doi.org/10.36073/1512-0902-2025-120-127
UDC: 628.3; 579.841; 502.174

# Harnessing Purple Phototrophic Bacteria (PPB) for Circular Bioeconomy and Wastewater Valorization in Georgia

**Natela Dzebisashvili, Darejan Dughashvili**
Institute of Hydrometeorology at Georgian Technical University
e.mail: n.dvalishvili@gtu.ge

The work was prepared within CA21146 - Fundamentals and applications of purple bacteria biotechnology for resource recovery from waste (PURPLEGAIN)

**Summury.** Purple phototrophic bacteria (PPB), a metabolically versatile group within Proteobacteria, offer promising solutions for circular bioeconomy through bioresource recovery and wastewater treatment. The paper examines the potential of PPB-based biotechnology in the context of Georgia. The aim of the study was to find out how PPB systems adapted to local realities can be effectively implemented. The paper reflects the latest international innovations and best practices in the development and implementation of PPB systems. The ways of integrating PPB technologies into the sustainable waste management and renewable energy sectors in Georgia are also discussed.

**Key words:** Purple phototrophic bacteria (PPB), circular bioeconomy, wastewater treatment, resource recovery, photobioreactors

**Introduction.** Purple phototrophic bacteria (PPB), particularly the two main subgroups—purple sulfur bacteria (PSB) and purple non-sulfur bacteria (PNSB)—are known for their remarkable metabolic plasticity and ecological adaptability. These microorganisms can flourish in a wide range of environmental niches, including anaerobic aquatic systems, sediments, and wastewater environments, due to their ability to perform multiple modes of metabolism depending on the availability of light, carbon, and electron donors (Capson-Tojo et al., 2020; Sakarika et al., 2019). They are capable of phototrophic growth under anaerobic light conditions, as well as chemotrophic growth in dark environments using organic compounds. This metabolic versatility allows them to utilize various carbon sources such as volatile fatty acids, alcohols, and organic acids, and to employ diverse electron donors including hydrogen sulfide, molecular hydrogen, and ferrous iron.

Because of these capabilities, PPB are emerging as ideal microbial platforms for advanced biotechnological applications. Their roles in processes such as biological hydrogen production, bioplastic synthesis through accumulation of polyhydroxyalkanoates (PHAs), and efficient treatment of organic-rich wastewaters have been demonstrated in both lab-scale and pilot-scale systems (Guzman et al., 2019; Semenov et al., 2011). They not only contribute to pollution mitigation but also enable recovery of high-value bioresources from waste, aligning well with principles of the circular bioeconomy.

Georgia, as a country with a rapidly expanding agro-industrial sector and persistent challenges in wastewater management infrastructure, provides an excellent case for the application of PPB-based technologies. Sectors such as winemaking, dairy production, and livestock farming generate substantial amounts of organic waste, much of which is currently underutilized or improperly treated. PPB can serve as a biological bridge between waste management and value-added production. Despite global progress - especially in countries like Spain, China, and India, where integrated PPB technologies have been tested and optimized (Capson-Tojo et al., 2020)—the South Caucasus region, including Georgia, remains underrepresented in applied PPB research and deployment.

This research aims to fill that gap by assessing the technical feasibility, economic viability, and environmental benefits of implementing PPB-based systems in Georgia. In particular, it explores how PPB can contribute to organic waste valorization, renewable energy generation, and the development of a more circular and sustainable economy. Additionally, we propose pathways for adapting international best practices to local conditions, fostering innovation, and building research capacity within the Georgian context.

**Biology and Metabolism of PPB.** PPB are able to thrive and grow in anaerobic or microaerobic conditions, utilizing light as their primary energy source. Under these conditions, they can harness a variety of organic and inorganic compounds as electron donors, which further enhances their adaptability to diverse environments (Fukuzumi et al., 2018). Their highly efficient photosynthetic apparatus is considered one of the most advanced in nature, with quantum yields that reach 100% in their reaction centers and over 80% in light-harvesting complexes. This makes them exceptionally efficient at converting light energy into chemical energy, far surpassing many other microbial systems (Semenov et al., 2011). Additionally, PPB are capable of performing a wide range of metabolic processes, including photoheterotrophy, where they use light to oxidize organic carbon sources, and photoautotrophy, where they convert carbon dioxide into organic carbon through photosynthesis. This metabolic flexibility also extends to fermentation and respiration, allowing them to maintain energy production even in the absence of light, further enhancing their survival in fluctuating environmental conditions (Csiki et al., 2018).

