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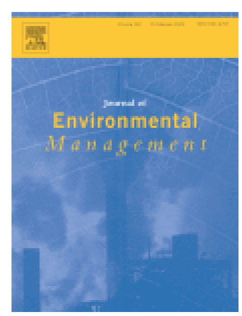

Enhanced microbial degradation of PET and PS microplastics under natural conditions in mangrove environment

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Abstract

In-situ bioremediation of mangrove soil contaminated with polyethylene terephthalate (PET) and polystyrene (PS) microplastics was investigated using indigenous microbial consortium with adequate capacity to degrade the plastics. Eight (8) bacteria were isolated from plastic/microplastic-inundated mangrove soil and screened for the ability to degrade PET and PS microplastics. Optical density at 600 nm and colony forming unit counts were measured to evaluate the growth response of the microbes in the presence of PS and PET microplastics at different times of exposure. Structural and surface changes that occurred post biodegradation on the microplastics were determined through EDS and SEM analysis. The obtained results demonstrated the elongation and disappearance of peaks, suggesting that the microbial consortium could modify both types of microplastics. The overall results of the microplastic degradation showed varied degrees of weight loss after 90 experimental days, with the treated plot recorded 18% weight loss. The augmented soil was increased in the concentrations of Si S, and Fe and decreased in the concentrations of C, O, Na, Mg, Al, Cl, and K after bioremediation.

Introduction

Plastics are pervasive and slow-degrading polymers in environmental waste, whose application has been augmented over the past few years due to their combined features of light weight, strength, flexibility, low cost and easy production (Wilkes et al., 2017; Stagner, 2016). With extensive application of plastics, around 49% of gross manufacture is devised for single-use packaging (Regusa et al., 2021), thus accentuating the importance of plastic disposal, primarily low- and high-density polyethylene (LDPE and HDPE), polystyrene (PS), and polyethylene terephthalate (PET) (Peixoto et al., 2017). Recycling of polyethylene is not economically viable as the cost associated with the production of plastics is lesser than the cost associated with recycling (Tolinski, 2012). Therefore, a large amount of such plastics is discarded after use, thus increasing the quantity of plastic wastes in the environment (Álvarez-Barragán et al., 2016).

More than 250,000 tons of plastic debris (over 5 million plastic items) have been discovered afloat at sea (Eriksen et al., 2014), with a considerable amount entering the marine environment from different sources, including industrial and urban effluents, sewer overflows, atmospheric deposition, rivers, run-offs, direct inputs, and the uncontrolled disposal of waste (Tolinski 2012). Plastics are moved by currents, and they aggregate in areas of low water movements. Considerable aggregations of floating plastic debris were first reported in the North Pacific Ocean (Moore, 2008; Moore et al., 2005; Eriksen et al., 2014). Similar scenarios have been reported in other oceans, including the North Atlantic (Lusher et al., 2014), South Pacific, and Indian Ocean (Eriksenet al., 2014). Among plastic debris, microplastics (plastic items that are less than 5 mm in diameter) are of particular concern in terms of the environment, human health, and animal health (Barboza*et al.*, 2018).
Microplastics are global contaminants of special concern that have been ubiquitously detected in sediments (Zamprogno et al., 2021), water, sea salt (Kosuth et al., 2018), marine biota (Berlino et al., 2021), food stuff (Barboza et al., 2018), atmosphere (Brahney et al., 2021), and sewage sludge. The microplastics present in the aquatic environment result from the breakdown of microplastic debris (secondary microplastics) or from primary microplastics (those intentionally manufactured for use).

Microplastic problem has received increased attention over the last few years, and while a significant number of studies have documented the distribution, quantification, fate, sources, and pathways and the ingestion of microplastics by aquatic biota has increased, few studies have been carried out on the degradation of microplastics. The landfill disposal of plastics and incineration release a huge quantity of CO_2 and increase global warming (Eriksson and Finnveden, 2009). Bioremediation using biological agents, such as bacteria, fungi, and algae, has been reported to be the best method to reduce plastic wastes in an eco-friendly manner (Pathak, 2017). Synthetic biodegradable polymers (such as polyesters and starch-based polymers) are associated with major problems, including higher cost and durability than synthetic polymers, such as polyethylene, polypropylene, PS, and PET (Leaversuch, 2002; Leja and Lewandowicz, 2010). Polyethylene is non-biodegradable due to its hydrophobic character, which limits the diffuseness of water and other enzymes, acids, and bio-surfactants produced by microorganisms. The use of additives, such as antioxidants and stabilizers, during the production process and higher molecular weight makes polyethylene non-biodegradable (Albertsson and Banhidi, 1980; Zheng et al., 2005; Koutny et al., 2006; Krueger et al., 2017). Otake et al. (1995) observed partial biodegradation of polyethylene film in moist soil over a period of 32 years. Tribedi and Sil (2013) reported that polyethylene persists in the environment for a longer period as it is not susceptible to microbial attack due to the absence of functional groups. Abiotic factors, such as temperature, UV, and chemical treatments, must be considered prior to the biodegradation process for highly resistive materials, such as polyethylene, because of their hydrophobic nature and large molecular weight (Koutny et al., 2006).

