

Post-Covid-19 Pandemic Awareness on The Use of Micro- and Nano Plastic and Efforts into Their Degradation - A Mini Review

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ABSTRACT

Micro- and nano plastic pollution poses a global threat and causes a future problem, and needs greater global attention. Its pollution is exacerbated recently by the excessive use of plastic polymers to prevent and handle the COVID-19 pandemic at a global scale. This review covered the major concerns about the characteristics, effect, and bioremediation of micro-and nano plastics. Many aquatic organisms easily ingest micro-and nano plastic at different trophic levels. This ingestion caused negative health impacts to all living organisms. Microplastic directly affects living organisms like mechanical injury, false satiation, declined growth, promoted immune response, and energy loss. Other debilitating effects include disrupted enzyme activity and production, decreased fecundity, oxidative stress, and mortality. Nano plastic could enter the circulatory system and caused negative effects on the cellular and molecular levels. Bioremediation of microplastic by selected higher and lower eukaryotes, bacteria, fungus, and algae on several polymers was previously reported. However, not much literature is available on nano plastic biodegradation. Therefore, the current review will focus on the characteristics, effect, and bioremediation effort of micro-and nano plastic.

Keywords: Biodegradation, COVID-19, Microplastic, Nano plastic, Pollution.

Introduction

Today, plastic has been a global problem, especially for aquatic ecosystems. After their first commercial development in the 1930s and 1940s, plastics became widespread because of their convenience, durability, and low cost [1]. The world plastic production reached 288 million in 2012, a 620% increase since 1975 [2]. The plastic industry grew rapidly up to 335 million tons in 2016 [3].

During the COVID-19 pandemic, research showed a decrease in air pollution in China [4], India [5], Rio de Janeiro [6], and Sao Paolo [7]. On the other hand, the COVID-19 pandemic causes a serious problem about the plastic used by many people in various working and healthcare personnel. During a pandemic, the demand for face

masks, gloves, coveralls, gowns, goggles, and face shields has been increased dramatically [8]. It will be a serious problem for the environment during post-COVID-19.

COVID-19 started in Wuhan, China, where 116 million personal protective equipment (PPE) was needed per day or about 12 times the usual condition [9]. If the global population uses a standard disposable face mask (one per day), this produces a monthly wastage of 129 billion face masks and 65 billion gloves [10]. Until February 2020 last year, to complete this demand, China intensified its daily production of medical masks to 14.8 million [11]. In April 2020, The Japanese Ministry of economy, trade, and industry (METI) ordered

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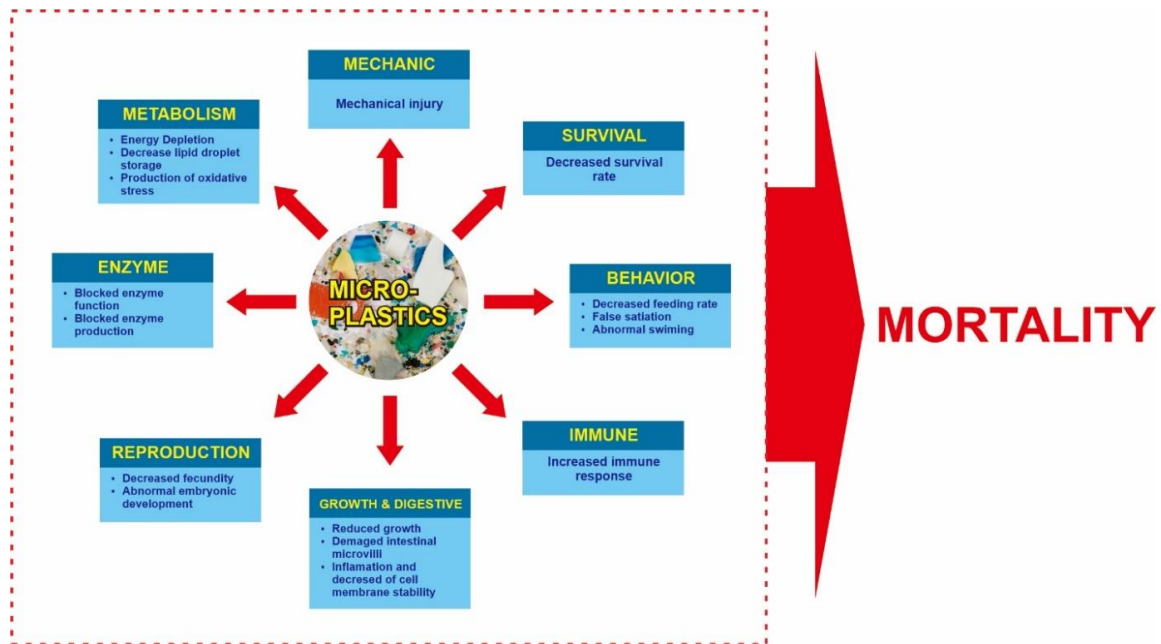


