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THE MICROPLASTICS EFFECTS AND POSSIBLE BIOLOGICAL SOLUTIONS IN MARINE ENVIRONMENT: A REVIEW

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REVIEW ARTICLE

Abstract

The ubiquitous plastic pollutant, occurring as the microplastic (<5 mm) particles in the marine environments. Pristine regions include ocean in Arctic and Antarctica were observed with the presence of marine plastic pollution contributed by few potential transportation routes. The existence of marine plastic pollution poses severe ecotoxicological and ecological risk to the marine organisms and subsequently compromising human population benefits. Hence, this review aims to discuss about marine microplastics, emphasizing their toxic effects to marine organisms and the possible biological approaches to remove marine microplastic. Several combined toxicity effects contributed from the combination of microplastic and chemical additives (i.e., Polybrominated diphenyl ethers, oxybenzone, chlorpyrifos & glyphosate) were also discussed to highlight the actual presence of these pollutants in the marine plastic polluted sites. Recent studies have suggested the plastic biodegradation as a feasible removal approach, thus the potential exploitation of the microorganisms was reviewed in accordance with the marine plastic pollution.

Keywords:

Microplastic; Marine environment; Plastic pollution; Biodegradation; Marine organisms

INTRODUCTION

In general, plastics are polymers with high molecular weight which can be moldable into various shapes by applying higher temperatures (Eyerer, 2010; Ahmed et al., 2018). The mouldability property in plastics allows them to be shaped when soft and hardened to a rigid and elastic form, thus supporting the economic demand in global markets. To date, most of the commodity productions (i.e., party decorations, child entertainments, food packaging materials, textile fabrics, electronic appliances and automotive) is highly dependent on plastic polymers, notably in reducing the production costs due to its low weight, high durability and better conveniency (Andrady, 2017; Philips, 2017; Heidbreder et al., 2019). The huge global plastic production in 2018 (i.e., almost 360 million tons per year) was about 12 million tons greater than in 2017. The extensive use of plastics raises environmental threats to the surrounding organisms along with the well-being of human populations, hence the existing era was recognized as 'Plastic Age' (Thompson et al., 2009; Andrady, 2017). Few studies reported on the high robustness of plastics that makes them highly resilient to be broken down or removed, contributing global plastic pollutions in the environments with persisted toxic effects (Pruter, A.T. 1987; Yoshida et al., 2016; Austin et al. 2018). Consequently, coastal and marine environments are the frequent victims of plastics pollution originated from the human activities (Vince and Hardesty, 2017; Critchell et al., 2019). Haward (2018) suggesting that the major contribution in marine plastic pollution is from the land–based sources which travel and contaminate the marine environments. These plastics were accumulated on the sea floor (94%), and near the shorelines (5%), while little of them will stay on the ocean surface (1%) (Carney Almroth and Eggert, 2019). The marine environments were exposed to different groups of tiny plastics, including polyethylene (PE), polycaprolactone (PCL), polyurethane

(PUR), polyhydroxybutyrate (PHB), polyhydroxyalkanoate (PHA), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polybutylene succinate (PBS), polylactic acid (PLA), polypropylene (PP), and polystyrene (PS) (Ahmed et al., 2018). Among them, microplastics such as PE, PP, PS, and PVC are non-biodegradable, posing harmful environmental concerns to the marine ecosystem. Furthermore, worst scenarios in marine environments were spotted when these tiny plastics (i.e., PE and PS) conjugated with other hazardous pollutants (i.e., heavy metals, pesticides, and polycyclic aromatic hydrocarbons), leading to the detrimental effects for the marine biota as compared to the microplastics alone (Auta et al., 2017; Guzzetti et al., 2018; Sørensen et al., 2020).

MARINE MICROPLASTICS: ITS TOXIC EFFECTS TO MARINE ORGANISMS

To date, the biological effects of tiny plastics particles on marine organisms are partially understood as those effects tend to be species-specific (Reichert et al., 2018). Few studies suggested that marine organisms ingest microplastics which then block and accumulate in their gastrointestinal tract to give false signal of satiation that causes starvation, leading to bad growth and corrupted body conditions (Jabeen et al., 2018; Wang et al., 2020). In a study with mysid shrimp (*Neomysis japonica*), Wang et al., (2020) reported the PS microplastics were accumulated in several organs (i.e., brain, stomach, gastrointestinal tract and liver), leading to low food intake and causes insufficient nutrients as well as deaths due to disruptive hunting activities contributed by low swimming movements and toxins. Besides that, disruption of internal digestive system, abnormal hormone levels and reproduction capability of marine organisms were disrupted due to toxic effects of the ingested microplastic (Mak et al., 2019). For instances, adult zebrafish (*Danio rerio*) were reported to have several abnormal behavioral activities identified after the exposure of virgin PE microplastics for 4 days, including erratic swimming and strange tail bending upward/downward that reduce the swimming abilities in zebrafish and raise survival concerns. Other toxic effects in adult zebrafish were also recognized such as the deposition of toxic by–product, sulfur oxide which damages the digestive guts due to the upregulated cytochrome P450 1A gene, while the compromised oogenesis activity which eventually change all male zebrafishes to female zebrafishes due to overexpressed vitellogenin gene that interferes the endocrine hormone.

