Impact of Micro- and Nano-Plastics on Environment and Food Chain: A Brief Overview

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Abstract

Micro- and nano-plastics (MPs and NPs) are generated from the breakdown of larger plastic materials or through direct release. Their extensive distribution and persistence have made them a significant global environmental issue. Plastic particles of smaller size, measuring from several µm to nm, affect diverse ecosystems, that includes terrestrial, freshwater and marine environments. Their presence possesses significant consequences for biodiversity, ecosystem balance and human well-being. This review presents a brief examination of the pathways, fate and impacts of MPs and NPs in the environment, as well as their incorporation into the food chain. MPs and NPs serve as the carriers for toxic chemicals and pathogens, thereby enhancing their potential risks. Consumption of these substances by various organisms, including plankton and humans, results in bioaccumulation and biomagnification, which increases significant issues regarding food safety and security. The long-term effects of MPs and NPs on the environment and human health are not yet fully understood, indicating a need for further investigation. This review summarizes the existing knowledge and highlights the critical necessity for interdisciplinary research and global collaboration to address the environmental and food chain risks associated with MPs and NPs, thereby promoting the long-term sustainability of ecological systems and human health.

Keywords:

microplastics; nanoplastics; food chain; environmental concern; plastic waste; degradation.

Highlights:

- Micro- and nano-plastics (MPs and NPs) are widespread environmental pollutants from larger plastic breakdowns.
- MPs and NPs threaten biodiversity and ecosystem health, impacting wildlife and human well-being.
- MPs and NPs carry harmful chemicals and pathogens, increasing their potential environmental and human health risks.
- MPs and NPs originate from multiple sources, complicating their detection and quantification.
- More research and global cooperation are essential to address the health and ecological risks of plastic pollution.

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1. Introduction

Plastics are versatile and adaptable material that manufacturers can readily utilize to make new products and intermediates. Plastic is employed in multiple industries owing to its considerable adaptability, either in the manufacturing process or as a component in the end products. The predictions of plastic production indicate that it might potentially triple by 2050, from an estimated 380 million tonnes in 2018 [1, 2]. Packaging itself accounted for 40% of Europe's 51.2 million metric tonnes of plastic consumption in 2018 [3].

Floating waste has accumulated significantly in marine environments due to the increased use of plastic and inadequate disposal methods and infrastructure. It has been shown that 10% of the 8.3 billion tonnes of plastic generated worldwide till 2023 is ending up as plastic waste in both freshwater and marine habitats. The increasing concern over plastic pollution is highlighted by this figure. Scientists initially focused about effect of plastics on the environment and risk of biomagnification of associated plasticizers on human health in the early 1970s [4]. As far as it is known, microplastics (MPs) and nanoplastics (NPs) are the result of the slow breakdown of larger plastic particles in both freshwater and marine environments [5, 6]. As it is known that the ocean has long been accepted as worldwide repository for plastic waste.

Soil and other terrestrial ecosystems serve as MPs reservoirs, according to recent research [7, 8]. People are vulnerable to environmental plastics because they can breathe them in, swallow them through food and get them through their skin. Another potential route of indirect ingestion of MPs and NPs is through personal care products including lip balm, toothpaste and various cosmetics. MPs have made their way into the food chain as a consequence of the abundant plastics in the environment, putting consumers at risk.

MPs have been found in many different goods, including water, seafood, sugar, honey, beer and sea salt, according to recent studies [9]. In other several environmental matrices, including freshwater, marine, sediments, biota, soils and ambient air, MPs and NPs, which are small fragments of synthetic polymers (plastics) were found. They are also found in food and water, which means they are emerging anthropogenic particle pollutants [10-24]. The term MPs were initially used in 2004 by Thompson et al. to describe the little pieces of plastic found in marine environments [25]. MPs should not be more than 5 mm in size, according to Arthur et al. [26]. NPs are plastic particles and fibers smaller than 1 μm, whereas MPs are those between 1 μm and 1 mm in size [27-30]. MPs that are 1 to 5 mm in size are considered as large [28, 29]. Lightweight, versatile, moldable, flame-resistant and corrosion-resistant plastics have many uses and advantages. By facilitating ease and safety in variety of applications, these characteristics improve the lives of millions of people throughout the world [31]. However, plastic pollution in environment and food sources is a global problem that needs immediate attention.

