Bio. Res. Today 2024, 6(4):148-151

Biotica Research Today

e-ISSN: 2582-6654

April, 2024

Article ID: RT1608 **Popular Article**

Revolutionize Recycling by Genetic Engineered Plastic Eating Bacteria: Prospective and Challenges

Ritika Pradhan, Manaswini Mahalik, Mamali Gantayat, Ankita Rout, Kumudini Bhoi, Sudeepta Mallick, Murchhana Grahacharya*, Manaswini Mahapatra and Jyoti Prakash Sahoo*

Faculty of Agriculture and Allied Sciences, C.V. Raman Global University, Bhubaneswar, Odisha (752 054), India

Open Access

Corresponding Author

Jyoti Prakash Sahoo and Murchhana Grahacharya

: jyotiprakashsahoo2010@gmail.com;
shreemanju2003@gmail.com

Conflict of interests: The author has declared that no conflict of interest exists.

How to cite this article?

Pradhan, R., Mahalik, M., Gantayat, M., *et al.*, 2024. Revolutionize Recycling by Genetic Engineered Plastic Eating Bacteria: Prospective and Challenges. *Biotica Research Today* 6(4), 148-151.

Abstract

The emergence of plastic-eating bacteria represents a significant advancement in biotechnology and offers a potential solution to the global plastic waste problem. These bacteria have naturally evolved to consume polyethylene terephthalate (PET) by producing enzymes like PETase. Scientists have been able to modify and improve the bacteria's enzyme production, turning them into more effective PETase factories by using genetic engineering. This could lead to a more sustainable method of recycling PET plastics, reducing the accumulation in landfills and oceans. Moreover, by breaking down plastic waste, these bacteria could help mitigate the adverse effects on marine ecosystems and human health caused by plastic pollution. However, it is important to note that PETase only decomposes PET plastic and there are other plastic types that remain a challenge. Further research and development are necessary for widespread commercial application of plastic eating bacteria, and to address the full spectrum of plastic waste.

Keywords: *Escherichia coli, Ideonella sakaiensis*, Plastic-consuming bacteria, Polyethylene terephthalate

Introduction

In recent years, the emergence of plastic-eating bacteria has sparked significant interest and hope in addressing the escalating global crisis of plastic pollution (Buranyi, 2023). These remarkable microorganisms possess the extraordinary ability to metabolize and break down various types of plastic, offering a potential solution to the pervasive environmental threat posed by plastic waste (Anonymous, 2023). Amidst this burgeoning field of research, one notable example is *Ideonella sakaiensis*, a gram-negative bacterium discovered in Japan in 2016, named after the city of Sakai where it was found (Ali *et al.*, 2023). It has garnered attention for its capability to degrade polyethylene terephthalate (PET), a common plastic used in beverage bottles and food packaging (Anonymous, 2023).

Furthermore, ongoing research endeavours have unveiled the potential of other bacteria, including those capable of functioning at colder temperatures, expanding the scope of plastic degradation (Buranyi, 2023). These cold-adapted bacteria have demonstrated proficiency in breaking down certain types of plastic, such as low-density polyethylene (PE), offering new avenues for combating plastic pollution in diverse environmental conditions (Ali *et al.*, 2023). Despite the promising advancements, challenges persist, including the limited capacity of certain bacteria to degrade specific types of plastic and the need for further research to optimize enzymatic activity (Buranyi, 2023). Nonetheless, the discovery of plastic-eating bacteria represents a pivotal step towards developing sustainable solutions to mitigate the detrimental effects of plastic pollution on ecosystems worldwide (Anonymous, 2023).