Microplastics can also induce inflammation in cells and organs by stimulating the production of reactive oxygen species (ROS) (Parolini et al., 2020; Murano et al., 2020). A study conducted by Parolini et al. (2020) reported a significant oxidative stress found in clam gills after the PET microplastic exposure. This event was due to the inhibited antioxidant enzyme (i.e. glutathione peroxidase, GPx gene) in gills, leading to severe lipid peroxidation on their cell membranes as well as other cellular components, and producing inflamed cells and organs at the end of treatments.On the other hand, few studies focused on the combined effect posed by different conjugated pollutants involving microplastics and toxic chemical additives (i.e. Polybrominated diphenyl ethers, oxybenzone, chlorpyrifos & glyphosate) (Gu et al., 2020; O'Donovan et al., 2020; Bellas and Gil, 2020). By referring to the actual marine plastic polluted sites, plastic particles tend to adsorb some persisted chemicals found in water environments, which subsequently ingested by marine organisms, leading to more severe ecotoxicological effects on them as compared to the microplastic pollutant alone (Auta et al., 2017). This concern has raised a research interest to elucidate the actual effect posed by the chemical additive and microplastic on marine organisms. Few studies reported on the adverse effect of microplastic with or without chemical pollutants on aquatic organisms were documented in Table 1, respectively.

POSSIBLE REMOVAL OF MARINE MICROPLASTICS BY BIOLOGICAL APPROACHES

Marine microplastic pollutions pose an emerging threat to the wildlife and subsequently compromise benefits of the human population as it gives rise to ecotoxicological and ecological risks. In addition, the rate of microplastics entering the environment succeeded the rate of removal due to enormous usage by the consumer annually. Thus, the widespread of marine plastic pollutants leads to the huge research interest in exploring various applicable removal treatments to remedy plastic pollutants from water bodies, hence decreasing its bioavailability and toxic effects to the marine organism. Several methods have been proposed include membrane technology, advanced filtration system, electrical–coagulation and chemical coagulants. However, it was established that these tiny plastic particles generally are highly persistent in nature, smaller in size and low visibility which these contribute to the difficulty in manual–based treatment (Auta et al., 2017). Besides that, chemical methods were cost expensive (i.e., frequently replace cathode and anode due to passivation & high electricity cost) and may raise poisonous threats to the treatment site as toxic lead– and aluminum–based coagulants were used to coagulate the microplastic particles (Padervand, 2020). Therefore, a more feasible approach could be utilized by exploiting microorganisms that are capable in degrading microplastic polymers since it is environmentally friendly, low costs and highly applicable in different environments. Biodegradation is a process in which microorganisms are used to break down synthetic plastic polymers. Biodegradation is feasible due to the possibility of plastic particles to serve as a sole carbon and energy supply to plastic degrative microbes. Several studies highlighted the potential utilization of microbes in plastic

Table 1. The adverse effects of microplastics combined with other toxic chemicals on marine organisms

Organisms	Microplastic (MP)		Contaminant		Exposure time	Toxic Effects	Reference
	Size (diameter)	Concentration	Type	Concentration			
MP Type: PS							
Marine mussel (*Mytilus coruscus*)	2 µm	0–2.5 µg/L	Polybrominated diphenyl ethers, BDE–47	0–10 µg/L	21 days	The combined effect of MP and BDE-47 led to some events such as elevated respiration rate, higher expression rate for acid phosphatase, alkaline phosphatase and reactive oxygen species. In overall MP has exaggerates the effect of BDE-47, mainly affecting the defense mechanisms and cellular metabolism.	Gu et al., 2020
MP Type: LDPE							
Shell clam (*Scrobicularia plana*)	11–13 µm	1 mg/L	Oxybenzone, BP–3	82 ng/g	14 days	Gills were the major affected site associated with abnormal biomarker modification. The adsorption of BP3 on MP caused a significant oxidative attack and damage when compared to the sole MP treatments. High genotoxic level (i.e., DNA damage) also contributed by the combination of BP3 and MP.	O'Donovan et al., 2020
MP Type: High Density PE, HDPE							
Marine copepod (*Acartia tonsa*)	2–10 µm	100 mg MP/L	Chlorpyrifos, CPF	100 mg CPF/L	24 h	HDPE served as a vector to increase the bioavailability of CPF to the marine copepod. Significant lethal effects were identified where the presence of HDPE–CPF has contributes to a great amount (i.e., > twenty–fold) of toxic effects as compared to single treatment of CPF alone., leading to high mortality rate.	Bellas and Gil, 2020
MP Type: PE & PET							
Planktonic crustacean (*Daphnia magna*)	2.09 µm	0.01 mg dry weight/mL	Glyphosate, Gly	2.5 mg/L	7 days	The exposure of MP has significantly increased the mortality rate in planktonic crustacean contributed by Gly–acid (i.e., 40.8% for PE & 17.5% for PET) and Roundup Gran (i.e. 14% for PE & 10.7% for PET), respectively, while slightly decreased with Gly–IPA.	Zocchi and Somaruga, 2019

