

Mechanism and effect of microplastics toxicity in aquatic system

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Abstract. In recent years, the increasingly serious plastic waste pollution has gradually become a global problem. Microplastics (MPs) as an emerging pollutant has received attention. MPs are toxic to humans and many other organisms, and they can accumulate in organisms and amplify their toxic effects through the food chain, thus causing damage to marine biodiversity. Moreover, the seafood provided by the ocean is an important source of food for human beings, and MPs accumulated in fish and crustaceans may be ingested by human beings and cause damage to the digestive system, immune system, respiratory system, nervous system and reproductive system. With the increasing severity of marine plastic pollution, the effect of MPs on aquatic organisms should be of greater concern. By analyzing *in vitro* or *in vivo* experimental studies on microalgae, corals, and fish, the effects of MPs on microalgae photosynthesis, coral growth, and fish growth and reproduction were investigated, as well as the oxidative stress induced by MPs in these organisms. It is hoped that it will help people to understand the harmful effects of MPs on aquatic organisms from these three organisms, so that the toxic effects of MPs can be taken seriously.

Keywords: microplastics; aquatic organism; toxic effect; oxidative stress.

1. Introduction

Plastics are synthetic organic polymers formed by the polymerization of monomers. Their simple production conditions and low processing costs enable them to be produced in large quantities, and they are widely used around the world because of their lightweight nature, durability and corrosion resistance. Despite the convenience of the production process and utilization, the disposal of plastic waste is still a challenge. The large-scale development of the plastics industry has led to the accumulation of plastic debris on land and in the oceans, even in the polar regions. A large amount of plastic waste is currently dumped in landfills or in the environment, but the most widely known disadvantage of plastics is that they are difficult to degrade naturally, leading to continuous environmental pollution [1]. The massive accumulation of plastic waste has become a major environmental problem, making it one of the major environmental pollutants today. Plastics in the environment can be broken down into smaller particle sizes.

Among them, microplastics (MPs) are a hot research topic in recent years. MPs are not only found in plants and animals, but also can be detected in the gastrointestinal tract and feces of human beings, so their harmful effects on the ecosystem are the focus of discussion [2]. MPs usually refer to synthetic polymer particles with a diameter of less than 5 mm. The more common ones currently include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS) and acrylonitrile-butadiene-styrene copolymer (ABS) [3]. MPs can be found in the effluent from some industrial processes, and plastics can be broken down by microorganisms or external forces to MPs, which are able to penetrate into the soil or enter the water column and are absorbed by organisms through the respiratory tract and they can be accumulated in the gastrointestinal tract, the liver, and the heart of the organisms and be passed on through the food chain [3]. Studies have shown that MPs entering cells not only affect the cellular organelles and their normal physiological activities, but also trigger cellular stress responses, leading to the overproduction of reactive oxygen species and the production of cytokines related to inflammatory response, which in turn affect ATP synthesis and trigger inflammatory responses in tissues [4]. MPs also accumulate in the gastrointestinal tract, liver, lungs and kidneys, causing damage to these organs and affecting the normal physiological activities of each

organ [1, 4]. MPs in the liver cause inflammatory reactions, affecting lipid metabolism and protein metabolism [1]. In the gastrointestinal tract, MPs cause a decrease in the secretion of mucus, which can cause a certain degree of disruption of the intestinal mucosal barrier, and disrupt the balance of intestinal bacteria, and cause impaired digestive function or damage to the intestinal flora [2]. In the lungs, MPs also induce the expression of pro-inflammatory factors and apoptosis-related proteins, leading to inflammatory responses and lung tissue damage or fibrosis [3].

Marine plastic pollution has been under constant scrutiny in recent years due to the increasing amount of plastic waste entering the oceans and the extremely slow degradation rate of plastics, which has resulted in large amounts of plastic debris on the coasts, seabed and ocean surface. In the marine environment, external forces such as ocean currents and ultraviolet light can easily lead to further decomposition of plastic debris into MPs, which can be dispersed with ocean currents in water bodies around the world. These MPs can be easily ingested by various aquatic organisms in the water and produce toxic effects. The objective of this research is to discuss and summarise the results of the existing reviews and studies to reveal the effects of MPs on aquatic organisms and their possible mechanisms from three directions, including microalgae, coral and fish.

