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EDITORIAL

Nanoplastics are potentially more dangerous than microplastics

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Nanoplastics are probably much more dangerous for living organisms than microplastics because they are more abundant and reactive. They can potentially reach more remote locations and penetrate in living cells. Here we compare nanoplastics with microplastics and engineered nanoparticles, with focus on formation, size, reactivity, mobility, biofilms, and interactions with microbes, pollutants and natural organic matter.

Higher reactivity

Plastic pollution in freshwater and on land continues to increase and threaten the health of humans and ecosystems (Azeem et al. 2022; Dhaka et al. 2022; Larue et al. 2021; Vethaak and Legler 2021). Currently, there are major concerns about small fragments produced from the degradation of large plastic debris (Boyle and Ormeci 2020; John et al. 2022; Mu et al. 2022; Sharma et al. 2021). These small plastic fragments are classified based on their diameter as macroplastics above 5000 µm, microplastics from 1 to 5000 µm, and nanoplastics below 1 µm. Solar light radiations, weathering processes and natural enzymes are driving factors that transform bulk plastics into microplastics and then nanoplastics (Sorasan et al. 2022; Othman et al. 2021). Physical and chemical properties of particles such as size, crystallinity, polarity and surface charge are modified during degradation processes, which affect the fate and behaviour of microplastics and nanoplastics in the environment (Atugoda et al. 2022; Mitrano et al. 2021). In other words, while microplastics and nanoplastics are often discussed together in the literature, they have distinct mobility and toxicity in different environmental compartments. Figure 1 summarizes the distinctive behaviours of microplastics and nanoplastics in the environment. Overall, nanoplastics are more reactive, more abundant, and they can reach more remote locations and penetrate more easily into living cells.

Are nanoplastics more dangerous than engineered nanoparticles?

Engineered nanoparticles refer to chemicals or materials that are engineered with particle size between 1 and 100 nm . Insights gained from decades of studies on engineered nanoparticles shed light on the environmental behaviours of nanoplastics. However, undiscriminated extrapolation is strongly discouraged because nanoplastics and engineered nanoparticles display different properties. First of all, the size range of nanoplastics extends to 1 µm while engineered nanoparticles fall within the size range of 1–100 nm. Secondly, environmental nanoplastics are produced from the breakdown of plastic wastes, whereas engineered nanoparticles are synthesized as uniform materials in the chemical industry. Approximately 5000 tones of plastic wastes were globally released into the environment in 1950–2015, a major fraction of which was broken down to microplastics and nanoplastics. Therefore, it is

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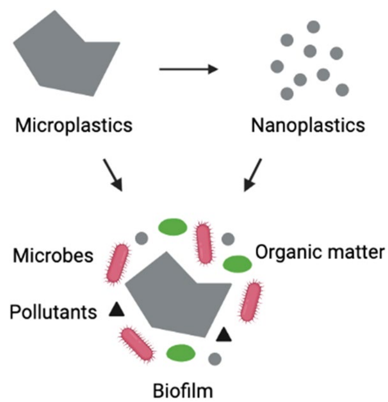

Fig. 1 Microplastics, with sizes lower than 5 mm, are fragmented in the environment into thousands of nanoplastics, with sizes lower than 1 micron. Nanoplastics display much higher reactivity and adsorption capacity due to their higher surface area to volume ratios. Being much more abundant, nanoplastics can potentially reach more remote locations. Microplastics adsorb and carry microbes, pollutants, humic organic matter and nanoplastics, which form biofilms. Nanoplastics adsorb onto and penetrate into microbes. Created in Biorender.com

likely that the amount of nanoplastics would be orders of magnitude higher than engineered nanoparticles.

Environmental nanoplastics are significantly more heterogeneous than engineered nanoparticles. Indeed, engineered nanoparticles are synthesized with uniform compositions for selective applications. Comparatively, environmental nanoplastics are polydisperse with various particle sizes, reactivities and surface properties. Nanoplastics also differ from engineered nanoparticles with respect to their interactions with light and natural organic matter that influence their mobility and degradation (Brewer et al. 2020). Finally, plastic materials usually contain small amounts of additives in addition to their main polymer precursor, and leaching of such additives commonly occurs (Allan et al. 2022; Turner and Filella 2021). Forthcoming studies should show potential toxic effects of additives in plastics. Many studies have examined the fate, mobility, and toxicity of engineered nanoparticles, and public health agencies have come up with policies for such materials (Hochella et al. 2019; Sharma et al. 2015). However, very little is known on the behaviour of nanoplastics in humans and in the environment. Such measurements should be part of future research on the formation, degradation, and toxic effects of nanoplastics.