This metabolic versatility enables PPB to degrade a wide array of organic pollutants commonly found in both domestic and industrial wastewater, including volatile fatty acids, amino acids, alcohols, and other complex organic compounds (Puyol et al., 2017). Their ability to process these diverse pollutants makes them particularly effective in decentralized treatment systems, where wastewater is often heterogeneous and challenging to treat using conventional methods. Furthermore, PPB thrive in mixed-culture bioreactors, where they can coexist with other microorganisms, allowing for a more efficient and cost-effective treatment process. The ability to use mixed cultures without the need for sterilization further reduces operational costs and makes them a more sustainable alternative to traditional wastewater treatment methods.

**Technological Applications of PPB.** PPB have been extensively utilized in biotechnological processes for the production of various valuable bioresources, including biohydrogen (Capson-Tojo et al., 2020), polyhyd-roxyalkanoates (PHAs) (Sakarika et al., 2019), and microbial proteins (Cao et al., 2020). Biohydrogen production, for instance, is one of the most promising applications of PPB, as these microorganisms can convert organic substrates into hydrogen gas under anaerobic conditions. This process not only generates hydrogen, a clean fuel, but also helps in the recovery of organic carbon from waste streams, making it a dual-purpose technology for both energy production and waste treatment. Similarly, polyhydroxyalkanoates (PHAs) are biodegradable plastics produced by PPB through the accumulation of carbon sources, particularly fatty acids and alcohols, which are abundant in organic waste. These bioplastics offer a sustainable alternative to conventional petroleum-based plastics, as they decompose naturally in the environment. Furthermore, PPB can produce microbial proteins, which have various applications in animal feed, food products, and even as a source of alternative proteins for human consumption. The microbial protein production is particularly important in the context of food security, as it provides a protein-rich alternative to traditional sources like soy and animal-based products, all while utilizing organic waste as a substrate.

Mixed-culture biotechnologies, which involve the use of diverse microbial communities, have shown significant advantages in optimizing PPB-based systems for treating complex waste streams. These biotechnologies allow for the treatment of mixed waste without the need for sterilization, significantly reducing operating costs. The use of mixed cultures not only reduces the financial burden of maintaining axenic (pure) cultures but also enhances the robustness of the treatment process, as microbial communities are often more resilient to environmental fluctuations. By fostering synergistic interactions among different microorganisms, mixed-culture systems can improve the efficiency of pollutant degradation, nutrient cycling, and the overall stability of the bioreactor (Winans et al., 2017). These technologies are particularly useful in regions with variable waste compositions and in decentralized systems, where the cost of maintaining a sterile environment would be prohibitively high.

In terms of reactor design, innovations in photobioreactor systems, such as tubular and raceway configurations, have greatly advanced the performance of PPB-based processes. Tubular photobioreactors, with their elongated, cylindrical design, allow for better light distribution and enhanced exposure of the bacteria to sunlight, which is crucial for maximizing photosynthetic activity. Raceway ponds, which are shallow, open-channel systems designed for the large-scale cultivation of microalgae and phototrophic bacteria, have been particularly effective in maximizing biomass productivity. These open-pond systems allow for optimal mixing and circulation of the culture, ensuring uniform distribution of nutrients and light. Studies have shown that in pilot-scale applications, raceway ponds with volumes ranging from 10 to 35 $m^3$ have been successful in treating agro-industrial waste, such as winery effluents and dairy waste, while simultaneously recovering valuable products like PHAs and microbial proteins (Capson-Tojo et al., 2020). The integration of these advanced bioreactor designs with PPB-based systems not only improves the overall productivity and efficiency of the process but also makes it more scalable and adaptable to different types of organic waste.

