Rafidain Journal of Science

https://rsci.uomosul.edu.iq

Vol. 34, No. 4, pp. 143-153, 2025 (December)

Review Article

Biological Effects of Microplastics: A Review

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p-ISSN: 1608-9391
e -ISSN: 2664-2786

Article information

Received: 18/4/2025
Revised: 10/6/2025
Accepted: 22/6/2025

DOI: 10.33899/rjs.2025.190521

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ABSTRACT

Microplastics (MPs) are ubiquitous environmental contaminants with the potential for far-reaching impacts on ecosystem processes and human health. This review consolidates contemporary scientific understanding of the biological impacts of microplastics on a range of organisms and across various ecological contexts. Research demonstrates that microplastics cause physical damage, inflammation, oxidative stress, neurotoxicity, and disruptions to reproductive processes across a range of species. Furthermore, MPs act as vectors for co-occurring pollutants and host unique microbial communities. Among the possible physical effects are blocking of the intestines and injuries of the tissues, while the chemical toxicity may be due to the plastics' additives and the environmental contaminants that have been swallowed. Microplastics were found to be the cause of the mentioned negative effects like; less feeding efficiency, less growth, behavior changes, and less reproduction in the aquatic organisms. Land studies are fewer in number but these studies still indicate changes in soil microorganisms and crop production. Through empirical evidence, the possibility of translocation across biological barriers in mammals is shown, which raises the stakes for human health. Even though there has been considerable progress in research, still there are major gaps in knowledge on the effects of low-dose chronic exposure, impact of Nano plastics, and the development of comprehensive risk assessment frameworks.

Keywords: biological impacts, microplastics, inflammation, bioaccumulation

INTRODUCTION

Definition and Classification of Microplastics

Microplastics are conventionally defined as plastic particles with dimensions less than 5 millimeter (GESAMP, 2015). They are typically categorized as either primary microplastics, which are manufactured at microscopic size (e.g., microbeads in personal care products), or secondary microplastics, which result from the degradation of larger plastic items through environmental processes (Frias and Nash, 2019). These particles vary considerably in their physical and chemical characteristics, including polymer composition (e.g., polyethylene, polystyrene, polyvinyl chloride), morphology (fibers, fragments, films, pellets, beads), surface properties, and additive content (Hartmann *et al*., 2019; Rochman *et al*., 2019).

Environmental Prevalence and Routes of Exposure

Microplastics have practically been found in every environmental compartment studied, right from the polar ice caps to the deep-sea sediments (Bergmann *et al*., 2017; Woodall *et al*., 2014). The terrestrial, freshwater, and marine organisms are exposed to microplastics by the ways of ingestion, inhalation, or body contact. Humans could be exposed to microplastics through eating and drinking contaminated food and drinks, breathing in airborne particles, and using personal care products with microplastics in them (Wright and Kelly, 2017).

Scope and Objectives of the Review

The objective of this review is to bring together the present scientific knowledge about the biological impacts of microplastics on different taxonomic groups and in various ecological settings. It investigates the routes of their toxicity, the physiological responses, and the possible ecological consequences while pointing out the major uncertainties and the areas of future research.

Mechanisms of Microplastic Toxicity

Physical Effects

Microplastics inflict physical harm by excoriating the epithelial linings in the digestive tract or lungs (Jeong *et al*., 2016). For marine creatures, the swallowed microplastics can get stored in their digestive tract and create a scenario of gastrointestinal blockage, and even their feeding range can be reduced, and they may feel full when actually they are not (Cole *et al*., 2013). Physical impacts can even reach the cell level as microplastics can directly damage the membranes and tissues of the cells by their mechanical force (von Moos *et al*., 2012).

Chemical Effects

On top of physical impacts, microplastics can exert toxicity by chemical mechanisms:

Leaching of Plastic Additives

Plastic polymers are generally composed of numerous additives such as plasticizers, flame retardants, stabilizers, and colorants, which have the possibility to be extracted from microplastics during the exposure to environmental conditions or in biological fluids (Hermabessiere *et al*., 2017). A large group of these substances, among others phthalates, bisphenol A, and brominated flame retardants, are recognized as endocrine disruptors and can have an impact on developmental, reproductive, and metabolic processes (Talsness *et al*., 2009).

Vector Effects for Environmental Contaminants

Owing to the hydrophobic nature of their surfaces and their large surface area to volume ratio, microplastics are very good adsorbents of persistent organic pollutants (POPs), heavy metals, and other environmental contaminants (Rochman *et al*., 2013). The ingestion of such particles permits the toxic substances to be released in the digestive environment, thus enhancing their bioavailability and toxicity by a process known as the "Trojan horse" effect, which is similar to the way it happens among regular horse and human relations (Koelmans *et al*., 2016).