2. Sources of MPs

MPs can be categorized into two types. Primary MPs refer to indirect or direct use as raw materials for polymer goods, and they are commonly used in household goods such as facial cleansers and toothpaste [5]. Secondary MPs commonly produced from larger plastic fragments, and they are formed by the breaking, cracking and gradual deterioration of larger plastic fragments [5]. MPs enter the environment in a variety of ways. Since sewage treatment systems are not effective in removing MPs from sewage, primary microplastics can enter water bodies directly through industrial or domestic sewage and accumulate in rivers, lakes and oceans [6]. Larger plastic fragments will be gradually decomposed into secondary MPs due to external forces. For example, plastic fragments floating in the ocean will become fragile and gradually decompose under the combined effect of ultraviolet light irradiation and the mechanical force of ocean currents to form smaller plastic particles [7]. These MPs accumulated in the environment can be easily ingested during biological feeding and further accumulated in the organisms.

3. Effect of MPs on the aquatic system

3.1. Microalgae

Microalgae are very important primary producers in aquatic ecosystems and generally contain chloroplasts that are capable of photosynthesis, thus producing organic matter and releasing oxygen and playing a key role in maintaining the balance of aquatic ecosystems [8]. At the same time, microalgae have the characteristic of being sensitive to pollutants, so they are also widely used as bioindicators of pollution in aquatic environments [8]. However, this characteristic also leads to microalgae being very susceptible to MPs.

The existing research showed the growth of microalgae was inhibited after reaching a certain concentration of PS MPs in environment [9]. Chlorophyll fluorescence revealed the effect of PS particle size on the photoconversion efficiency (F_v/F_m) of the photochemical reaction centers of the microalgae, which decreased with increasing PS particle size, especially at a PS particle size of 2 μm , where the F_v/F_m of the algae was only 43% of the control group. Humic acid (HA) was used to investigate the toxicity mechanism of PS of different sizes, and the results showed that HA could reduce the toxicity of small-sized PS (0.1 μm and 0.5 μm) on microalgae and restore their fluorescence parameters (OJIP parameters) to normal levels. However, it had no effect on microalgae under the influence of large particle size PS (1 μm and 2 μm), and the OJIP parameters of microalgae exposed to 2 μm PS changed more compared to those exposed to 0.1 μm PS. Small particle size PS would be adsorbed on the surface of microalgae in a large amount, thus affecting the material

exchange between microalgae and the environment. The above studies illustrate that different particle sizes of polystyrene microplastics (PS MPs) produce different mechanisms of influence on microalgae, with smaller sized MPs adsorbing on the surface of microalgae and decreasing the fluidity of the cell membrane. Larger MPs will cause obstruction to the process of light absorption by microalgae and affect their photosynthesis.

The possible mechanisms of growth inhibition and toxic effects caused by MPs on microalgae has been developed [10]. At the initial stage of the experiment, the growth of microalgae in the environment of nylon MPs was significantly inhibited, and the higher the concentration of MPs, the higher the growth inhibition of microalgae. The contents of two major pigments, chlorophyll a and carotene, of the microalgae also decreased compared with the control group. The research investigated the oxidative damage caused by nylon MPs by detecting changes in two antioxidant enzymes, SOD and GPX, and the lipid peroxidation marker malondialdehyde (MDA). MPs cause the overproduction of reactive oxygen species (ROS). SOD is capable of converting radical superoxide to H_2O_2 , and SOD is able to convert radical superoxide into H_2O_2 to eliminate the excess ROS, and GPX is able to eliminate the H_2O_2 produced in this process, thus realizing the antioxidant effect. The oxidative stress caused by MPs resulted in a significant increase in the SOD activity of the microalgae, whereas the activity of GPX showed a trend of increasing and then decreasing with the increase of exposure time, indicating that the presence of MPs inhibited the activity of antioxidant enzymes. The decrease in GPX activity would result in incomplete elimination of H_2O_2 , which would in turn cause oxidative damage to the cellular structure of the microalgae. The MDA content of microalgae exposed to MPs increased significantly compared to the control group, proving that MPs induced lipid peroxidation in the membrane, leading to membrane damage. Transcriptomic analysis of microalgae further revealed the toxic effects of MPs. The results showed that nylon MPs led to the dysregulation of the expression of genes such as TCA cycle and photosynthesis in microalgae, which in turn affected the normal physiological activities of microalgae. Although exposure of microalgae to low concentrations of MPs did not cause long-term growth inhibition, this may lead to sustained damage to microalgae by MPs.