**Relevance for Georgia.** Georgia's agricultural and food-processing industries are among the leading contributors to organic waste generation in the country, producing large amounts of biomass, food residues, wastewater, and other organic by-products. However, much of this organic waste remains either untreated or is underutilized, leading to environmental pollution and the loss of valuable resources (Mario Martin-Gamboa et al., 2023). These waste streams include materials like fruit and vegetable scraps, whey from dairy production, and animal manure from livestock operations, all of which have the potential to be converted into valuable bioresources. The agricultural and food-processing industries in Georgia, particularly in Kakheti and Samtskhe-Javakheti, produce significant quantities of organic waste as part of their regular operations. Kakheti, known for its extensive vineyards and wineries, generates large amounts of organic waste, including grape pomace, skins, and seeds, which often remain unused or improperly disposed of. Similarly, Samtskhe-Javakheti, with its rich history in dairy farming and livestock production, generates considerable volumes of effluents and organic by-products from these industries. In many cases, this waste is either dumped into the environment or used inefficiently, contributing to pollution and missed opportunities for resource recovery.

Purple phototrophic bacteria (PPB) present an innovative and sustainable alternative for converting these organic wastes into valuable bioresources. PPB-based technologies can be utilized to treat and valorize agro-industrial wastes in a variety of ways, making them ideal candidates for waste-to-resource applications. For example, PPB can be deployed in small-scale bioreactors designed to treat organic waste effluents from the winery, dairy, and livestock industries. By utilizing the metabolic flexibility of PPB, these industries can treat their wastewater in a way that not only reduces the environmental impact of their operations but also recovers valuable products such as biohydrogen, microbial proteins, and bioplastics. The use of bioreactors offers a decentralized, cost-effective solution that can be implemented locally to avoid the high costs associated with transporting waste to central treatment plants. In regions like Kakheti, where wine production is a key industry, PPB can effectively break down the complex organic compounds in winery wastewater and produce renewable bioresources that can be reintegrated into the production cycle (Srivastava, P. et al., 2024).

Additionally, the relatively high annual solar irradiance in both Eastern and Western Georgia makes the deployment of photobiological processes especially favorable. The combination of abundant sunlight and the phototrophic capabilities of PPB creates an energetically viable system for waste treatment and resource recovery. PPB, being photosynthetic organisms, can utilize light as an energy source, which reduces the need for external energy inputs. This characteristic makes them particularly well-suited for regions with high solar exposure, such as Georgia, where the climate provides ample sunlight for photobiological processes. As a result, PPB-based technologies not only offer environmental benefits but also provide an energy-efficient alternative to conventional waste treatment methods, reducing operational costs and increasing overall sustainability (Ciani, M. et al., 2024).

Furthermore, Georgia's existing wastewater treatment infrastructure offers a strategic advantage for implementing PPB-based systems. Many of Georgia's municipalities face challenges related to nitrogen and carbon removal in wastewater treatment plants. Existing infrastructure could be retrofitted with PPB systems to address these challenges, improving the efficiency of nutrient removal while also enabling the recovery of valuable bioresources. Nitrogen and carbon compounds are often difficult to remove from wastewater using conventional treatment methods, but PPB have the ability to degrade these pollutants efficiently while simultaneously producing valuable products. By integrating PPB into the existing infrastructure of wastewater treatment plants, municipalities can not only meet regulatory requirements for wastewater quality but also contribute to the development of a circular economy, where waste is transformed into valuable resources that can be reused within the local economy (Manikanta M. Doki et al., 2024). This retrofitting approach reduces the cost and complexity of implementing new technologies, making it a more feasible solution for municipalities struggling with outdated or overburdened treatment systems.

**Isolation and Adaptation of Local Strains.** To ensure effective bioreactor performance, the local adaptation of PPB strains is a key factor in optimizing their efficiency for specific applications. In Georgia, various natural sources such as sludge, ponds, and riverbanks have been identified as rich habitats for phototrophic microbial communities, which could serve as a source for the isolation of PPB strains. These environments, often abundant in organic matter, provide ideal conditions for the growth of diverse microbial populations, including those capable of performing phototrophic processes. Natural sources like riverbanks and ponds, where organic waste and nutrients accumulate, create a suitable environment for the proliferation of phototrophic microorganisms. Studies have shown that such microbial communities are not only diverse but also highly adapted to local environmental conditions, making them valuable for the isolation of native PPB strains that can thrive in Georgia's specific climate and agricultural context (J.R. Almeida et al., 2023). In the context of Georgia's rural regions, where agro-industrial waste is prevalent, these natural habitats are particularly abundant and accessible, providing an invaluable resource for local biotechnological applications.