Biological Interactions: The "Plastisphere"

Microplastics in the environment initiate the formation of specific microbial biofilms, which are called the "plastisphere", and these biofilms are unlike the other microbial populations that are present in the vicinity (Zettler *et al*., 2013). The biofilms may contain disease-causing microorganisms and thus, they have the potential to move pathogens along the routes of their transport all over the globe (Kirstein *et al*., 2016). The plastisphere can also influence the degradation of the plastic and the sorption-desorption characteristics of co-occurring contaminants.

Biological Effects Across Taxonomic Groups

Effects on Aquatic Invertebrates

Aquatic invertebrates are particularly vulnerable to microplastic exposure due to their feeding strategies and position in food webs. Effects documented in invertebrates include:

1. Filter feeders such as bivalve mollusks can accumulate significant quantities of microplastics (Van Cauwenberghe and Janssen, 2014).
2. Reduced feeding and energy reserves in blue mussels *Mytilus edulis* (Van Cauwenberghe *et al*., 2015)
3. Impaired reproduction in copepods *Calanus helgolandicus* (Cole *et al*., 2015)
4. Developmental abnormalities in sea urchin embryos *Paracentrotus lividus* (Martínez-Gómez *et al*., 2017)
5. Transgenerational effects in *Daphnia magna* (Martins and Guilhermino, 2018)
6. Altered behavior and predator avoidance in shore crabs *Carcinus maenas* (Watts *et al*., 2015)

Effects on Fish

Fish may encounter microplastics through direct ingestion or trophic transfer. Documented effects include:

1. Intestinal damage and altered gut microbiome in European sea bass *Dicentrarchus labrax* (Pedà *et al*., 2016)
2. Liver toxicity and metabolic disruption in Japanese medaka *Oryzias latipes* (Rochman *et al*., 2013)
3. Crucian carp *Carassius carassius* experience neurobehavioral changes and altered predator-prey interactions (Mattsson *et al*., 2017)
4. Various species faced with endocrine disruption and reproductive impacts (Sussarellu *et al*., 2016)

Effects on Terrestrial Organisms

Microplastic impacts on terrestrial organisms are less studied, however, their effects are started to be research, and among such impacts are:

1. Possible changes in the gut bacteria and reduced growth of earthworms *Eisenia fetida* (Rodriguez-Seijo *et al*., 2017)
2. Absorption and the movement of microplastics in agricultural plants (Li *et al*., 2020)
3. Negative effects on the microorganisms in the soil and the soil health indirectly through these effects (Rillig *et al*., 2017)

Potential Effects on Humans

Research on direct human health impacts is still a limited field of study, but the following aspects are of potential concern:

1. Small microplastics (<10 micrometers) being absorbed through the intestinal epithelium (Wright and Kelly, 2017)
2. Accumulation in organs like liver, kidney, and placenta being a possibility (Ragusa *et al*., 2021)
3. Increased inflammation and oxidative stress being some of the possible effects (Hwang *et al*., 2020)
4. Animal studies suggesting neurodevelopmental and reproductive effects as potential concerns (Prüst *et al*., 2020)

Physiological and Cellular Responses

Inflammation and Immune Responses

It has been proven that exposure to microplastics elicits inflammatory reactions in different species. Release of cytokines and immune cell activation can take place in fish and marine invertebrates as a consequence of microplastics ingestion (Avio *et al*., 2015; Brandts *et al*., 2018). Long-term inflammation can lead to the destruction of tissues and the disruption of various bodily functions.

Oxidative Stress

Oxidative stress, an increase in free radicals and a disabled antioxidant defense response, is a typical reaction of cells to microplastics (Jeong *et al*., 2016; Paul-Pont *et al*., 2016). The products of oxidative damage, such as lipids, proteins, and DNA, have been found in different aquatic organisms exposed to microplastics.

Metabolic Disruption

Microplastics are capable of disrupting energy metabolism as well as the distribution of nutrients among organisms. Literature has indicated that there were changes in energy reserves, lipid metabolism, and glycogen deficiency as a result of microplastic exposure (Rist *et al*., 2016; Wright *et al*., 2013). Such disruptions in metabolism can have an impact on growth, reproduction, and overall endurance.