remediation by showing considerably decrease in dry weight of microplastics and stimulate physiochemical alterations. These studies mainly focused on the frequently found microplastics include PE, PP & PS which were correlated to their abundancy in current plastic polluted site. For instances, Auta et al. (2018) reported the degradation of PP microplastic by *Bacillus* sp. strain 27 (i.e., 4.0% decrease in dry weight of PP after 40 days) and *Rhodococcus* sp. strain 36 (i.e., 6.4% decrease in dry weight of PP after 40 days) isolated from mangrove sediments. In addition, the deterioration half-life study (i.e., time to decrease amount of PP by half) showed shorter half-life of 346 days in *Rhodococcus* sp. strain 36 while isolates 27 recorded with a longer half-life of 693 days.

To date, several plastic degrative strains isolated from various sources have been proposed include *Pseudomonas aeruginosa* E7, *Streptomyces albogriseolus* LBX-2, *Acinetobacter* sp. and *Bacillus gottheilii*, highlighting their potential remediator for plastic pollutants especially on PP, PE, PS and PET, respectively (Jeon and Kim, 2015; Auta et al., 2018; Shao et al., 2019; Wang et al., 2020). Although most studies focused on single strain plastic degradation, yet few studies explored the plastic degrative ability in microbial consortium due to their emerging applications in the environmental pollution research (Pattanasuttichonlakul et al., 2018). The emerging microbial consortium has been applied in petroleum hydrocarbon degradation due to its higher catabolic removal ability contributed by varied enzymatic responses which eventually enhances the diesel degradation as compared to the single bacterial strain (Chaudhary and Kim, 2019). Thus, the research oppurtunity by utilising microbial consortium has gained attention in the removal of various environmental pollutants, especially on microplastics. Park and Kim, (2019) reported a relatively higher PE microplastic degradation was observed in bacterial consortium (i.e., 14.7% decrease in dry weight of PE after 60 days & 22.8% decrease in PE microplastic diameter) retrieved from a landfill. In the study, the dorminant species existed in the bacterial consortium was identified as *Bacillus* sp. and *Paenibacillus* sp., in which they found these significant colonized bacteria on PE surfaces that further deteriorate the microplastics supported by the result from SEM, FTIR and Gas Chromatography Mass Spectrophotometry (GC-MS). Besides bacteria, fungus also one of the potential plastics degrative microorganisms which has been proposed in recent times. For instances, Paco et al., (2017) highlighted a marine fungus (*Zalerion maritimum*) can be served as a tool of plastic bioremediation where it recorded more than 43% removal rate of PE microplastic after 14 days. They examined the biological compounds (i.e., higher carbohydrate level & lower protein concentration) gradually with time, in which these results disclose a probability of *Z. maritimum* utilized PE microplastic as their carbon uptakes. Similarly, Zhang et al. (2020) reported the fungus (*Aspergillus flavus* strain PEDX3) isolated from the intestines of wax moth (*Galleria mellonella*) displayed an efficient deterioration of HDPE microplastic, giving a mass loss of 3.90 ± 1.18% after 28 days. Noteworthily, the plastic degrative gene study suggesting the potential plastic bioremediation in *A. flavus* strain PEDX3 was contributed by the up-expression of two laccase-like multicopper oxidases (i.e., AFLA_006190 & AFLA_053930) which catalyze oxidative cleaving on plastic polymers and increase its eliminatory efficiency. Thus, fungus might be an interesting remediator on plastic pollutants, yet more clarifications are needed to understand the toxicity effects of these microplastic particles on fungus and the possible ecological concerns after the fungus bioremediation to the treated sites.

CONCLUSION

The microplastics widespread in the marine environments was contributed by the huge consumption of commercial plastic products in a yearly basis. The accumulation of microplastics on the seawater surfaces or condensed into the marine sediments, posing ecotoxicological threats to the amrine organisms due to high susceptibility of accidental ingestion events. The dominance of PE, PS, PP and PET microplastics were reported in the marine environments, leading to severe deteriorations on the physiological conditions and rendered the survival rates in marine organisms. Although there were few studies focused on the toxic effects posed by the microplastic (i.e., with or without chemical additives) on marine organisms, yet most biological effects were partially understood as these microplastics tend to act distinctly on different marine organisms, which are known as species–specific. More investigations are needed by exploring the effects of microplastics on a broader range of marine animals, and such information is beneficial in understanding the actual role played by each microplastics in the aquatic organisms. There is an urgent need to find a suitable remediation approach in removing these toxic marine plastic pollutants. Many removal treatments have been proposed, yet recent studies supported the emerging bioremediation application by exploiting the plastic degradative ability in the microorganisms. This promising method seems to be feasible in marine environments mainly due to their low operational cost, environmentally safe and diversify applicability (i.e., in–situ or ex–situ treatments). By comparison, microbial consortium has higher plastic degradative potential probably due to their diverse enzymatic abilities and possession of the various catabolic pathways when compared to single strain bacterial. Fungus also one of the feasible plastics remediators contributed by their high degradation rate and the ability to use plastics as their sole carbon sources.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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