Isolation techniques play a critical role in selecting the most effective strains for bioreactor systems. Traditional methods of isolation include selective anaerobic culturing under infrared light, which helps to promote the growth of PPB strains that are adapted to anaerobic environments, commonly found in agricultural and industrial waste streams. Additionally, the enrichment of samples with organic acids or sulfides has proven effective in stimulating the growth of PPB species, as these organisms are known to metabolize a wide range of organic compounds. This selective culturing process ensures the enrichment of highly efficient and robust strains capable of thriving in the nutrient-rich but often complex and contaminated waste environments typical of agro-industrial effluents. The use of selective enrichment techniques also improves the likelihood of isolating strains that possess superior metabolic capabilities, enabling them to degrade pollutants while producing valuable by-products such as biohydrogen or bioplastics. These methods not only enhance strain performance but also make the isolation process more efficient and cost-effective for large-scale applications (Ali Moradvandi et al., 2024).

Furthermore, genomic and proteomic profiling of native strains offers an advanced approach for identifying and selecting high-performing isolates suited for specific biotechnological applications. By analyzing the genetic makeup of PPB strains, researchers can pinpoint key traits and metabolic pathways that contribute to the bacteria's ability to efficiently degrade pollutants, recover bioresources, and produce valuable compounds. Proteomic profiling, which involves analyzing the proteins expressed by these strains under various conditions, further aids in understanding the mechanisms of metabolism, pollutant degradation, and energy production within the bioreactor systems. These advanced molecular techniques allow for a more targeted selection process, ensuring that only the most effective strains are used in bioreactor systems, thereby optimizing overall system performance. The integration of these methods has the potential to significantly enhance the efficiency and sustainability of PPB-based biotechnologies (Sara Díaz-Rullo Edreira et al., 2024).

In addition, the use of mixed-culture systems has been shown to be particularly effective in optimizing PPB performance in bioreactors. In such systems, PPB can be combined with other microbial species to create a more robust and resilient microbial community capable of treating a wider range of waste substrates. Mixed-culture systems are especially advantageous for handling complex waste streams, as they allow for the synergistic interaction between different microbial species. The optimization of these systems involves the promotion of PPB dominance by adjusting factors such as light regimes, feedstock pre-treatment, and nutrient control. By fine-tuning these environmental parameters, researchers can enhance the growth and activity of PPB while suppressing competing microorganisms that may not be as effective at degrading pollutants or producing valuable by-products. Furthermore, the flexibility of mixed-culture systems allows for their adaptation to different waste streams, enabling the treatment of a variety of organic and inorganic pollutants. As such, the optimization of mixed-culture systems is a crucial step in the development of sustainable PPB-based waste treatment and bioresource recovery technologies (Abbas Alloul et al., 2023).

**Environmental and Economic Assessment.** While laboratory and pilot studies have shown that PPB-based systems hold great potential, the large-scale application of such technologies in Georgia requires a comprehensive life cycle assessment (LCA) and techno-economic analysis (TEA) to evaluate their viability. These studies are crucial in determining whether the advantages observed in small-scale studies can be replicated at larger scales, taking into account local conditions such as climate, waste characteristics, and existing infrastructure. Preliminary LCA results have suggested that PPB systems have favorable energy balances and carbon footprints when compared to conventional wastewater treatment methods, highlighting the potential of PPB for sustainable waste management. In particular, PPB-based technologies offer an energy-efficient alternative to traditional treatment, with a reduced reliance on chemical inputs and a lower overall environmental impact. LCA also reveals the potential for PPB systems to contribute to the circular bioeconomy by recovering valuable by-products such as bioplastics, biohydrogen, and biofertilizers while treating agro-industrial waste. Such systems could significantly reduce the environmental burden associated with conventional treatment methods, making them an attractive option for Georgia's green development agenda (Sakarika et al., 2019; Hassan Azaizeh et al., 2022).