Figure 1. Effect of microplastic on organism

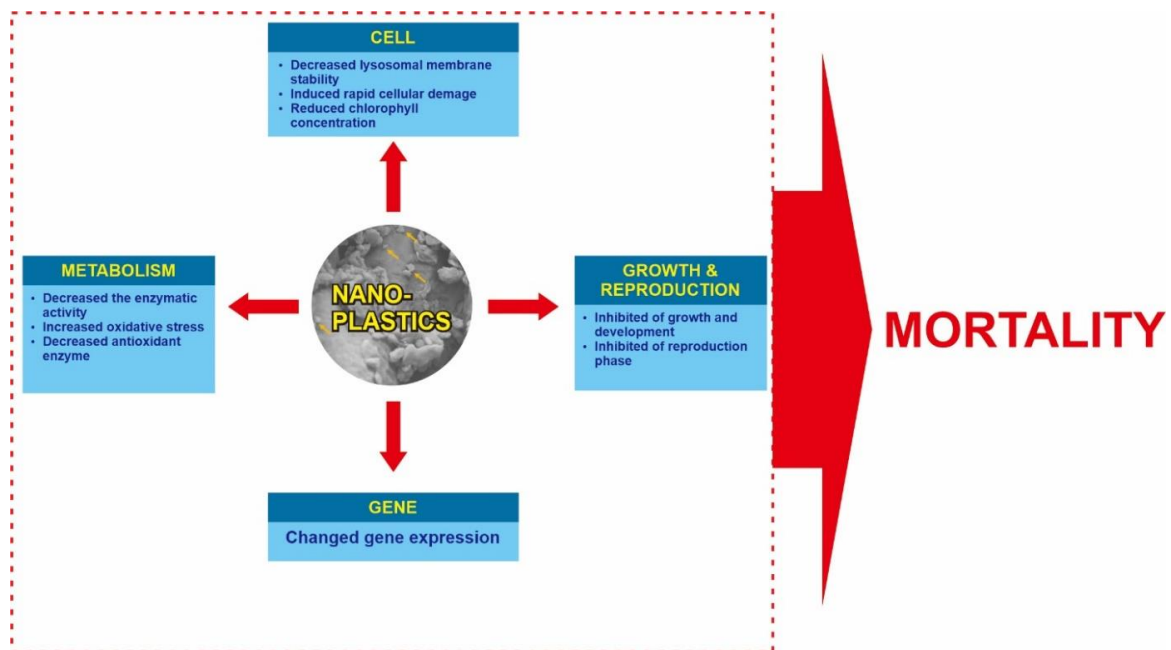


Figure 2. Effect of nano plastic to different organism

face masks per month over 600 million [12].

A dramatic increase in medical waste was also reported in Catalonia and Spain (350% and 370%, respectively) [13]. About 5336–38426 million face masks were estimated for Saudi Arabia. The total microplastic content from Bahrain and Qatar was 1.7–12.3 and 3.10–22.31 thousand tons, respectively [14]. On the other hand, Singapore was produced 1,400 tons of plastic waste from package take-out meals and home-delivered groceries

during an 8-week lockdown [15]. All this plastic waste generated at a global scale will end up in landfilled or incinerated, leading to higher negative environmental impacts. Very minor of these wastes were sent to the recycling plant because plastic mixtures were difficult to recycle because of their natural characteristics. Current estimations of 4–12 million tonnes/year of plastics go into the seas and oceans without properly treated [16].