Neurotoxicity

Newly discovered data indicate that microplastics might have neurotoxic effects such as:

1. Fish and invertebrates exhibiting modified acetylcholinesterase activity (Oliveira *et al*., 2013)
2. Brain tissue suffering oxidative damage (Ding *et al*., 2018)
3. Changes in behavior that point to a decline in neural functioning (Chen *et al*., 2017)

Reproductive and Developmental Effects

Microplastics and related chemicals could encompass various disturbances to the motto of breeding and maturity:

1. Altered gametogenesis and fertilization success (Sussarellu *et al*., 2016)
2. Embryonic developmental abnormalities (Martinez-Gomez *et al*., 2017)
3. Endocrine disruption affecting breeding hormone signaling (Rochman *et al*., 2014)

Ecological Implications

Trophic Transfer and Biomagnification

Research shows microplastics can move up food chains when contaminated prey are eaten by predators (Setälä *et al*., 2014). While plastic particles themselves don't seem to increase in concentration at higher food chain levels, the harmful chemicals attached to them might accumulate in top predators (Nelms *et al*., 2018).

Population and Community Effects

While most research has focused on individual-level effects, potential population and community consequences include:

1. Reduced population growth rates due to impaired reproduction (Cole *et al*., 2015)
2. Altered community composition resulting from differential sensitivity among species (Green *et al*., 2016)
3. Microplastics could harm important ecological functions that benefit humans, such as when filter-feeding organisms that clean water or decomposers that recycle nutrients are affected (Galloway *et al*., 2017)

Interactions with Other Stressors

Microplastics rarely exist in isolation but rather as one component of multiple anthropogenic stressors. Interactions with climate change, ocean acidification (increasing seawater acidity from absorbed CO2), chemical pollution, and habitat degradation may exacerbate effects, potentially leading to synergistic impacts that exceed the sum of individual stressors (Browne *et al*., 2015).

Microorganisms That Break Down Microplastics

Some bacteria and fungi can help break down microplastics in nature, offering potential solutions for this widespread pollution problem:

How Bacteria Break Down Plastics

Several types of bacteria can degrade certain plastics, though usually very slowly in natural environments (Yuan *et al*., 2020):

1. Marine bacteria like *Bacillus*, *Pseudomonas*, and *Ideonella* can break down some plastics (Danso *et al*., 2019)
2. A remarkable bacterium called *Ideonella sakaiensis* can actually eat PET plastic (used in water bottles) using special enzymes (Yoshida *et al*., 2016)
3. Bacteria first form a biofilm (thin layer) on plastic surfaces before beginning to break them down (Rummel *et al*., 2017)

How Fungi Break Down Plastics

Fungi have different abilities that complement what bacteria can do:

1. Some fungi produce powerful enzymes that can attack hard-to-degrade plastics (Paço *et al*., 2017)
2. White-rot fungi (like those found on rotting logs) are particularly good at breaking down various plastic types (Gajendiran *et al*., 2016)

Working Together: Mixed Microbial Communities

When different microorganisms work together, they often break down plastics better than single species working alone:

1. 1. It has been shown that the combination of fungi and bacteria can lead to faster plastic degradation (Brunner *et al*., 2018)
2. Microbes in nature, especially those found in polluted plastic regions, have developed the ability to utilize plastics as their source of energy (Sarkhel *et al*., 2020)

Challenges and Limitations

Real-world applications are still facing several challenges even though lab results are very promising:

1. In nature, the degradation of plastics by microbes is extremely slow as compared to the optimal lab conditions
2. Certain additives used in plastics are capable of killing microbes or stopping their growth on plastics
3. The breakdown of some common plastics such as polyethylene and polypropylene is particularly hard
4. Temperature and nutrients are the environmental factors that have the most significant impact on the speed of breakdown

Future Directions

Researchers are exploring different strategies in making plastic-eating bacteria more efficient:

1. Upgrading the natural enzymes that break down plastics to enhance their performance in terms of both speed and efficiency
2. Creation of exclusive mixtures of organisms that are intentionally envisioned for various kinds of plastics.
3. Combining microbial methods with physical or chemical treatments to speed up the whole process.

Microbes, despite being a promising and environment friendly option for the microplastics problem, cannot be relied on in the present situation because the degradation rates are still quite slow for removing the microplastics effectively. A lot of research is still required to bring microbial solutions closer to the practical application.

Knowledge Gaps and Research Directions

Methodological Challenges

One of the major issues that microplastic researchers still confront is the disparity between research methods (Cowger *et al*., 2020; Hartmann *et al*., 2019):

- Various methods are used for sampling, extraction, and characterization which in turn lead to difficult comparisons between studies.
- Limited ability to detect and characterize Nano plastics (<100 nm)
- Need for environmentally relevant exposure scenarios that reflect real-world conditions

Nano plastics: The Emerging Frontier

Nano plastics, the smallest fraction of plastic debris, have unique challenges because they are able to pass through biological barriers like cell membranes and the blood-brain barrier (Mattsson *et al*., 2015). Researchers have been unable to study the environmental presence and the biological effects of Nano plastics because of a lack of effective detection methods, despite their possible toxicity being of greater concern than their size (Prata *et al*., 2020).