For Georgia, implementing a modular rollout of PPB-based waste valorization units at municipal or industrial nodes presents an exciting opportunity to stimulate green jobs and significantly reduce pollution. These small-scale units could be deployed at various locations, including agricultural hubs and food-processing centers, where waste generation is high. Such localized solutions would not only reduce transportation costs but also ensure that the technologies are directly aligned with the regions' waste characteristics. Additionally, the modular nature of the systems means they can be scaled up gradually, minimizing the financial risk and making them adaptable to varying operational needs. The integration of these systems would align with EU-aligned environmental policies, supporting the country's commitment to sustainability and climate goals. Moreover, PPB-based technologies could create new avenues for economic growth, particularly in rural areas, by generating local employment opportunities in bioreactor operation, maintenance, and waste management. As a result, these systems would contribute to the economic development of rural communities, promoting sustainable agricultural practices and reducing environmental degradation in line with EU standards (María del Rosario et al., 2024).

The techno-economic analysis (TEA) of PPB-based systems in Georgia should consider a range of factors to evaluate their long-term economic feasibility. One of the key elements in this analysis is the cost of photobioreactors, which can vary significantly depending on the design, size, and materials used. Additionally, seasonal light variability plays a crucial role in the efficiency of photobioreactors, especially in Georgia, where sunlight intensity and duration fluctuate throughout the year. These variations can impact the overall biomass productivity and the economic viability of the systems, requiring adjustments to operational strategies and possibly additional energy inputs during the winter months. Another important aspect of the TEA is the potential revenue from the valuable by-products that PPB can produce, including bioplastics, hydrogen, and biofertilizers. These by-products not only provide a sustainable source of income but also have high demand in the global market, enhancing the profitability of PPB-based technologies. Therefore, a detailed TEA will help optimize operational parameters and ensure that the implementation of PPB systems can be both economically viable and aligned with environmental objectives (Moia I. C. et al., 2024).

**Challenges and Future Directions.** Key barriers to the large-scale implementation of PPB-based biotechnologies include challenges such as low awareness among stakeholders, lack of standardized measurement protocols, and various technical difficulties associated with scaling up bioreactors. Despite the clear advantages that PPB technologies offer for waste valorization and sustainable development, there remains a gap in understanding and acceptance in certain sectors. Low awareness limits the allocation of resources and development of supportive frameworks. The lack of standardized measurement protocols complicates the assessment and comparison of PPB systems across different regions and applications, creating a barrier to the widespread adoption of these technologies. Without standardized frameworks, it becomes difficult to ensure consistency in performance evaluations, which can deter stakeholders from supporting large-scale deployments. Furthermore, technical difficulties in scaling up bioreactors present a challenge for moving from laboratory studies and small pilot projects to commercial-scale operations. The complexities of bioreactor design, light distribution, and nutrient control must be optimized for larger systems to achieve consistent and efficient results at scale. Addressing these challenges requires collaboration between researchers, engineers, and industry leaders to develop cost-effective and scalable solutions (Luciano Bosso et al., 2024).

However, despite these obstacles, there has been significant progress in overcoming some of the barriers through global collaboration. Global networks like PurpleGain have played a pivotal role in harmonizing metrics and fostering interdisciplinary collaboration among researchers, industry experts, and practitioners. Through platforms like PurpleGain, information exchange, research collaboration, and joint initiatives have enabled standardization of key performance indicators for PPB-based technologies, facilitating more accurate and comparable data across studies. These efforts have also helped raise awareness about the potential of PPB for wastewater treatment, bioremediation, and the circular bioeconomy, especially in countries with emerging interest in these technologies. By promoting interdisciplinary collaboration, PurpleGain has ensured that experts from different fields—such as biotechnology, environmental engineering, and industry—work together to advance PPB research and commercial application. This collaboration is crucial for overcoming the technical and practical challenges that have thus far slowed down the implementation of PPB-based solutions (Marta Cerruti et al., 2023).

For Georgia, the establishment of a national research program focused on PPB technologies could serve as a catalyst for innovation. With support from EU and local grants, such a program could help accelerate research and development, ensuring that Georgia stays at the forefront of green biotechnology. This initiative could also address the barriers related to awareness and standardization, bringing together researchers, and industry stakeholders to create a cohesive framework for PPB application in the country. Furthermore, cross-sector collaborations between universities, municipalities, and industries are vital to unlocking the full potential of PPB biotechnologies. Universities can lead in terms of research, strain isolation, and bioreactor optimization, while municipalities can provide real-world applications and serve as pilot sites for testing these technologies. Industries, particularly those in the agro-industrial and waste management sectors, can help scale up the technology and bring it to market. By working together, these sectors can ensure that PPB-based solutions are developed in a way that is both scientifically sound and economically viable, contributing to Georgia's sustainable future and circular economy goals.