There were two polymer characteristics of

plastic: thermoplastic (can be molded repeatedly on heating), such as polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), and polystyrene (PS); and thermosets (once formed, cannot be heated and remolded), such as polyurethane (PUR) and epoxy resins for coatings [17]. Large plastic pieces were degraded to micro- and nano plastic size particles by various mechanisms, such as physico-chemical and biological degradation [18, 19].

Micro- and Nano plastic

The microplastic were spread all over the oceans [20, 21], lands [22], and freshwaters like rivers and lakes [23]. Microplastics consist of numerous size-ranges; diameters of <10 mm [24], <5 mm [25], 2–6 mm [26], <2 mm [27] and <1 mm [28]. Microplastics can be described according to the main categories are fragments (rounded and angular), pellets (cylinders, disks, and spherules), filaments (fibers), and granules.

Nano plastic was referred to any particles smaller than 100 nm, or the upper limit to 1 µm and with a Brownian motion (random motion of particles suspended in a medium) in the aqueous system [29]. Nano plastics with high surface reactivity could, directly and indirectly, affect soil ecosystems and in all habitats, including groundwaters and surprisingly at the north Atlantic subtropical gyre [30]. The gyre itself is part of 75% of the open ocean on earth. Nano plastics were formed by degradation of polyethylene (PE) and polypropylene (PP) by UV irradiation [31] and on disposable polystyrene (PS) cup lids [32] or by physical mechanism [33].

Effect of Microplastic on Aquatic Organism

Microplastics' sizes make them easily ingested by a lot of aquatic organisms at different trophic levels [34]. The ingestion can cause negative health impacts (Figure 1).

Microplastics were also found in ostracods (*Notodromas monacha*), annelids (*Lumbriculus variegatus*), gastropods (*Potamopyrgus antipodarum*), and crustaceans (*Gammarus pulex* and *Daphnia magna*) [35]. The effects of microplastics on zooplankton crustaceans include abnormal embryonic development, decreased lipid droplet storage, decreased feeding rates, energy depletion [36], and decreased survival [37]. Some studies also observed reduced growth [38], altered reproduction [36, 38], delay in molting [39], abnormal

swimming behavior [38], and damaged intestinal microvilli [40]. Microplastics reduce growth, reproduction [41], assimilation efficiency [42], and a mortality increase that was exponential to the exposure dose on amphipods [43]. Microplastics ingestion by *Mytilus edulis* can cause tissue inflammation and decrease cell membrane stability of the digestive system [48]. *Oryzias latipes* fed polyethylene exhibit bioaccumulation, liver glycogen depletion, fatty vacuolation, and single-cell necrosis, and early tumor formation [49]. Microplastics can cause nuclear membrane disruption, oxidative stress, the release of damage-associated molecular patterns [44].

The effects of microplastics on organisms can be divided into chemical and physical mechanisms. Chemical effects of microplastics involve the absorption of other contaminants on the surface or the release of plastic monomers if they physically interact with the organisms' tissues [45]. Microplastics can be found on the gastrointestinal tract of fish, gills, liver, and muscle of wild specimens [46]. Effect of microplastics on zebrafish (*Danio rerio*) liver was shown on induction of anti-oxidative enzyme activity, the alteration of metabolism, tissue inflammatory [47] immune response activation, and increase of genes regulation related to the complement system [50].

Microplastics accumulate waterborne contaminants including metals (Al, Fe, Sn, Cu, Zn, Cd, U, Sb) [51], nonylphenol and bisphenol A [52], and bio-stabilization, bioaccumulation, and toxic compounds [54]. Microplastics can be a vector for human waterborne pathogens (Genus *Vibrio*) influencing the water quality [55].