3.2. Corals

Coral reefs provide food and habitat for a wide range of aquatic organisms and are an important link in marine biodiversity. Coral reefs also play an important role in dispersing wave energy and reducing coastal erosion, acting as natural coastal barriers. With the increasing pollution of the oceans by plastics, the toxic effects of MPs on corals have come under scrutiny.

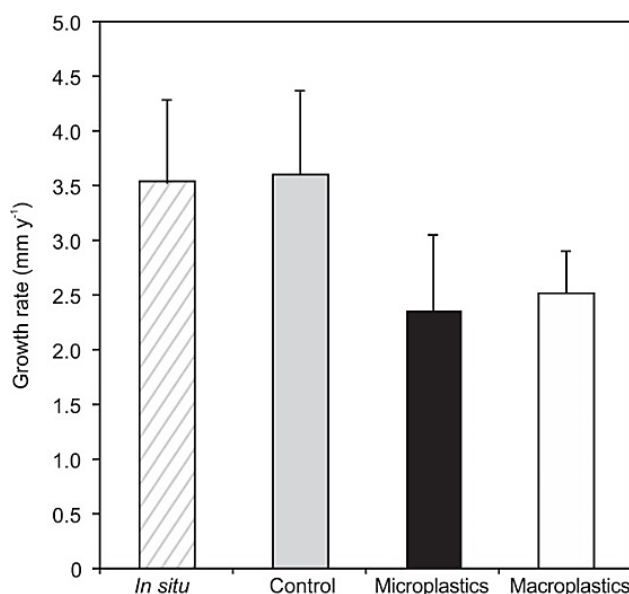


Figure 1. Average skeleton growth rates of *Lophelia pertusa* polyps *in situ* and under aquaria experimental conditions after 69 days of incubation [2].

The presence of MPs in the environment decreased the feeding rate and growth rate of cold-water corals. Corals exposed to MPs had significantly lower capture rates than controls after 7 and 20 days, and polyp activity was significantly lower after 20 and 47 days of exposure. In addition, skeletal growth rates and polyp growth rates of corals exposed to microplastics were significantly lower than those of controls (Figure 1). The reduction of skeletal growth rate and skeletal mineralization rate caused by microplastics affects the growth rate. Deep-sea cold-water corals grow more slowly, so the reduction in skeletal mineralization rate may have a greater impact on their growth in the long term.

The effects of MPs on algae that live in symbiosis with the coral, such as *zooxanthellae*, also act on the coral. The zooxanthellae are not only able to provide corals with energy through photosynthesis, but they are also involved in the calcification of the coral's skeleton, making them an indispensable presence for corals. Chen et al. studied the coral *goniopora columna* exposed to polyethylene microplastic (PE-MP) [11]. After 7 days of exposure to PE-MP, the polyp length of the coral was significantly lower than that of the control group. The adaptability of the polyps was also significantly lower than that of the control group, and the negative effects of PE-MP on the polyps became more severe as time increased. The effect of PE-MP on the symbiotic *zooxanthellae* was investigated. After one day of exposure to different concentrations of PE-MP, the densities of *zooxanthellae* in the experimental group all showed different degrees of decrease compared to the control group. After 5 d, the densities of zooxanthellae in 5, 10, 50 and 300 mg/L PE-MP environment were significantly increased, while the densities of zooxanthellae in 100 mg/L PE-MP environment were slightly lower than that of the control group. The results suggest that different concentrations of PE-MP lead to an imbalance in the density of *zooxanthellae*, which may disturb the symbiotic relationship between corals and *zooxanthellae* and negatively affect corals. In addition, the coral polyp tissue sections were observed after staining with PE-MP. The results showed that the coral mesentery of the experimental group showed different degrees of PE-MP accumulation, and the signs of mesenteric atrophy and vacuolar appeared in the corals. The above phenomena were found in coral tissues exposed to a low concentration (5 mg/L) of PE-MP, and as the concentration of PE-MP increased, the coral tissues' vacuolation symptoms were more severe, suggesting that PE-MP causes tissue damage in the coral mesentery.