**Conclusion.** Purple phototrophic bacteria (PPB) represent a transformative and highly promising technology that could significantly drive Georgia's sustainable development agenda forward. These bacteria, due to their remarkable metabolic flexibility, can be applied in various waste-to-resource systems, offering potential solutions to environmental problems that are currently facing the country. Their application can reduce environmental burdens by efficiently treating agro-industrial wastewater, converting organic waste into valuable bioresources such as bioplastics, biohydrogen, and microbial proteins. By integrating PPB into waste management systems, Georgia could lower its reliance on traditional, energy-intensive waste treatment methods, thus reducing the environmental impact of industries, especially in agriculture, food processing, and energy production.

Furthermore, the widespread adoption of PPB-based technologies could have profound socio-economic benefits for Georgia's rural economies. These technologies can support rural development by providing new income streams through waste valorization and the creation of green jobs in bioreactor operations, waste management, and the emerging bioeconomy sectors. Rural areas, where agro-industrial waste is often underutilized, could greatly benefit from PPB systems that offer a sustainable method to convert organic waste into valuable products. This would enhance local economies by creating new industries, fostering entrepreneurship, and improving the livelihoods of rural populations. Additionally, as PPB technologies are scalable, they could be deployed in small- to medium-sized operations, making them accessible even to smaller municipalities and agricultural businesses.

By adopting PPB technologies and integrating them into a circular bioeconomy framework, Georgia would not only be addressing its environmental and economic challenges but also aligning with global climate goals. The technologies could contribute to the reduction of greenhouse gas emissions, improvement of carbon and nutrient cycles, and promotion of renewable energy. This approach is particularly aligned with the broader goals of global sustainability that aim for reduced waste, enhanced resource recovery, and minimized environmental degradation. As climate change mitigation becomes increasingly important on the global stage, Georgia's early adoption of such transformative technologies would position it as a forward-thinking leader in the region.

However, realizing the full potential of PPB in Georgia requires strategic investment in key areas, such as local strain isolation to ensure the adaptation of PPB to Georgia's unique environmental conditions, the deployment of bioreactors that can optimize the performance of these bacteria, and increased public engagement to raise awareness about the benefits of these technologies. By fostering public-private partnerships, supporting research in local academic institutions, and securing EU and international funding, Georgia can accelerate the development of PPB-based solutions. Local research centers can play a key role in leading the development of PPB strains and bioreactor optimization, while industry collaboration will be critical for scaling up these technologies.

**ლიტერატურა – References - Литература**

1. Abbas Alloul, Naïm Blansaer, Paloma Cabecas Segura, Ruddy Wattiez, Siegfried E. Vlaeminck, Baptiste Leroy Dehazing redox homeostasis to foster purple bacteria biotechnology, Trends in Biotechnology, Volume 41, Issue 1, 2023, Pp 106-119, https://doi.org/10.1016/j.tibtech.2022.06.010
2. Ali Moradvandi, Edo Abraham, Abdelhak Goudjil, Bart De Schutter, Ralph E.F., LindeboomAn identification algorithm of switched Box-Jenkins systems in the presence of bounded disturbances: An approach for approximating complex biological wastewater treatment models, Journal of Water Process Engineering, Volume 60, 2024, https://doi.org/10.1016/j.jwpe.2024.105202
3. Cao, Y., Xu, H., Han, Y., & Wang, D. (2020). Production of microbial protein by purple non-sulfur bacteria using wastewater: A review. *Bioresource Technology*, 319, 124164. https://doi.org/10.1016/j.biortech.2020.124164
4. Capson-Tojo, G., Ruiz, D., Moscoviz, R., Santa-Catalina, G., Bernet, N., & Trably, E. (2020). Purple phototrophic bacteria for resource recovery: Challenges and opportunities. *Biotechnology Advances*, 43, 107567. https://doi.org/10.1016/j.biotechadv.2020.107567