The passage highlights the prevalence of plastic in everyday life, from water bottles to food packaging and electronic devices. It emphasizes the widespread use of plastic and raises the question of what happens to it after its initial purpose is fulfilled (Buranyi, 2023). The ideal scenario is for plastic to be recycled into new products, thus minimizing waste and environmental impact (Ali *et al.*, 2023). The

Article History

RECEIVED on 29th March 2024 RECEIVED in revised form 05th April 2024 ACCEPTED in final form 06th April 2024

reality is starkly different; a significant portion of plastic fails to undergo recycling and instead finds its way into landfills and water bodies, perpetuating environmental degradation (Anonymous, 2023). In this article, the prospective benefits and the inherent challenges associated with the utilization of genetically engineered plastic-eating bacteria, aiming to illuminate both the opportunities and the complexities of this ground-breaking technology are discussed.

The Plastic Predicament

The proliferation of plastic in the environment has reached alarming levels, escalating with each passing year. An astounding 12 million metric tonnes (Mt) of plastic infiltrate the oceans annually, compounding the existing 362 million Mt already present, with 4.1 million Mt originating from Canada alone (Ali *et al.*, 2023). This abundance of plastic poses a grave threat to marine life, constituting a staggering 80% of all marine debris (Anonymous, 2023). Animals such as whales, fish and seabirds ingest plastic waste, leading to severe health complications (Ali *et al.*, 2023). Additionally, other forms of plastic debris pose risks of entanglement or suffocation to marine creatures (Buranyi, 2023). Microplastics exacerbate the issue further, as they detach from larger plastic items and infiltrate the food chain, amplifying the ecological repercussions of plastic pollution (Ali *et al.*, 2023). While there exist numerous benefits to utilizing plastic materials, the predominant drawback lies in their limited biodegradability (Anonymous, 2023).

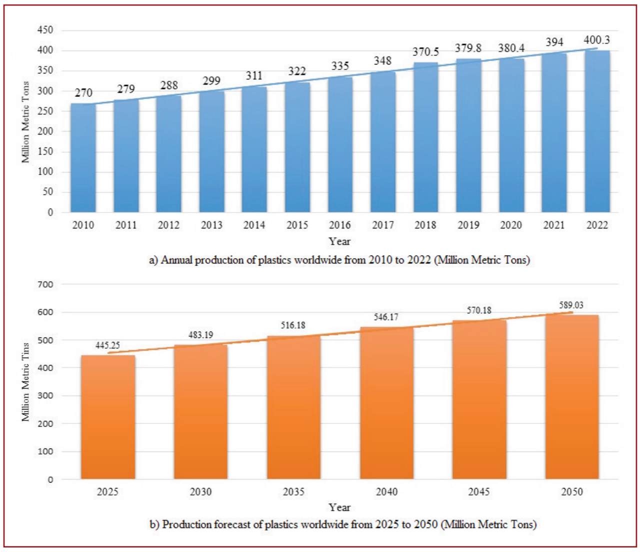

Figure 1: Global plastic production and forecast (Jaganmohan, 2024a; Jaganmohan, 2024b)

Furthermore, in 2022, the worldwide production of plastics surged to an astounding 400.3 million metric tons, reflecting a 1.6% rise from the previous year (Jaganmohan, 2024a) (Figure 1a). Since the 2010, the production of plastics has experienced exponential growth, owing largely to the remarkable adaptability of these materials (Jaganmohan, 2024a). This versatility continually propels production rates upward. Concurrently, the market value of plastics shows a consistent upward trend. Projections indicate that global thermoplastics production will reach 445.25 million metric tons by 2025, with annual volumes expected to ascend in the subsequent decades (Jaganmohan, 2024b). By 2050, production levels are estimated to soar to around 590 million metric tons, constituting a growth of over 30% compared to 2025 figures (Jaganmohan, 2024b). Notably, between 2010 and 2020, global plastics production surged from 270 million metric tons to nearly 370 million metric tons (Jaganmohan, 2024b) (Figure 1b).