The European Union's plastics production fell slightly in 2018 and 2019 to 61.8 and 59.7 Mt, respectively. But the worldwide plastic production increased annually and reached 368 Mt in 2019 [31]. MPs contamination levels are correlated with the manufacturing stages of thermoplastics like polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET). This shows the worldwide presence of MPs in both drinking water and freshwater (PP > PS > PVC > PET) [32]. Polybutylene adipate-co-terephthalate (PBAT) and polylactide (PLA) are mostly employed for agricultural and food packaging applications.

Tire wear particles (TWP) made up of 40-60% synthetic polymers (such styrene butadiene rubber, SBR) and paint particles or surface coatings are also included in MPs [27]. MPs usually contain more than one component of fillers, pigments, binders and additives. Table 1 presents the physical characteristics of typical synthetic polymers.

2. Generation of MPs and NPs in the environment

Marine ecosystems contain approximately 20% of MPs, whereas land sources account for more than 80% of MPs. Low density, resilience and buoyancy are three major characteristics of MPs which help it to disperse across the globe [35, 36]. Coastal tourism, fishing, aquaculture and land-based sources are the primary causes of plastic pollution in marine ecosystems [35, 37, 38]. Various studies found that more than 800 million metric tonnes of plastics in the water body come from land-based sources [39]. The microscopic size of MPs and NPs makes it difficult to filter during wastewater treatment. Consequently, these plastic fragments will most likely end up in the freshwater supply system, rivers and seas [40]. MPs and NPs can be found in waterways like rivers and seas due to natural erosion processes, which occur in soil [41].

Table 1. Physical properties of typical polymers that undergo degradation into MPs and NPs [33, 34].

Chemical compound	Mechanical properties	Common applications	Specific gravity (g cm^{-3})	Common shape
PS	Low heat conductivity, inert and long-lasting	Thermal insulation, food containers, building materials	0.96-1.1	Fragments, films, foams
Low-density polyethylene (LDPE)	-	Plastic bags, drinking straws, curtains	0.91-0.93	Fragments, films, foams
Polyethylene (PE)	High tensile strength	Shopping bags, bottles	0.91-0.96	-
High-density polyethylene (HDPE)	-	-	0.94	-
PP	High tensile strength, resistance to abrasion, and smooth texture	Textile fibers, packaging materials, straws	0.83-0.84	Fibers
PET	High tensile strength, resistance to abrasion, and smooth texture	Textile fibers and packaging materials	1.37	Fibers,fragments, films, foams
Polyamide/nylon (PA)	High durability and high tensile strength	Textiles, sportswear, carpets, fishing gear	1.0-1.2	Fibers
PVC	-	Piping	1.38	Fragments, films, foams
Polyacrylate/acrylic	Transparent, high resistance to breakage, elastic	Road markings	-	Fibers
Expanded Polystyrene (EPS)	-	Floats, cups, expanded packaging	<0.05	Fragments, films, foams
Acrylonitrile butadiene styrene (ABS)	-	3D printer, protective equipment	1.06-1.08	Pellets
PLA	-	3D printer	-	Pellets

