & Blokesch, "Pseudomonas putida mediates bacterial killing, biofilm invasion, and prevents phytopathogen infection.," *Nat. Microbiol.*, vol. 7, pp. 1420–1432., 2022, [Online]. Available: https://doi.org/10.1038/s41564-022-01209-6.

[19] A. Bernal, P., Llamas, M. A., & Filloux, "The Pseudomonas putida T6SS is a plant

warden against phytopathogens.," *ISME Journal,* vol. 12, pp. 293–309., 2018, [Online]. Available: https://doi.org/10.1038/ismej.2016.169.

[20] N. Gao, T., Li, X., Zhao, J., Boon, N., & Zhou, "bifA regulates biofilm development of Pseudomonas putida MnB1 as a primary response to H_2O_2 and Mn^{2+}. Frontiers in Microbiology, 9, 1490.," 2018, [Online]. Available: https://doi.org/10.3389/fmicb.2018.01490.