Effect of Nano plastic on Aquatic Organism

Nano plastic can enter the circulatory system and cause negative effects at cellular and molecular levels (Figure 2). Nano plastics can be easily adsorbed by green algae and affect the microbe's photosynthetic mechanism [56]. Nano plastics can accumulate in the digestive tract of sea urchin [53], while polystyrene-NH₂ nano plastics could attach with lipid bilayers on the cell membrane. -NH₂ could also decrease lysosomal membrane stabilization, increase oxyradical production in hemolymph serum, and induce rapid cellular damage (membrane blebbing and loss of filopodia) [57].

Nano plastics changed the mussel's (*Mytilus galloprovincialis*) expression of the gene and decreased enzymatic activity. Other induced effects

include disrupted neurotransmission, increased the oxidative status and peroxidative damage [58]. Also, nano plastics could increase regulation in the central nervous system and inhibit acetylcholinesterase activity of zebrafish (*Danio rerio*) significantly [59].

Nano plastics cause the overexpression of reactive oxygen species (ROS), inhibited the development, growth, and reproduction of *Daphnia pulex*. Low nano plastics (0.1 and 0.5 mg.l⁻¹) were caused by overexpression of the MAPK pathway genes, HIF-1 pathway, Cu,Zn-superoxide dismutase (SOD), and activity of glutathione-S-transferase. Antioxidant enzymes such as catalase, SOD, and Cu, Zn-SOD were decreased after exposure to nano plastics [60]. Nano plastics could reduce population growth and chlorophyll concentrations in the green alga *Scenedesmus obliquus*. For *Daphnia*, nano plastics could reduce its body size and disturbed reproduction system [61].

Increased nano plastics concentration in *Macrobrychium nipponense* effect decreased antioxidant enzymes and increased lipid peroxidation and hydrogen peroxide. The activities of non-specific immune enzymes increased and then decreased when nano plastics concentration increased. Similarly, the expressions of immune-related genes generally increased and then decreased [62; 63].

Accumulation of nano plastics on *Corbicula fluminea* occurred in the mantle, visceral mass, and gill. This accumulation of nano plastic also produces oxidative stress that causes oxidative damage to the liver, neuron, and intestine by anti-oxidation system imbalance [64].

Bioremediation of Micro- and Nano plastic

The microbial micro-and nano plastic degradation is a multistep process involving biodeterioration (changing the physio-chemical properties of the polymer by an enzyme), bio-fragmentation (reduction of the complex into a simpler polymer by enzymes or acids), assimilation (merger of the molecules by microorganisms), and mineralization (oxidized metabolites produced by degradation) [65]. UV radiation and photooxidation can increase bioremediation [66, 67].

The previously reported microplastic degradation by selected microorganisms is listed in Table 1. Past research has been focused on bacteria and lower eukaryotes (fungi) as bioremediation agent [68]. Many literatures have shown that unicellular microalgae, single species or consortia with bac-

teria can degrade endocrine disrupting chemicals like microplastics in wastewaters. Seaweeds like *Fucus vesiculosus* are also good plastic degraders as they can remain suspended on the water surface [69].

Several freshwater Magnoliophyta such as *Eichhornia crassipes*, *Pistia stratiotes*, and *Lemna minor* were used for removing heavy metals and several pollutants in Waste Water Treatment Plants (WWTPs) [70]. In addition, higher eukaryotes have potential for elimination of microplastics from WWTPs for instance annelids (sandworms), echinoderms (sea cucumbers) and some other animals that still under investigation. Seagrasses and macrophytes seem to be good candidates as well for future consideration. [71].

Microorganisms like *Rhodococcus ruber* [72] and fungus *Penicillium simplicissimum* [73] able to degrade polyethylene (PE) by producing an extracellular enzyme. The thermophilic bacterium