Biostimulation popularly called indigenous bioremediation is mainly related to the addition of nutrients to stimulate biodegradation by the indigenous microorganisms. Studies reported that the slow biodegradation rate of microplastics leads to their breakdown in smaller size hence increasing their persistence in the environment. On the other hand, the usage of stimulants and inducers could help in increasing the enzyme activities to enhance the microplastics degradation rate. For instance, Satti et al. (2018) stimulated the native microbial community using 0.2% sodium lactate (Satti et al., 2018). The author reported the increase in the mineralization rate of PLA (24%) in the soil at ambient temperature for 150 days. Moreover, the author also suggested further optimization with a stimulant to further increase the degradation rate and reduce the degradation time. In general, bioaugmentation is mainly involved in using pure and/or consortia polymer-degrading cultures and the addition of genetically engineered microorganisms to increase the biodegradation activities (Kalogerakis et al., 2015). Recently, efforts to isolate microbial consortia and/or pure cultures from microplastics have occurred in marine/terrestrial habitats to design possible site-specific tailored bioaugmentation strategies for increasing microplastics biodegradation. Interaction between the microorganisms and the surface of microplastics and the biochemical changes confirmed the potential use of bioaugmentation.

In the present study, microbes formulated in the treatment were indigenous mangrove bacteria that were enhanced in the laboratory and therefore expected to thrive well and provide better degradative performance when introduced back into the mangrove environment. This study is the first report of a project that aimed to investigate the degradation of microplastics in natural marine environments and gain information on the behavior of the tested microplastics in the presence of physical strength due to tidal inundation and waves. *In-situ* bioremediation of mangrove soil that was artificially contaminated with PET and PS microplastics was investigated using indigenous microbial consortium with adequate capacity to degrade plastics. This manuscript is of great scientific importance for combining laboratory and *in-situ* remediation of plastics with biological technologies. It deals with a real environmental problem in this region. For having been carried out in a region where few reports exist on the bioremediation of microplastics in the mangrove and few studies in the international literature in such environment are available, this study could arouse the interest of the scientific community.

Section snippets

Polymer characterization

For degradation experiments, microplastics were obtained by grating/cutting commercial plastic materials obtained from plastic producing industries made of PET and PS by using a bastard-cut hand file and scissors. The grated plastics obtained were passed through sieves (mesh sizes of 2 mm and 5 mm; mesh no. 60; Chunggye Industrial Mfg., Co., Seoul, Republic of Korea) to screen off larger debris. Each was irradiated for 2 days under ultraviolet rays and stored for further use. The sizes of the

Isolation and identification

A total of Twenty bacteria were isolated from the different mangrove environments. The list demonstrated diverse genera of microbes that included aerobic gram-positive and gram-negative bacteria. The growth patterns were distinctive enough to enhance identification and differentiation into individual isolates. The isolated species belonged to 16 genera of *Bacilli*, 5 genera of Proteobacteria, and one genera of Actinobacteria. The microbes isolated reflected the native bacteria community found in

Author contribution

This work was carried out in collaboration between all authors. Author HSA anchored conceptualization, data curation, formal analysis and funding acquisition. Authors OPA, JDB and SAA handled the Investigation, Methodology and Writing -original draft, writing-review and editing and Project administration while authors VIC, AAH, AZ and SHF took care of resources, software, supervision, validation and visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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- First evidence of meso- and microplastics on the mangrove leaves ingested by herbivorous snails and induced transcriptional responses
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- Bioremediation of microplastics in freshwater environments: A systematic review of biofilm culture, degradation mechanisms, and analytical methods
  2023, Science of the Total Environment

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However, these bacteria originate from nature and animals. For example, Auta et al. (2022) successfully isolated nine bacteria that could degrade PET and PS from 22 bacterial groups isolated from mangrove soils. After 90 d of culture, the weight loss of PET in the experimental group was 18 %, whereas that of PS was 15 %.

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- A review of microplastic pollution in aquaculture: Sources, effects, removal strategies and prospects
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- Migration of microplastics from plastic packaging into foods and its potential threats on human health
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- Research article

  Biodegradation of thermo-oxidative pretreated low-density polyethylene (LDPE) and polyvinyl chloride (PVC) microplastics by *Achromobacter denitrificans* Ebl13
  Marine Pollution Bulletin, Volume 181, 2022, Article 113830

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  Bacterial communities on polyethylene microplastics in mangrove ecosystems as a function of exposure sites: Compositions and ecological functions

Journal of Environmental Chemical Engineering, Volume 10, Issue 3, 2022, Article 107924

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  New insights into the vertical distribution and microbial degradation of microplastics in urban river sediments
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  Biofilm development of *Bacillus siamensis* ATKU1 on pristine short chain low-density polyethylene: A case study on microbe-microplastics interaction
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