5. Ciani, M., Vargas-Estrada, L., Adessi, A., Muñoz, R., Influence of Digestate Dilution on Carbohydrate and Pigment Content During Biogas Upgrading Coupled with Nutrients Recovery by Parachlorella Hussii N9 and Cyanothece Sp. Ce4, 2024, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5043375
6. Csiki, Z., Balázs, M., Tóth, A., & Varga, L. (2018). Metabolic pathways in purple phototrophic bacteria: An overview. *Hungarian Agricultural Engineering*, 34, 5–10. https://doi.org/10.17676/HAE.2018.34.5
7. Fukuzumi, S., Kotani, H., Ohkubo, K., Ogo, S., Tokunaga, M., & Kasuga, K. (2018). Mechanisms of photosynthetic electron transfer in purple bacteria. *Coordination Chemistry Reviews*, 355, 54–73. https://doi.org/10.1016/j.ccr.2017.10.007
8. Guzman, M. S., Rengasamy, K., & Bose, A. (2019). Biological production of hydrogen by purple non-sulfur bacteria: Process optimization and applications. *Renewable and Sustainable Energy Reviews*, 113, 109246. https://doi.org/10.1016/j.rser.2019.109246
9. Hassan Azaizeh, Hiba Nazmi Abu Tayeh, Roland Schneider, Joachim Venus, Pilot Scale for Production and Purification of Lactic Acid from Ceratonia siliqua L. (Carob) Bagasse, Fermentation 2022, 8(9), 424; https://doi.org/10.3390/fermentation8090424
10. J.R. Almeida, E. Serrano León, E. Lara Corona, J.C. Fradinho, A. Oehmen, M.A.M. Reis, Ammonia impact on the selection of a phototrophic - chemotrophic consortium for polyhydroxyalkanoates production under light-feast / dark-aerated-famine conditions, Water Research, Volume 244, 2023, https://doi.org/10.1016/j.watres.2023.120450
11. Luciano Bosso, Melisa Olave, Maeva Gabrielli, Multidimensional conservation gaps and indications in seahorses, Conference: Biodiversity positive by 2030 At: Bologna, DOI: 10.6092/unibo/amsacta/7995, 2024, https://www.researchgate.net/publication/386376039_Multidimensional_conservation_gaps_and_indications_in_seahorses#fullTextFileContent
12. Manikanta M. Doki, Arun Kumar Mehta, Debkumar Chakraborty, Makarand M. Ghangrekar, Brajesh K. Dubey, Abbas Alloul, Ali Moradvandi, Siegfried E. Vlaeminck, Ralph E.F., LindeboomRecovery of purple non-sulfur bacteria-mediated single-cell protein from domestic wastewater in two-stage treatment using high rate digester and raceway pond, Bioresource Technology, Volume 413, 2024, https://doi.org/10.1016/j.biortech.2024.131467
13. María del Rosario, Jose Antonio Magdalena, Jean-Philippe Steyer, Renaud Escudié, Gabriel Capson-Tojo, Potential of enriched phototrophic purple bacteria for H2 bioconversion into single cell protein, Science of The Total Environment, Volume 908, 2024, https://doi.org/10.1016/j.scitotenv.2023.168471
14. Mario Martin-Gamboa, Luis D. Allegue, Daniel Puyol, Juan Antonio Melero, Javier Dufour, Environmental life cycle assessment of polyhydroxyalkanoates production by purple phototrophic bacteria mixed cultures. Journal of Cleaner Production Volume 428, 2023, https://doi.org/10.1016/j.jclepro.2023.13942
15. Marta Cerruti, Guillaume Crosset-Perrotin, Mythili Ananth, Julius Laurens Rombouts, David G. Weissbrodt, Syntrophy between fermentative and purple phototrophic bacteria to treat and valorize carbohydrate-rich wastewaters, Bioresource Technology Reports, Volume 22, 2023 https://doi.org/10.1016/j.biteb.2023.101348
16. Moia I. C., Kanaropoulou A., Ghanotakis, D, Carlozzi P., Touloupakis E., Photofermentative hydrogen production by immobilized Rhodopseudomonas sp. S16-VOGS3 cells in photobioreactors, Energy Reviews, Volume 3, 2024, https://doi.org/10.1016/j.enrev.2023.100055
17. Puyol, D., Batstone, D. J., Hülsen, T., Astals, S., Peces, M., & Krömer, J. O. (2017). Resource recovery from wastewater by biological technologies: Opportunities, challenges, and prospects. *Frontiers in Microbiology*, 7. https://doi.org/10.3389/fmicb.2016.02106
18. Sakarika, M., Angelidaki, I., & Fotidis, I. A. (2019). Purple phototrophic bacteria and photosynthetic systems for resource recovery from wastewater. *Bioresource Technology*, 274, 268–278. https://doi.org/10.1016/j.biortech.2018.11.063
19. Sara Díaz-Rullo Edreira, Ioanna A Vasiliadou, Amanda Prado, Juan José Espada, Ruddy Wattiez, Baptiste Leroy, Fernando Martínez, Daniel Puyol, Elucidating metabolic tuning of mixed purple phototrophic bacteria biofilms in photoheterotrophic conditions through microbial photo-electrosynthesis, Commun Biol., 2024, 18;7(1):1526. https://doi.org/10.1038/s42003-024-07188-0
20. Semenov, A. Y., Melkozernov, A. N., & Blankenship, R. E. (2011). Light-harvesting in photosynthetic bacteria: Efficiency, regulation, and adaptation. *Biochimica et Biophysica Acta (BBA) - Bioenergetics*, 1807(9), 1030–1039. https://doi.org/10.1016/j.bbabio.2011.03.010