3.3. Fish and invertebrates

MPs also have toxic effects on the digestive, immune, reproductive, and nervous systems of various aquatic animals [12]. A series of studies on zebrafish exposed to PS MPs was investigated, where they found the effects of MPs on the reproductive organs of zebrafish [13]. Using average optical density (AOD) as an indicator of ROS levels, AOD levels in testes and ovaries of zebrafish in 100 µg/L and 1000 µg/L environments were significantly increased after 21 days, suggesting that the MPs resulted in the overproduction of ROS in the sex organs of zebrafish. The apoptosis rate of male zebrafish testis cells was significantly increased and the basement membrane thickness was significantly decreased at a high concentration (1000 µg/L). This suggests that MPs affect the reproductive system of fish and may have long-term effects on fish reproduction.

The toxic effects of MPs on juvenile fish may further exacerbate the decline of fish populations. Barboza et al. studied *dicentrarchus labrax* juveniles exposed to MPs and revealed that MPs accumulate in the gills of the fish [14], causing oxidative damage to the gill lipids, which causes damage to the gill cells and lead to gill inflammation. An increase in the activity of the antioxidant enzyme SOD was found in the gills of juveniles exposed to 0.26 mg/L MPs, whereas the activities of both SOD and catalase (CAT) were increased in the liver, suggesting that MPs induced oxidative stress in the gills and liver of fish. In contrast, in the gills of juvenile fish exposed to 0.69 mg/L MPs, in addition to the increase in SOD activity, an increase in the activities of CAT and glutathione-S-transferase (GST) was also observed. This suggests that higher concentrations of MPs may lead to more severe oxidative stress in the organs, which in turn causes an increase in the activities of more antioxidant enzymes. Despite the increase in CAT and GST activities induced by higher concentrations of MPs, lipid peroxidation (LPO) levels in gills were significantly elevated, suggesting

that lipid oxidative damage occurs in gills. The research also revealed the effect of microplastics on the handling of metallic mercury by fish. The results showed that juvenile fish in MPs-containing environments exposed to the same concentration of Hg were more likely to accumulate Hg in their gills and livers relative to those exposed to Hg only. This may be due to the adsorption of Hg on the surface of the MPs or to the fact that the MPs interfered with the fish's mechanism for eliminating Hg from the body. These results suggest that not only are microplastics themselves toxic to aquatic organisms, but the presence of microplastics may also interfere with their metabolism or elimination of certain toxic substances, enhancing the damage to aquatic organisms.

4. Conclusion

Different sizes of MPs have different toxicity effects on aquatic organisms, and their toxicity is mainly due to the excessive production of ROS and oxidative stress, leading to a series of damages to tissues and organs and affects their normal physiological processes. The interaction of MPs with other toxic substances may lead to easier entry and accumulation of toxic substances in organisms, resulting in the enhancement of the toxic effects of these toxic substances. Under the current situation where MPs are inevitably contained in global water bodies, it is all the more important to use and dispose of plastics correctly to reduce the harm they cause to the environment. From the source, people can reduce the use of plastics and use environmentally friendly materials such as biodegradable plastics as substitutes. In terms of disposal, people should handle plastic waste in a more standardised way to avoid more plastic entering rivers and oceans. At the same time, the development of biodegradable treatment of plastics will also help reduce the impact of plastic pollution on the environment.

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