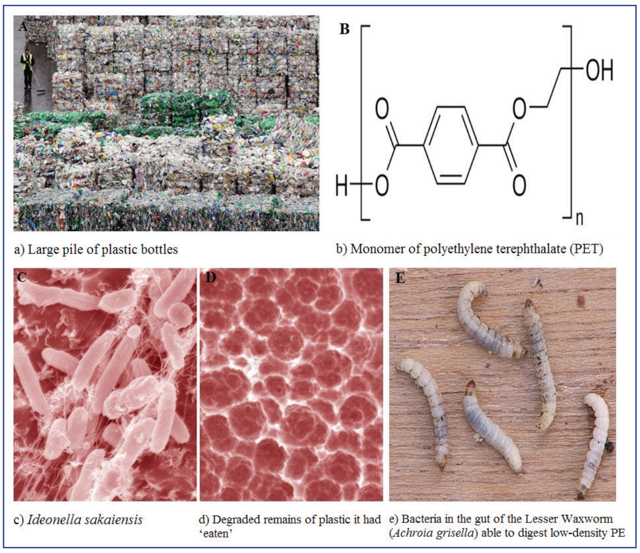

Figure 2: The plastic predicament and finding the plastic eating bacteria (Anonymous, 2023)

Finding the Plastic Eating Bacteria

The proliferation of plastic waste has become a global crisis, posing significant environmental challenges (Figure 2a) (Anonymous, 2023). For instance, an empty jug of laundry detergent discarded into the ocean today will endure for centuries, underscoring the urgent need for innovative solutions to address this enduring issue (Anonymous, 2023). However, *E. coli*'s predilection for sugars hindered its efficacy in breaking down plastic (Ali *et al.*, 2023). In contrast, *Ideonella sakaiensis* exhibits a preference for polyethylene terephthalate (PET) (Figure 2b), a common plastic variant utilized in the production of water bottles and food packaging, showcasing its unique adaptability to degrade this specific plastic compound (Anonymous, 2023).

In March 2016, researchers in Japan stumbled upon a remarkable revelation and they observed that certain bottles within a recycling facility were undergoing degradation, courtesy of bacteria (Anonymous, 2023). This newfound bacterium was subsequently identified and named *Ideonella sakaiensis* (Figure 2c and 2d). This is believed to have naturally developed the capability to metabolize a specific type of plastic as its sustenance (Anonymous, 2023). While scientists have long explored the potential of microorganisms, such as bacteria, to degrade plastic, previous attempts primarily utilized *Escherichia coli* (*E. coli*) bacteria (Jaganmohan, 2024a). Moreover, in February 2023, scientists suggested the answer might be in waxworms (Jaganmohan, 2024b). Waxworms are the larvae of wax moths. The scientists found that bacteria in the gut of the Lesser Waxworm (*Achroia grisella*) (Figure 2e) were able to digest low-density PE (Jaganmohan, 2024b). This kind of plastic is used in things like shopping bags and bubble wrap. While there is still a lot of research to do, it is a promising start (Anonymous, 2023).

Physical and Chemical Attributes of *Ideonella sakaiensis*

Ideonella sakaiensis is a bacterium from the genus Ideonella and family Comamonadaceae capable of breaking down and consuming the plastic polyethylene terephthalate (PET) using it as both a carbon and energy source (Buranyi, 2023). The bacterium was originally isolated from a sediment sample taken outside of a plastic bottle recycling facility in Sakai City, Japan. *Ideonella sakaiensis* is a gram-negative, aerobic bacterium with a rod-shaped morphology (Buranyi, 2023). It is motile, possessing a single flagellum and forms colourless, smooth and circular colonies (Anonymous, 2023). The bacterium typically measures between 0.6 to 0.8 µm in width and 1.2 to 1.5 µm in length. Moreover, *Ideonella sakaiensis* exhibits positive for oxidase and catalase tests. It thrives within a pH range of 5.5 to 9.0, with optimal growth observed at pH 7 to 7.5 (Buranyi, 2023). The bacterium shows growth across a temperature range of 15-42 °C (59-108 °F), with the best growth occurring at temperatures between 30-37 °C (86-99 °F) (Anonymous, 2023).