Figure 1 shows that both primary and secondary sources contribute to the generation of MPs and NPs [42]. The term "primary source" is used to describe man-made MPs and NPs that have many consumer and industrial uses, such as exfoliants in cosmetics and cleansers, drug delivery particles in medicines and industrial air blasting procedures [36]. The secondary source of MPs and NPs in both terrestrial and aquatic environments comes from MP products that break down into particles smaller than microns [36]. Various processes like biodegradation and others can make plastics to degrade into smaller particles known as MPs and NPs (Figure 1). Hydrolysis, thermo-oxidative degradation, physical degradation, photodegradation and thermal degradation are the examples of non-biodegradation mechanisms [43-46]. Thermal degradation also called as heat degradation is a non-natural commercial process. On the other side, weathering is a physical degrading agent that breaks bigger polymers into tiny plastics. Natural chemical reactions known as photodegradation and hydrolysis utilize water molecules and ultraviolet light to degrade polymers into their component monomers. Plastics that do not biodegrade undergo structural disintegration, which in turn alters their mechanical characteristics and increases their specific surface area. This alteration enhances the physical-chemical reactions and interactions with microbes [47].

Biodegradation of plastics is possible with the support of microorganisms found in nature [49]. These organisms develop extracellular enzymes that can break the chemical bonds present in plastics [50]. This technique produces polymers with changed molecular structures, known as nano-sized plastics, which are of tiny particles of plastic. Billions of NPs with a larger surface area produced with a single gramme of MPs. The daily flow of plastic into the seas indicates that NPs are abundantly present in the marine ecosystem.

Also, plastic waste decomposes more quickly in coastal areas than in ocean environments. Plastics mostly decompose by oxidation, which is initiated by solar UV exposure [51]. Additionally, plastic degrades more quickly in coastal areas due to the presence of salt [52]. Plastic breaks down more quickly in marine habitats than on land because of naturally existing microbes and increasing salt concentrations [41].

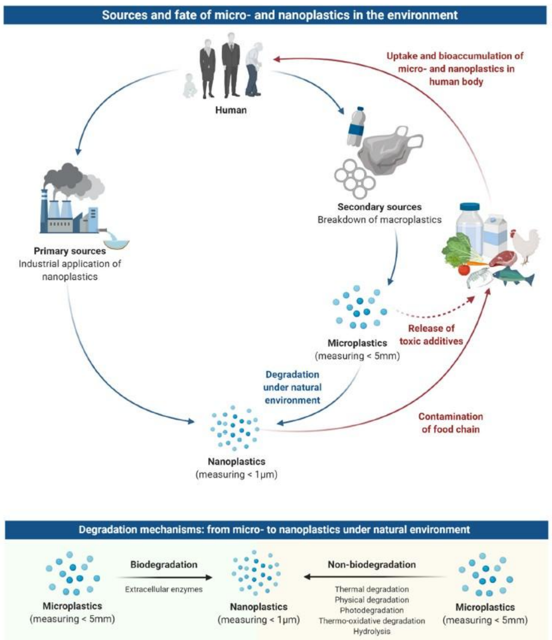

Figure 1. Primary and secondary sources of MPs and NPs [48].

3. MPs and NPs in the food chain

MPs and NPs found in food systems will have major effects on human health [42, 53, 54]. It is most likely that many food products include MPs and NPs due to their high bioavailability and extensive prevalence in both aquatic and terrestrial ecosystems. Animal consumption [55], contamination during food preparation [56], and/or leaching from food and drink packaging [57] are some of ways that MPs and NPs enter into human diets, according to a research study. Some foods that have MPs and NPs fragments are honey, beer, wine, salt, sugar, fish, chicken, prawns, terrestrial snail and water [58-63]. Recent studies have demonstrated that honeybees are capable of collecting MPs from the air, as well as their interactions with plants, soil and water (Figure 2) [64]. FTIR analysis revealed the presence of MPs in water samples collected from a variety of sources, including tap, bottled and spring water. The water samples collected from 159 locations globally has MP particles smaller than 5 mm (almost 81%) [65]. The findings revealed that 93% of the samples (259 bottles from 11 brands and 27 individual batches) had MP particles [57]. The following typical amounts of MP contamination in food have been found statistically: seafood - 1.48 particles/g, sugar - 0.44 particles/g, honey - 0.10 particles/g, salt - 0.11 particles/g, alcohol - 32.27 particles/l, bottled water - 94.37 particles/l, tap water - 4.23 particles/l and air - 9.80 particles/cm², respectively [66, 67]. The approximate amount of MP particles that humans swallow each year ranges from 39,000 to 52,000, which varies according to factors such as gender and age. The effects of plastic particles increase the annual total value by 74,000 to 121,000 particles. However, compared to persons who drink exclusively bottled water, drinking just tap water are likely to consume only around 4,000 extra particles every day [67]. According to the research, human's intake of MP is greatly affected by their food chain.

