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Impact of Microbial Communities on Microplastic Degradation in Aquatic Environments

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ABSTRACT

Microplastics are pervasive pollutants in aquatic environments, posing significant risks to marine life and human health. Microbial communities, including bacteria, fungi, and other microorganisms, have emerged as crucial agents in the degradation of microplastics. This paper reviews the role of microbial communities in the breakdown of microplastics, examining the mechanisms of microbial degradation, the influence of environmental factors, and the impact of microbial diversity on degradation efficiency. The study highlights the potential of biofilm-forming microbes and engineered microbial consortia in enhancing microplastic degradation. Moreover, it explores the application of microbial communities in bioremediation strategies aimed at mitigating microplastic pollution in aquatic ecosystems. The findings underscore the importance of understanding microbial ecology to develop effective approaches for managing and reducing microplastic contamination in water bodies.
Keywords: Microplastics, Microbial degradation, Aquatic environments, Biofilm, Bioremediation.

INTRODUCTION

Microplastics are tiny petrochemical particles found in water that have harmful effects on aquatic life and potentially humans. They are difficult to remove due to their size and properties. Microbial degradation is a promising method for reducing the mass and toxicity of these pollutants. Understanding microbial activity in relation to microplastic pollution is crucial for managing water bodies and protecting aquatic resources [1, 2, 3]. The microbial communities, including bacteria, archaea, fungi, viruses, and other microorganisms, inhabiting aquatic ecosystems have adapted to utilizing nutrients and energy from organic debris, including dead animals and plants, algae exudates, and engineered organic matter. Microbial communities may also include special microorganisms, termed biofilm formers, which colonize microplastics more easily than other microbes. In aquatic environments, microplastics have been hypothesized to aid in spreading contamination through microbial communities over long distances and to change the ecological structure of diverse aquatic species. By applying the existing knowledge of microbial ecology, biodegradable plastics, such as polyhydroxyalkanoates and polylactide, have been extensively produced using engineered microbes, and further converted microbial plastics to energy resources with concurrent waste treatment effects [4, 5].

ROLE OF MICROBIAL COMMUNITIES IN BIODEGRADATION OF MICROPLASTICS

Microplastics (MPs) are recognized as contaminants in the environment and have also been studied for their effects on human health, posing a serious threat. Therefore, there is an urgent need to clarify the fate, effects, and behavior of MPs in this world. Generally, MPs can be degraded by physical factors (e.g., heat and light) and chemical factors, producing smaller fragments over time. Organisms, particularly microbes, have also been reported to damage and fragment MPs or polymers over time. In this review, the role of microbial communities as MPs in aquatic environments was summarized. It is possible to use this information to develop strategies for the biological degradation of MPs for their removal or collection [6, 7]. Based on metadata analysis, microorganisms play a crucial role in degrading microplastics (MP). They adhere to and degrade MP particles or release enzymes to break them down. Microorganisms easily utilize MP as an energy source for growth and reproduction. Through hydrolysis, smaller compounds are produced. Bacteria, actinomycetes, and fungi utilize these compounds in energy metabolism. Understanding the ecological mechanisms of MP degradation can help develop strategies to efficiently remove MPs [8, 7].

MECHANISMS OF MICROBIAL DEGRADATION OF MICROPLASTICS

Microbial degradation efficiently removes MPs from the environment. Various biochemical and biological processes, both inside and outside microbial cells, degrade MPs. Enzymes such as lipases, proteases, and alpha-hydroxylases catalyze hydrolysis, oxidation, and reduction reactions. Nuclease enzyme activity has been found in seawater with polystyrene nanoparticles. Microorganisms attach to plastic particles through the organic layer and colonization by wood microbes [9, 10]. Microbial communities are capable of directly excreting extracellular enzymes which are, in fact, the initial step for the decomposition of different materials, such as microplastics. The extent of the degradation of the microplastics directly depends on the concentration of the enzymes: the higher the concentration, the lower the molecular weight of the organic fragment. Several research studies examined the effect of the microbial communities on the degradation of microplastics in aquatic environments. Since anaerobic degradation of ester-based plastics has received limited attention, quantitative research is necessary to validate their ecological impact on marine plastic biodegradation [11, 12].

FACTORS INFLUENCING MICROBIAL DEGRADATION OF MICROPLASTICS

There are wider influences from various additional factors that decide whether unplanned or planned microplastics will be degraded in aquatic environments. Some of these factors are directly related to the degradation capacity of the microbial community, such as higher microbial diversity or use of consortia with complementary metabolic abilities. On the other hand, there are also abiotic factors that can decide whether or not microplastics will be degraded by their corresponding microbial communities. These are often more general factors, but others could possibly be applied specifically to bioplastics. Moreover, a range of other factors related to environmental conditions, ecological parameters, and others may influence the efficiency of the biodegradation process [13, 14]. In summary, many factors influence the extent to which microbial communities degrade microplastics in aquatic environments, which can be classified into biotic (physical, chemical) and abiotic factors. Given the above description, to improve the efficiency of the biodegradation of micro- and nanoplastics in aquatic environments, it is advisable to optimize the frequently investigated biotic factors shaping microbial community functions, particularly diversity and composition. However, in order to better promote the desired process, it may be good to also take into account some of the elements influencing the physical properties, both of the communities and the aquatic systems [13, 4, 13].