Decomposing a Plastic Bottle: Under Bacterial Action

Initially, it's crucial to grasp that PET plastic comprises recurring units of $C_{10}H_8O_4$, known as monomers. These monomers possess the ability to undergo chemical reactions with other monomers, resulting in the formation of lengthy chains termed polymers (Buranyi, 2023). Various plastics employ diverse monomers to generate distinct polymer compositions (Anonymous, 2023). The interconnections between the monomers within plastic are exceptionally robust, rendering plastic resilient and enduring (Anonymous, 2023). While natural processes typically only fragment plastic into smaller pieces, they lack the capability to dismantle polymer chains (Anonymous, 2023). In contrast, *Ideonella sakaiensis* possesses the ability to disrupt the bonds between monomers (Anonymous, 2023).

Enzymes play diverse roles in the biological processes of living organisms, accelerating chemical reactions within cells. Among their functions, enzymes commonly facilitate digestion (Anonymous, 2023). Bacterial digestive enzymes operate to disassemble larger molecules into smaller counterparts, which the bacteria can subsequently absorb for sustenance, discarding any surplus. *Ideonella sakaiensis* produces a specific enzyme named hydrolysing PET (PETase), which cleaves the bonds within the polymer, yielding monomers (Anonymous, 2023). These monomers are then assimilated by the bacterium to generate energy (Buranyi, 2023). The natural bacterium can break down a thin (0.2 mm) film of low-crystallinity (soft) PET in about 6 weeks, while high-crystallinity (hard) PET takes more than 3 years to degrade, indicating slower degradation by the PETase enzyme (Buranyi, 2023).

Since much of the manufactured PET is highly crystalline (*e.g.*, plastic bottles), using the *Ideonella sakaiensis* PETase enzyme in recycling programs may require genetic optimization (Anonymous, 2023). The MHETase enzyme, which breaks down MHET produced by PETase into ethylene glycol and terephthalic acid, could also be optimized for recycling or bioremediation (Buranyi, 2023). These compounds can be further degraded into carbon dioxide by *Ideonella sakaiensis* or other microbes, or used to produce new PET in recycling plants. *Ideonella sakaiensis* is under study for its PET degradation capabilities to address water management issues in sewage-fed fisheries (Anonymous, 2023). Different strains of this bacterium have been found to be safe for fish growth (Anonymous, 2023). They efficiently utilize PET as a carbon source and thrive in wastewater and plastic-polluted ecosystems, suggesting cost-effective solutions for pollution control (Buranyi, 2023).

Advancement and Hurdles: Harnessing Bacteria for Plastic Waste Management

At first glance, harnessing bacteria appears as a promising solution to alleviate the burden of plastic waste plaguing the environment. The concept of cultivating *Ideonella sakaiensis* in abundance, introducing it to plastic waste and allowing the bacteria to metabolize it seems appealing (Anonymous, 2023). However, this approach is not without its challenges. The primary hurdle lies in the sheer volume of plastic waste accumulated over time. Throughout the history of plastic production, a staggering 8.3 billion metric tonnes have been generated, with a staggering 79% ending up in landfills or polluting the environment (Ali *et al.*, 2023). This colossal amount will persist until mechanisms capable of breaking it down emerge (Buranyi, 2023).

Additionally, bacterial digestion of plastic occurs at a sluggish pace, exacerbating the efficacy of this approach. Hence, scientists pondered whether there existed a means to accelerate this process (Ali *et al.*, 2023). In 2018, a breakthrough occurred when researchers at the University of Portsmouth deciphered the three-dimensional structure of PETase (Ali *et al.*, 2023). Although this pace remains insufficient to address the entirety of the waste accumulated, it marks a promising initial stride forward. Building upon this advancement, in 2020, scientists at the same institution combined PETase with a similar enzyme, culminating in the creation of a 'super-enzyme' (Ali *et al.*, 2023). Remarkably, this amalgamation facilitated a six-fold increase in the rate of plastic degradation, signifying a significant leap towards more efficient plastic waste management (Buranyi, 2023).