21. Srivastava, P., Villamil, J.A., Melero, J.A. et al. Using inorganic acids to stop purple phototrophic bacteria metabolism improves PHA recovery at a large scale. Biomass Conv. Bioref. 14, 17693–17703 (2024). https://doi.org/10.1007/s13399-023-03810-z
22. Winans, K., Kendall, A., & Deng, H. (2017). The use of mixed microbial cultures in bioprocessing: Advantages, challenges, and applications. *Journal of Industrial Ecology*, 21(5), 1093–1106. https://doi.org/10.1111/jiec.12571

**უდკ: 628.3; 579.841; 502.174**

**იისფერი ფოტოტროფული ბაქტერიების (PPB) გამოყენება ცირკულარული ბიოეკონომიკისა და ჩამდინარე წყლების ვალიორიზაციისთვის საქართველოში / ნათელა ძებისაშვილი, დარეჯან დუღაშვილი/** სტუ-ის ჰმი-ის შრომათა კრებული-2025.-ტ.136.-გვ.120-127. - ინგ., რეზ. ქართ., ინგლ. რუს.

პროტეობაქტერიების შემადგენლობაში შემავალი მეტაბოლურად მრავალმხრივი ჯგუფი - იისფერი ფოტოტროფული ბაქტერიები (PPB) წარმოადგენენ ბიორესურსების აღდგენის, ჩამდინარე წყლების გაწმენდის და შესაბამისად წრიული ბიოეკონომიკის პერსპექტიულ გადაწყვეტას. ნაშრომში განხილულია PPB-ზე დაფუძნებული ბიოტექნოლოგიების გამოყენების შესაძლებლობები საქართველოს პირობებში. შესწავლის ობიექტს წარმოადგენდა ის, თუ როგორ შეიძლება ადგილობრივ რეალობაზე მორგებული PPB სისტემების ეფექტური დანერგვა. ნაშრომში ასახულია უახლესი საერთაშორისო ინოვაციები და საუკეთესო პრაქტიკა PPB სისტემების განვითარებისა და დანერგვის კუთხით. აგრეთვე განხილულია PPB ტექნოლოგიების ინტეგრირების გზები ნარჩენების მდგრადი მართვისა და განახლებადი ენერგიის სექტორებში საქართველოში.

**УДК: 628.3; 579.841; 502.174**

**Использование пурпурных фототрофных бактерий (PPB) для круговой биоэкономики и валоризации сточных вод в Грузии**/Натела Дзебисашвили, Дареджан Дугашвили/ Труды IHM, GTU. -2025. -т.136. -стр.120-127. - Англ., Рез. Груз., Англ., Рус.

Пурпурные фототрофные бактерии (PPB), метаболически универсальная группа в составе Proteobacteria, предлагают перспективные решения для циркулярной биоэкономики посредством восстановления биоресурсов и очистки сточных вод. В статье рассматривается потенциал биотехнологии на основе PPB в контексте Грузии. Целью исследования было выяснить, как можно эффективно внедрить системы PPB, адаптированные к местным реалиям. В статье отражены последние международные инновации и передовой опыт в разработке и внедрении систем PPB. Также обсуждаются пути интеграции технологий PPB в секторы устойчивого управления отходами и возобновляемой энергетики в Грузии.