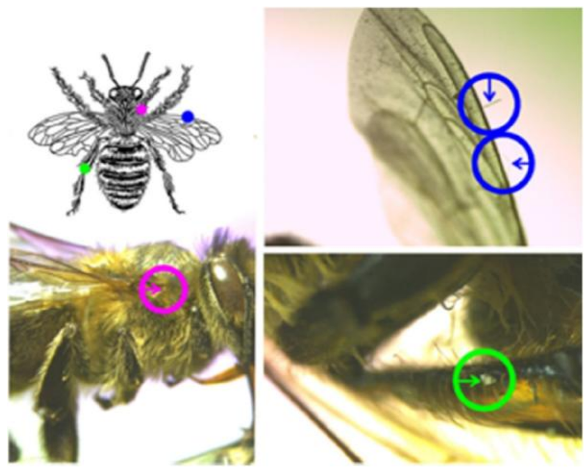

Figure 2. MPs from the active samples of honeybees [64].

Evidence for the presence of NPs in food is lacking due to the scarcity of easily available testing procedures [66, 68]. The breakdown of MP waste shows the presence of NPs in food chains as shown by several studies [45, 68]. Research on polystyrene beverage cup lids found that NPs were released during the degradation of material over time [49]. Marine ecosystems experience microbial degradation due to the presence of microbes that decompose hydrocarbons. A "plastisphere" ecology has been developed due to presence of these microorganisms on plastic waste [46]. Lot of plastic wastes present in aquatic environments explains that MPs may be able to survive degradation processes and results in additional NPs [69]. Many products employ NPs for commercial purposes; eventually, these NPs available in rivers and landfills will find their way to enter into human food chains [66, 68].

4. Challenges and outlook

Identifying the polymer type or the interactions between MPs and living organisms with existing risk and exposure assessments of MPs are insufficient. Another difficulty arises from the fact that natural particles cannot be adequately isolated from MPs throughout the sampling, analysis and characterization operations. Figure 3 provides a summary of the primary characterizations of plastic waste as reported in the literature, along with the methodologies employed for their identification and analysis.

Furthermore, there is currently no way to get the exact information needed to calculate the MP concentrations and degradation times, including details on sources, dispersion methods, standardized measures, parameters and timescales. However, it is still a big problem for scientists to determine whether micrometer-sized natural particles, such as cellulose, clay or chitin, are poisonous or not. The ongoing contamination of the atmosphere with MPs and the high rates of plastic waste generation on a yearly basis have led environmental protection organizations to impose landfill limitations in regions like the European Union. Incineration, gasification and pyrolysis are some of the waste-to-energy processes that have been forced into use. In this, incineration is the most common and results in the release of heavy metals, halogens and persistent organic pollutants. Many things which affect the emissions include incinerator's design, operational parameters, the materials being burned and the technology used to control air pollutions [70]. Implementation a circular economy approach that maximizes the recycling of polymers for extended usage is a more practical strategy. This will reduce the plastic waste and decrease the generation of MPs and NPs. Furthermore, it is anticipated that the increasing utilization of biodegradable polymers will decrease the environmental retention time of mesoplastics and the emission of MPs.

