The Potential of Marine Bacteria in Plastic Biodegradation: A Review

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Abstract

Ocean plastic pollution has become a significant problem affecting ecosystems and human health. One promising approach to address this issue is biodegradation by marine microorganisms, particularly bacteria. This article reviews recent studies (2021–2024) exploring the ability of marine bacteria to degrade plastics. Based on the research, certain marine bacteria have been proven capable of producing enzymes effective in breaking down various plastics. The article also discusses the challenges and opportunities in developing biotechnology based on marine bacteria to tackle plastic pollution.

1. Introduction

Plastic pollution has become one of the most pressing global environmental challenges, with approximately 8 million metric tons of plastic entering the oceans annually, threatening marine ecosystems and human health by accumulating microplastics in the food chain. Plastics, such as polyethene (PE), polypropylene (PP), and polystyrene (PS), are difficult to degrade due to their complex molecular structures and strong chemical bonds, allowing them to persist in the environment for hundreds of years. Conventional approaches like mechanical recycling and incineration have limitations, including low efficiency and pollutant emissions. Therefore, biology-based solutions, particularly biodegradation using microorganisms, offer a promising alternative due to their environmentally friendly and sustainable nature.

Marine bacteria have shown remarkable potential as plastic biodegradation agents due to their adaptability to extreme environments and ability to produce specific enzymes capable of breaking down polymer bonds. Recent studies reveal that marine bacteria, such as *Vibrio alginolyticus*, *Pseudomonas* spp, and *Bacillus* spp, can degrade various plastics through enzymatic oxidation and hydrolysis processes. A study by Imron et al. (2020) demonstrated that *V. alginolyticus* can degrade complex hydrocarbon compounds, indicating similar potential for plastics. Additionally, Zettler et al. (2021) found that marine bacteria have evolved to produce enzymes like PETase and MHETase, which effectively break down polyethene terephthalate (PET) and other plastics. These enzymes enable bacteria to break down plastics into simpler compounds, such as carbon dioxide and water or fragments that are easier to manage for recycling.

The advantage of marine bacteria lies in their genetic and metabolic diversity, which allows adaptation to various types of plastics in polluted marine environments. Research by Urbanek et al. (2021) showed that consortia of

marine bacteria from deep-sea sediments exhibit higher degradation efficiency compared to single isolates due to synergistic interactions among species. However, challenges such as relatively slow degradation rates, dependence on environmental conditions (temperature, pH, and salinity), and the need for scalable bioremediation infrastructure still need to be addressed.

With the increasing plastic pollution and the urgency to protect marine ecosystems, exploring the potential of marine bacteria as a biodegradation solution is highly relevant. This study aims to delve deeper into the capabilities of marine bacteria in degrading plastics, focusing on enzymatic mechanisms and their applications in managing plastic waste in marine environments.

2. Methodology

This article employs an in-depth literature study approach to collect, evaluate, and synthesize information from relevant written sources. The literature review analyzed scientific articles from indexed and reputable journals, published between 2021 and 2024. The literature search focused on the keywords: microplastics, marine bacteria, and biodegradation. Article selection was based on relevance to the study topic and the novelty of the information presented.

3. Result and Discussion

Several studies have identified marine bacterial communities capable of degrading various plastics. These findings highlight the potential of individual bacterial species and provide insights into the effectiveness of specific enzymes and the synergistic roles within microbial communities. A summary of recent research describing the relationship between bacterial species, types of degraded plastics, and involved enzymes can be seen in Table 1.

Table 1. Marine Bacteria as Plastic Degraders

No	Bacterial species	Types of plastic degraded	Enzyme produced	Research findings	Reference
1	*Vibrio natriegens*	PET (Polyethylene terephthalate)	*Is*PETase, *ls*MHETase	Engineered *V. natriegens* can depolymerise PET particles (<300 μm) in saline (seawater-like) media over 7 days.	Li et al. (2023)
2	*Alcanivorax xenomutans, Marinobacter sediminum, M.gudaonensis, Thalassospira xiamenensis, Nocardioides marinus*	PET (Polycarbonate terephthalate)	MHET dan TPA	Capable of degrading PET up to 1.8% within 30 days of incubation	Zhao et al. (2023)
3	*Ideonella sakaiensis*	PET (Polycarbonate terephthalate)	PETase	*I.sakaiensis* produces the PETase enzyme to degrade waste, with results 5-120 times faster.	Shi et al. (2021)
4	*Bacillus tropicus, B.cereus, Stenotrophomas acidaminohila, Brucella pseudintermedia*	PP (Polypropylene)	Protease Lipase Esterase	Significant weight loss of polypropylene microplastics was observed after 28 days of exposure to bacterial strains.	Jeyavani et al., (2024)
5	*Pseudomonas* sp, *Pandoraea* sp, *Dyella* sp,	PHB (Polyhydroxybutyrate) PE (Polyethene) PHA (Polyhydroxyalkanoate)	Extraculler and Intraseluler	After 30 days, the highest weight loss was observed in PHB (13.4%), PE (13.0%), and PHA (12.7%). Degradation half-	Ren & Ni (2023)

				life ($t_{1/2}$) of microplastics ranged from 67-116 days, with PHB being the most degradable (67.98 days) and PA the least (115.6 days)	
6	*Gordonia* sp, *Novosphingobium* sp,	EPS (Expanded polystyrene)	Hydrolase	In laboratory conditions, EPS degradation ranged from 2.7% to 7.7% after one month. Degradation rates may be lower in natural (in situ) environments.	Liu et al. (2023)
7	*A. xenomutans, Halomonas titanicae*	PS (Polystyrene)	Extraculler	Both bacteria degraded PS, producing microplastics and nanoplastics over 30 days of incubation with 10 mg PS film at 28°C.	Lv et al. (2024)