Long-term and Low-dose Exposure Effects

The majority of laboratory experiments use short-term exposure to concentrations that are much higher than present environmental levels. It is essential to carry out studies on chronic and low-dose exposures that more accurately represent the actual scenarios in order to learn about the possible subtle effects that may be overlapped by a long duration period (Rochman *et al*., 2019).

Human Health Risk Assessment

Substantial knowledge gaps remain existing in the areas of human exposure assessment and possible health impacts:

- There is no precise knowledge on the total amount of nano plastic exposure that individuals receive through food, water, and air, as well as other pathways.
- Researchers are still in the dark about the locations of nano plastics in the human body and the speed of their removal.
- Health risks of long-term exposure;
- To what extent different groups (children, pregnant women, the elderly) are vulnerable to Nano plastic exposure is still an area needing further research.

Conclusions and Recommendations

The literature surveyed in this article supports the view that microplastics can cause different negative biological effects in various taxonomic groups via physical, chemical, and biological pathways. Although acute toxicity at the present environmental concentrations seems to be restricted for a lot of species, slight long-term effects on the functions, growth, and reproduction could eventually lead to severe ecological impacts.

The following should be the main research priorities:

- Development of standardized methodologies for microplastic research
- Investigation of chronic, low-dose exposure effects under environmentally relevant conditions
- Enhanced focus on Nano plastics detection and toxicity
- Systems-level approaches to understand population and ecosystem implications
- Improved human exposure assessment and health impact evaluation

Policy recommendations based on current knowledge include:

- Implementation of the precautionary principle in plastic management
- Source reduction through regulatory restrictions on microplastic-containing products
- Improved waste management infrastructure to prevent plastic leakage to the environment
- Support for innovation in biodegradable and environmentally benign alternatives

While scientific understanding continues to evolve, the ubiquitous presence of microplastics and their demonstrated potential for biological harm warrant precautionary measures to reduce environmental inputs and minimize exposure risks.

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الآثار البيولوجية للمواد البلاستيكية الدقيقة: مراجعة

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الملخص

تدمج هذه المراجعة الفهم العلمي المعاصر للتأثيرات البيولوجية للدائن الدقيقة على مجموعة من الكائنات الحية وفي سياقات بيئية مختلفة. تُظهر الأبحاث أن اللدائن الدقيقة تسبب أضرارًا جسدية والتهابات وإجهادًا تأكسديًا وسمية عصبية واضطرابات في عمليات التكاثر عبر مجموعة من الأنواع. وعلاوة على ذلك، تعمل المواد البلاستيكية الدقيقة كناقلات للملوثات المتزامنة وتستضيف مجتمعات ميكروبية فريدة من نوعها. وتشمل الآثار الفيزيائية انسداد الأمعاء وتلف الأنسجة، وقد تنتج السمية الكيميائية من المواد المضافة في البلاستيك والملوثات البيئية المبتلعة. وقد ارتبط التعرض للبلاستيك الدقيق بانخفاض كفاءة التغذية، وتثبيط النمو، وتغير السلوك، وانخفاض التكاثر في الكائنات المائية. وتوجد دراسات أقل على اليابسة، ولكنها تشير إلى وجود تأثيرات على الكائنات الحية الدقيقة في التربة وغلة المحاصيل. تشير الأدلة التجريبية إلى إمكانية الانتقال عبر الحواجز البيولوجية في الثدييات، مما يزيد من المخاطر على صحة الإنسان. وعلى الرغم من التقدم الكبير في الأبحاث، لا تزال هناك ثغرات معرفية مهمة فيما يتعلق بتأثيرات التعرض المزمن بجرعات منخفضة وتأثيرات اللدائن النانوية وأطر شاملة لتقييم المخاطر. يسلط هذا الاستعراض الضوء على الحاجة إلى منهجيات بحثية موحدة ويدعو إلى توسيع نطاق التحقيق في سيناريوهات التعرض في العالم الحقيقي لتحسين تقييم المخاطر والقرارات السياسية الرامية إلى التخفيف من التلوث بالبلاستيك الدقيق.

الكلمات الدالة: التأثيرات البيولوجية، اللدائن الدقيقة، الالتهابات، التراكم البيولوجي.