ENVIRONMENTAL CONDITIONS

The degradation of plastics can occur directly through the action of microbes, which release plastic-degrading enzymes. It can also happen over time due to surface area effects. Microbial activities are influenced by environmental conditions such as temperature, pH, oxygen, and nutrient availability. Therefore, the microbial degradation of microplastics is influenced by both micro and macro-environmental factors during the initiation of colonization and the subsequent microbial colonization processes [15, 6, 6]. Comparing plastic biodegradability in different environments determines how the environment affects degradation. Microplastics made from various polymers may degrade on surfaces with few plastic-degrading microbes. Polymer degradability depends on initial degradation potential. Microbes have specific conditions and growth rates leading to distinct colonization and biofilm formation. The effectiveness of biodegradable plastics depends on microbial communities. Understanding biofilm structure development and microbial activities allows for engineered plastic substrates in the environment. This applies to biofilms in wastewater and marine coatings and their resistance to bio-fouling in water activities [16, 17, 13].

MICROBIAL DIVERSITY AND COMPOSITION

DYNAMICS OF MICROBIAL COMMUNITY UNDER DIFFERENT MICROPLASTIC TREATMENTS

In general, higher microbial diversity in resin-enriched microbial communities was associated with increased biodegradation after five weeks of incubation. However, there was variation in the ability of different microbial communities to degrade different types of plastics. The process of matching the plastic to the most suitable microorganisms is under investigation [18, 19]. Due to the high diversity and abundance of PMM in the polyethylene-incubating enrichment culture and the potential role of CAM to mediate dyed low-density polyethylene, a possible reaction in the growth of dyed low-density PMM was shown after four weeks. In addition, the community of the enrichment culture was the most diverse in these communities after 9 months of treatment. This indicates that highly tolerant bacteria and communities with versatile metabolism (further supported by metagenomics data) can be selected. The ecological principles of the microbial community, which are vis-a-vis the change, have a high potential in the degradation of microorganisms due to their rich biology in relation to biodegradation [20, 21, 22].

THE ROLE OF MICROBIAL COMMUNITIES AND MICROBIAL SPECIES

INDIVIDUAL MICROBIAL SPECIES/CONSORTIA WITH A HIGH CAPACITY TO DEGRADE MICROPLASTICS

A suite of bacterial strains with the ability to degrade low-density, linear low-density, and high-density polyethylene and polystyrene were isolated and identified. Aerobic consortia composed of multiple microbial species that showed cooperative co-metabolism could degrade PS and PE, reducing water surface tension. In addition, increased enzymatic activity was observed during biofilm formation [23, 24]. Five different bacterial strains of Comamonas testosteroni, Pseudomonas citronellolis, Dietzia natronolimnaea, Motorithrix salvanivorans, and Pontibacter korlensis were found to degrade PET, although exposure to low-weight fragments of PET potentially affects newborn growth and mammalian rxr transcription factors involved in the endocrine signaling pathway. Moreover, the degradation of polyester was unknown [25, 26]. An aerobic microbial community was isolated from sandy beach sediments, which showed the release of CO_2 from a 14C-labeled polymer and the biodegradable loss of polymer-coated 14C-PS films, while isolated and mixed beach communities showed the consumption of 14C-PS powder. No large differences were observed between microbial communities tested in PS mineralization at 28 and 8 C at night at mesophilic temperature, while in cold conditions a significant result was obtained. The role of the convincing community in the biomineralization of the polymer was unknown.

APPLICATIONS OF MICROBIAL COMMUNITIES IN MICROPLASTIC REMEDIATION

Rising water population pressure and the wide use of plastics are responsible for the daily input of microplastic particles from urban and industrial wastewater. The quantity of microplastics is expected to increase due to the high vaporization of debris and longer accumulation. As one of the best natural recyclers, the microbial population may aid in coping with this issue of microplastics. Bioremediation strategies use the metabolic activities of microorganisms to break down and eliminate hydrophobic pollutants from ecosystems. This section focuses on approaches that leverage the microbial community to address the dilemma of microplastics [27, 28, 29]. Several techniques have been suggested to improve the effectiveness of bioremediation. For microplastic removal from water bodies, various methods have been recommended and implemented, showing that microbial remediation is possible. Current research is analyzing naturally existing biofilms and their efficiency in managing microplastics. In situ strategies could reinforce naturally occurring communities for microplastic management. Available data suggests the potential use of microbial populations in resolving microplastic contamination. Biofilm treatment is an effective technology for removing microplastics from aquatic systems. Understanding local society's applications is crucial for developing profitable solutions for microplastic pollution in water bodies [8, 30, 10].

CONCLUSION

The degradation of microplastics in aquatic environments by microbial communities offers a promising solution to the growing problem of plastic pollution. Understanding the complex interactions between microplastics and microbial communities is crucial for developing effective bioremediation strategies. The ability of microbes to colonize and degrade microplastics, influenced by environmental factors and microbial diversity, plays a critical role in the overall efficiency of the degradation process. Future research should focus on optimizing microbial consortia and biofilm-forming species to enhance microplastic breakdown. Additionally, in situ applications of microbial communities in natural water bodies could provide sustainable and scalable solutions to reduce the ecological and health impacts of microplastic pollution

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