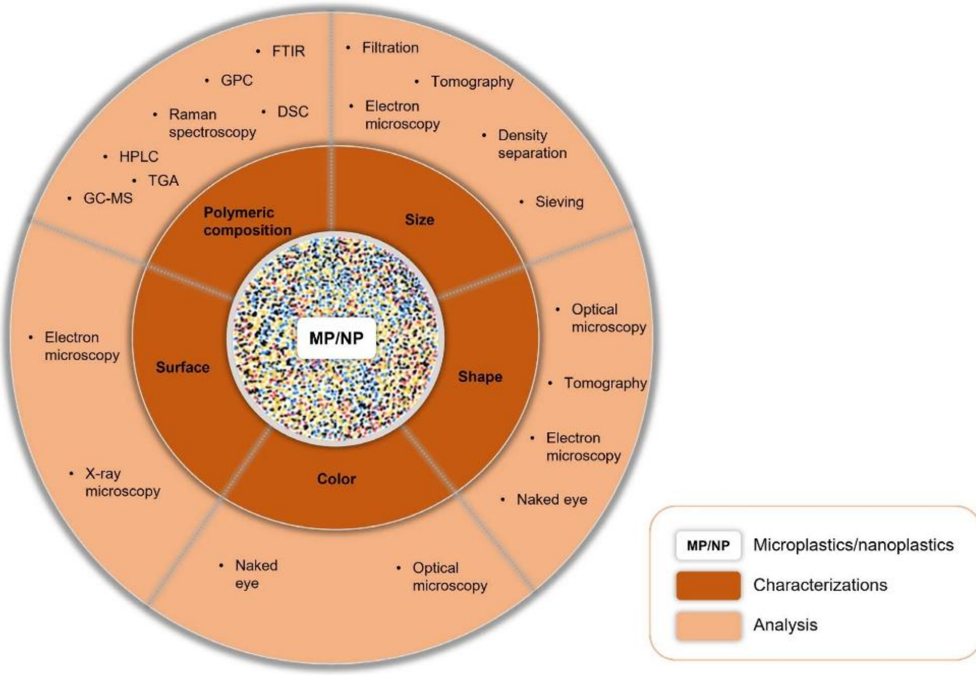

Figure 3. Overview of common plastic waste characterization techniques and analytical methods [33].

5. Summary and conclusions

The continuous fragmentation of polymeric materials or their deliberate production within industrial processes are the two main sources of MPs and NPs. The nonexistence of defined processes for sampling, analyzing and quantifying plastic waste is evident in the available literature and possess a difficulty. The development of reliable criteria for the classification of MPs and NPs, going beyond simple size description, is currently the subject of intense research. In indoor ambient air conditions, the most common morphologies of MPs include flakes, fragments, films, polyester, polyamide and polyacrylate-based fibers. Compared to more traditional cleaning methods, such as sweeping, vacuuming is more effective at reducing the resuspension of MPs and NPs. Carpets, furniture coverings and curtains made of synthetic fibers should be used carefully. In addition, indoor MPs must be captured adequately by maintaining air filtration and conditioning equipment. Factors inherent and extrinsic to the polymer, current environmental circumstances, and the actions of degradable organisms will have a role in determining the degradation rate. Regular cleaning operations of water bodies affected by plastic waste, legislation incorporating the polluter pays principle and corporate social responsibilities are vital for mitigating MPs and NPs contamination. The goal of these actions is to reduce the production of MPs/NPs and their ability to cross environmental matrices. In both natural and man-made conditions, environmental protection agencies need to set limitations on the amounts of MPs and NPs in the environment and food chains. As a result, there are a lot of research efforts in the field of MPs and NPs driven by the unforeseen problem of plastic pollution, which is a result of the remarkable improvements in technology, medicine and lifestyle that may be linked to the development of flexible polymer materials. It is believed that the new information will help reduce the negative impacts of new materials in the future.

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