High and Low Temperature Challenges

Another challenge arises due to the temperature requirements for enzyme activity, necessitating environments exceeding 30 °C. Unfortunately, such conditions are limited to specific regions, rendering the heating of bacteria to facilitate plastic digestion prohibitively costly both financially and environmentally (Anonymous, 2023). Fortunately, Swiss researchers have uncovered bacteria capable of metabolizing certain plastics at lower temperatures (Ali *et al.*, 2023). Observing these bacteria's production of enzymes effectively breaking down plastic at 15 °C, they speculate the feasibility of enzyme functionality even in temperatures as chilly as 4 °C (Buranyi, 2023).

Moreover, the drawback of cold-temperature bacteria lies in their limited ability to degrade only specific types of plastic - a common issue among plastic-consuming bacteria. For instance, only bacteria producing PETase can effectively degrade PET plastic, while cold-temperature bacteria are restricted to break down biodegradable plastics like polyester-polyurethane (PUR) (Anonymous, 2023). Meanwhile, numerous everyday items are crafted from polyethylene (PE), a different plastic variant found in shampoo and laundry detergent bottles, as well as plastic buckets and children's toys (Ali *et al.*, 2023). Unlike biodegradable plastics, PE remains resistant to bacterial digestion, posing a significant challenge (Buranyi, 2023). In February 2023, scientists proposed a potential solution involving waxworms, the larvae of wax moths (Buranyi, 2023). Examination of the gut bacteria of Lesser Waxworms (*Achroia grisella*) revealed their capacity to digest low-density PE, commonly utilized in shopping bags and bubble wrap (Buranyi, 2023).

Conclusion

The rise of plastic-degrading bacteria, such as *Ideonella sakaiensis*, presents a promising path for tackling the global plastic waste crisis. Through genetic modifications and enzyme enhancements, scientists have significantly improved the effectiveness of these bacteria in breaking down plastics, especially PET. However, challenges like scaling up bacterial populations, expediting the degradation process and addressing the variety of plastic types persist. Despite these obstacles, the environmental advantages of utilizing plastic-degrading bacteria are substantial, offering optimism for a more sustainable approach to plastic waste management. Continuous research and development are crucial to fully harness the potential of this innovative solution.

References

Ali, S.S., Elsamahy, T., Zhu, D., Sun, J., 2023. Biodegradability of polyethylene by efficient bacteria from the guts of plastic-eating waxworms and investigation of its degradation mechanism. *Journal of Hazardous Materials* 443(Part B), 130287. DOI: https://doi.org/10.1016/j.jhazmat.2022.130287.

Anonymous, 2023. Plastic-Eating Bacteria: Nature's Recyclers. In: *Let's Talk Science*. Available at: https://letstalkscience.ca/educational-resources/backgrounders/plastic-eating-bacteria-natures-recyclers. Accessed on: 25th March, 2024.

Buranyi, S., 2023. 'We are just getting started': the plastic-eating bacteria that could change the world. In: *The Guardian*. Available at: https://www.theguardian.com/environment/2023/sep/28/plastic-eating-bacteria-enzyme-recycling-waste. Accessed on: 25th March, 2024.

Jaganmohan, M., 2024a. Annual production of plastics worldwide from 1950 to 2022 (in million metric tons). In: *Statista*. Available at: https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/. Accessed on: 25th March, 2024.

Jaganmohan, M., 2024b. Production forecast of thermoplastics worldwide from 2025 to 2050 (in million metric tons). In: *Statista*. Available at: https://www.statista.com/statistics/664906/plastics-production-volume-forecast-worldwide/. Accessed on: 25th March, 2024.