Table 1. Selected microorganisms for microplastic degradation

No.	Species Organism	Type	Ref.
1	<i>Fucus vesiculosus</i>	Algae	[69]
2	<i>Egeria densa</i>	Macrophytes	[71]
3	<i>Brevibacillus borstelensis</i>	Bacteria	[66]
4	<i>Streptomyces</i> sp.	Bacteria	[74, 75]
5	<i>Pseudomonas stutzeri</i>	Bacteria	[75]
6	<i>Pseudomonas chlororaphis</i>	Bacteria	[80]
7	<i>Pseudomonas putida</i>	Bacteria	[81]
8	<i>Alcaligenes faecalis</i>	Bacteria	[75, 76]
9	<i>Clostridium botulinum</i>	Bacteria	[75]
10	<i>Rhodococcus ruber</i>	Bacteria	[73]
11	<i>Aureobasidium pullulans</i> sp	Bacteria	[79]
12	<i>Bacillus brevis</i>	Bacteria	[78]
13	<i>Bacillus cereus</i>	Bacteria	[83]
14	<i>Rhodococcus ruber</i>	Bacteria	[82]
15	<i>Comamonas testosteroni</i> F4	Bacteria	[84]
16	<i>Delftia</i> sp. WL-3	Bacteria	[85]
17	<i>Ideonella sakaiensis</i>	Bacteria	[87]
18	<i>Fusarium</i> sp.	Fungi	[77]
19	<i>Fusarium moniliforme</i>	Fungi	[77]
20	<i>Fusarium solani</i>	Fungi	[79]
21	<i>Penicillium roqueforti</i>	Fungi	[77]
22	<i>Penicillium simplicissimum</i>	Fungi	[73]
23	<i>Aspergillus flavus</i> PEDX3	Fungi	[88]

Brevibacillus borstelensis [66] and *Streptomyces* sp. can also degrade the same polymers [74]. *Alcaligenes faecalis*, *Streptomyces* sp., and *Pseudomonas stutzeri* [75, 76] can degrade polyhydroxyalkanoates (PHA) and polyhydroxy butyrate (PHB). PHA also can be degraded by fungi that have been isolated from soil (Basidiomycetes, Deuteromycetes, and Ascomycetes) [77].

Polycaprolactone (PCL) is easily degraded by *Alcaligenes faecalis* [76] and *Clostridium botulinum* [75], and *Fusarium* [77]. Polylactic acid (PLA) is degraded by *Bacillus brevis* [78], *Fusarium moniliforme*, and *Penicillium roqueforti* [73, 77].

Polyurethane is degraded by *Fusarium solani*, *Aureobasidium pullulans* sp., [79], and *Pseudomonas chlororaphi* [80]. Polyvinyl chloride (PVC) could be degraded by the *Pseudomonas putida* [81], whereas polystyrene by the actinomycete *Rhodococcus ruber* [82].

After 40 days, *Bacillus cereus* was reported to degrade 1.6% polyethylene (PE), 6.6% Polyethylene terephthalate (PET), and 7.4% polystyrene (PS). *Bacillus gottheilii* could degrade 6.2% polyethylene (PE), 3.0% polyethylene terephthalate (PET), 3.6% polypropylene (PP), and 5.8% polystyrene (PS) [83]. A combination of *Comamonas testosteroni* F4 and high pH showed effective degradation of PET [84]. *Delftia* sp. WL-3 can also consume 94% of 5 g.l⁻¹ of diethyl terephthalate (DET) as a carbon source in 7 days [85].

Biodegradation of nano plastic is a relatively new issue. Degradation of nano plastics still using an OH-mediated degradation process. This method could affect the ecosystems by increasing the amount of dissolved organic matter [86].

Conclusion

Microplastics and nano plastics have been shown serious effects on organisms ranging from genes to behavior. Bioremediation efforts are required to solve the microplastic and nano plastic problems, let alone reducing their utilization at the consumer's level. Microplastic bioremediation can be carried out by various organisms like algae, bacteria, and fungi. However, nano plastics are difficult to degrade. Nano plastics can disrupt the activity of organisms down to the level of genes and proteins. This may be difficult for many organisms to anticipate and, therefore, open for further research. On the other hand, fungi for microplastic bioremediation are still limited and require

further exploration and research efforts, especially at genomic and proteomic levels. Currently, post-COVID-19 derails efforts to reduce plastic utilization and plastic consumption. At the same time, its global production is expected to increase continuously. Recently, there has been a high number of scientific papers related to microplastic and little on nano plastic degradation. This may fill the knowledge gap regarding current occurrence level, fate, and environmental and health impacts.

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