Based on Table 1, research on marine bacteria in the context of plastic biodegradation has shown rapid development over the past three years. Studies indicate that *V.natriegens*, engineered to express *ls*PETase and *ls*MHETase from *I.sakaiensis*, exhibits the most prominent PET degradation efficiency in marine environments, attributed to its rapid growth rate and adaptability to high salinity (Li et al., 2023). This whole-cell biocatalyst system successfully hydrolysed PET into its main monomers, terephthalic acid (TPA) and ethylene glycol (EG), from both model substrates (BHET) and micro-sized PET particles. Zhao et al. (2023) reported that several bacteria, including *A. xenomutans*, *M. sediminum*, *M. gudaonensis*, *T. xiamenensis*, and *N. marinus*, were successfully isolated and confirmed to degrade PET. Four main strains were further tested and proven to cause a 1.3%–1.8% PET weight loss after 30 days of incubation. Analysis of degradation products revealed the presence of MHET and TPA monomers, indicating PET depolymerization. Shi et al. (2021) stated that the PETase enzyme from *I. sakaiensis* 201-F6 demonstrates higher hydrolytic activity and specificity for PET compared to other enzymes at room temperature. *I. sakaiensis* can secrete PETase to degrade waste approximately 5–120 times faster. Biodegradation engineering techniques can facilitate waste decomposition, such as cloning and transforming PETase-encoding genes in *Escherichia coli*.

Jeyavani et al. (2024) reported that during the biodegradation process (28 days), the growth, metabolic activity, and viability of *B. tropicus*, *B. cereus*, *S. acidaminophila*, and *B. pseudintermedia* all increased. Post-biodegradation, the weight loss percentage of PP MP treated with bacterial strains gradually decreased, with values of 51.5±0.5%, 47.5± 0.5%, 33±1%, 28.5±0.5%, and 35.5±0.5%, respectively. UV-Vis DRS and SEM analyses confirmed that bacteria adhering to MP caused cracks and cavities on its surface. PP MP degradation was inferred from changes in FT-IR spectra, particularly in the carbonyl group range of 1100–1700/cm, and changes in 1H NMR spectra, including chemical shifts and altered proton peak patterns. Bacterial strains facilitated PP MP degradation by secretion of protease, lipase, and esterase enzymes, classified as hydrolases.

Ren & Ni (2023) noted that, with domestication advancements, *Pseudomonas* sp, *Pandorae*a sp, and *Dyella* sp thrived in mixed strains. The possible degradation mechanism involves microbial aggregates adhering to the MP surface, forming complex biofilms, secreting extracellular and intracellular enzymes, breaking hydrolyzable chemical bonds or molecular chain ends by attacking MP

molecular chains, and producing monomers, dimers, and other oligomers, leading to a reduction in MP molecular weight.

Liu et al. (2023) identified *Gordonia* sp and *Novosphingobium* sp as potential PS degraders due to their ability to form colonies on EPS surfaces and utilize EPS as a carbon source. In laboratory conditions, EPS degradation rates ranged from 2.7 to 7.7% after one month. These rates may be lower in natural (in situ) environments. ATR-FTIR analysis indicated polymer oxidation in PS, marked by the appearance of C-H stretching and/or aldehyde groups in the 1000–2000/cm range, suggesting chemical changes due to bacterial activity. Lv et al. (2024) reported that *A. xenomutans* and *H.titanicae*, in PS degradation, produced microplastics and nanoplastics during 30 days of incubation with 10 mg PS film at 28°C. *A. xenomutans* mineralized 4.5% of PS, while *H. titanicae* mineralized 1.9%. However, 1.3% (*A. xenomutans*) and 1.9% (*H. titanicae*) of PS remained as microplastics and nanoplastics. Microplastic sizes decreased over time, from approximately 1344–1480 nm (day 3) to 496–614 nm (day 30), indicating a transition to nanoplastics (<1 µm). Bacterial degradation accelerated microplastic formation compared to mechanical abrasion, with rougher microplastic surfaces due to extracellular enzymes and oxidation.

4. Conclusion

Marine bacteria offer a promising and eco-friendly solution to tackle ocean plastic pollution. Various bacterial species have been found capable of degrading different types of plastics. Marine bacteria hold significant potential as plastic biodegradation agents due to their ability to produce polymer-degrading enzymes and adapt to harsh marine environments. However, challenges such as slow degradation rates and environmental optimization must be addressed for practical applications. With advancements in biotechnology and interdisciplinary approaches, marine bacteria could become a key solution in combating ocean plastic pollution, supporting marine ecosystem preservation and environmental sustainability.

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