Nanoplastics as source, carrier and sink of pollutants

Remarkably, microplastics and nanoplastics can be simultaneously sources, carriers and sinks of a wide range of environmental pollutants (Alimi et al. 2018). For instance, plastics such as low- and high-density polyethylene, polyamide, and polyethylene terephthalate can release their original monomers such as ethylene and terephthalic acid into the environment (Kumar et al. 2020; Zhang et al. 2021). Furthermore, additives such as phthalates, flame retardant, organotins, triclosan, and bisphenol may also be released during the degradation of microplastics and nanoplastics (Sait et al. 2021). Some of these additives being carcinogenic and endocrine disruptors, they are of high concern for the health of humans and ecosystems (Alabi et al. 2019). There is also a likelihood of toxic metals adsorption on the surfaces of microplastics and nanoplastics. Sorption of organic contaminants is another possibility of enhanced contamination of aquatic environments. Concentrations of persistent organic pollutants on microplastics were found much higher than in surrounding natural waters (Matijaković Mlinarić et al. 2022; Wagstaff and Petrie 2022). Interactions of inorganic and organic contaminants with microplastics and nanoplastics would potentially increase the risks associated with the ingestion of plastic particles. Microplastics and nanoplastics may also participate in long-term sequestration of pollutants in soils and sediments, followed by pollutant 'resurrection' in the biosphere to induce toxicity (Mottes et al. 2021).

Nanoplastics and microbes

Another potential risk of microplastics and nanoplastics is their colonization by microorganisms such as the formation of biofilms (Fig. 1, Wang et al. 2021). Fungus, algae, and bacteria are usually found in biofilms (Boudarel et al. 2018). Biofilm formation on plastic surfaces includes attachment of microorganisms, release of extracellular polymeric substances, and proliferation of microorganisms in biofilms. Extracellular polymeric substances such as proteins, nucleic acid, carbohydrates, and lipids protect microorganisms in biofilms from photodegradation, water shearing and physical abrasion. Properties of plastics such as surface functional groups and roughness may influence microbial growth in biofilms. For example, rough surfaces facilitate microbial attachment. Particle size is a major influencing factor in biofilm formation, in relation with the relative size of microorganisms and plastics. As a consequence, biofilm formation should be different

Table 1 Factors influencing biofilm formation with microplastics. Modified from Wang et al. (2021)

Physicochemical properties	Environmental conditions
Microplastic types	Temperature enhances microbial diversity
Surface functional groups, e.g. aromatic group enhances bacterial attachment, whereas cyclohexyl group repel bacteria	Salt content decreases biofilm growth
Surface roughness facilitates bacterial attachment	pH influences biofilm growth
	Nutrients enhance the carbon metabolism of biofilms

on nanoplastics versus microplastics, since the size and surface of nanoplastics is probably less suitable for microbial colonization. Instead, nanoplastics may attach on the surface of microorganisms and affect the local microbial community differently from microplastics. Overall, due to their smaller size, nanoplastics may act more as molecular pollutants that attach to, enter microbes and induce toxicity, than as simple carriers of pollutants.

Biofilm development depends on water quality such as salinity, temperature and pH (Table 1, Wang et al. 2021). Specifically, biofilms on plastics in freshwater would differ from those in seawater because freshwater microorganisms are adapted to freshwater pH of 6.5–9.0, and marine microbial communities are adapted to the pH of marine environments, of 8.08–8.33. Environmental factors account for about 31% of parameters controlling biofilm formation on microplastics. Nutrients like nitrogen and phosphorous influence the carbon metabolism in biofilms present on microplastics. However, only limited studies have investigated the influence of water parameters for biofilm development on microplastics.

Overall, more research is needed to assess the role of nanoplastics in the safety of human populations and aquatic species. Research may focus on mechanistic studies to evaluate the influence of temperature, salt content, and pH, and the sorption patterns of different pollutants on plastic surfaces. The studies may also include transfer mechanisms of contaminants among different types of microplastics and nanoplastics and other materials. Accumulation of microplastics and nanoplastics in plants and animals may cause food chain contamination, and identification of food safety risks. Similar investigations on transferring pollutants adsorbed on microplastics and nanoplastics in water and sediments may shed light on their risks to the ecosystems.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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