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Impacts of Microplastics and Mitigation Strategies for Microplastic Pollution

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Abstract: *Microplastics are hazardous to the environment. As an emerging pollutant, its health hazards have been extensively studied. In this brief paper, we introduce the types of micro plastics, their properties, hazardous health effects of microplastics on the environment, and mitigation strategies for the microplastic pollution effects on the environment, and reveal the toxic effects of microplastic cells, organoids, and animals, which consist of DNA damage and neurotoxicity, which will be helpful for the best understanding of microplastic impacts and mitigation strategies. This paper examines the sources and pathways of microplastic pollution, explores the potential impacts on various organisms and ecosystems, and critically evaluates existing and prospective mitigation strategies aimed at reducing microplastic generation, release, and environmental accumulation..*

Keywords*:* Emerging pollutant, mitigation strategies, Hazardous, Environmental accumulation

I. INTRODUCTION

Micro plastics are very dangerous in the environment. Plastics have been used worldwide as emerging pollutants. In 2019, the global annual output of plastic products reached 460 million tons, only 9% of which was recycled, and it is estimated that it will reach 1.2 billion tons by 2060.High yield and low recovery indicate that a large number of plastics enter the environment. Major commercial plastics on the market include polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). Plastics produce small fragments or particles through crushing, splitting, and degradation. In the 1970s, plastic particles were first discovered in the surface waters of the Atlantic. Thompson etal published a paper in science and proposed the concept of "microplastics" for the first time.

The microscopic particles, originating from the degradation of larger plastic items, industrial processes, and direct release, are now found in virtually every environment, from pristine polar regions to urban water systems. Toxicological studies on micro plastics are rapidly increasing. Experiments have shown that exposure to micro plastics induces a variety of toxic effects, including oxidative stress, metabolic disorders, immune responses, neurotoxicity, and reproductive and developmental toxicity. Addressing this challenge requires a multifaceted approach that tackles the root causes of micro plastic pollution, mitigates existing contamination, and promotes sustainable alternatives in the future. However, there is limited exposure to mitigation strategies for micro plastic impacts.

This review briefly summarizes the impacts and mitigation strategies for micro plastic pollution, which is a major problem we are facing today.

Types of microplastics:

Primary microplastics

Primary microplastic type A categorizes and considers microplastics as chemicals. This category includes types that are added directly to products (e.g., personal care products, cleaning agents, and paints). This component is frequently replaced by water-soluble polymers ("liquid microplastics"). Products are then often advertised as "microplastic-free" or "without microplastics."

The primary microplastic type B category includes plastic particles that are generated during the use of plastic products and directly introduced into the environment as microplastics. Examples include tire abrasion and clothing fibers from synthetic clothing.

Secondary Microplastics

Secondary microplastics include all microplastic particles created by the slow decomposition of large plastic parts or plastic waste in the environment. This can occur due to any kind of external influence, such as UV radiation, bacteria, or friction.

Properties of microplastics

The smaller the particles, the higher the probability that they will be absorbed into the organism. The probability of uptake is determined by hydrophobicity, charge, and functionalization of the particle surface.

Low hydrophobicity and negative surface charge lead to higher absorption. Furthermore, it is assumed that a protein corona forms on the particle surface owing to the accumulation of biomolecules, which also strongly influences the uptake and transport behaviour in the body.

Hazardous effects of Microplastics:

Microplastics that produce toxic effects are complex and are affected by many factors, including physical and chemical properties, exposure time, and additives. Microplastics are not only toxic, but also carriers of many pollutants that enter biological tissues and organs.

1. Toxic Effects in Human Organoid Experiments

Human organoids are the latest development of in vitro models and have been used as new exposure models for emerging contaminants such as microplastics. Compared to cells and animals, human organoids can better reflect the harmful effects of microplastics on the human body. At present, organoids that have been used for microplastics include airway organoids, forebrain organoids, intestinal organoids, and liver organoids. After microplastic exposure, all organoid models exhibited functional disorders. Cheng et al. further studied the combined effect of PS and biphenyl A (BPA) using liver organoids based on their previous research. The results showed that PS and BPA have synergistic hepatic effects, indicating the carrier function of microplastics. ERα and HNF4A have been proposed as potential biomarkers.

2. Toxic Effects in Animal Experiments

a. Metabolic Disorder

Previous animal experiments have confirmed that microplastics lead to liver and intestinal dysfunctions. Kang et al. found that microplastics induce intestinal damage in fish via two different mechanisms. PS with a size of 50 nm exhibits stronger oxidative stress, while PS with a size of 45 μm causes a significant imbalance in intestinal flora. Kim et al. reported that microplastics inhibit digestive enzyme activity in fish through a microalgae-crustacean-small yellow croaker food chain. Jin et al. also reported that the intestinal barrier and metabolic function are impaired in PS-exposed mice. Tan et al. demonstrated that microplastics significantly reduced lipid digestion in a simulated human gastrointestinal system, with PS showing the highest inhibition. The decrease in lipid digestion was independent of the PS size. Lu et al. reveals that PS exposure causes the local infection and lipid accumulation in the liver of fish and disrupts the energy metabolism. In addition, Deng et al. discovered that after exposure to microplastics and organo phosphorus flame retardants (OPFRs), the metabolites in mice changed significantly. It is noticeable that microplastics aggravate the toxicity of OPFRs, highlighting the health risks of microplastic co-exposure with other pollutants.

B. Immune Response

Microplastics can induce immune responses in the body. Yuan et al. reported that PE exposure activates the intestinal immune network pathway in zebrafish and produces mucosal immunoglobulins. Li et al. demonstrates that the secretion of IL-1α is increased in the serum of rats exposed to PE, but decreased in Th17 and Treg cells among $CD4^+$ cells. Lim et al. observed that the inhalation of PS upregulated the expression of inflammatory proteins (TGF-β and TNF-α) in the lung tissue of rats. Liu et al. found that PS exposure significantly increased the expression of inflammatory factors (TNF-α, IL-1β, and IFN-γ) in mice, and intestinal immune imbalance significantly increased the accumulation of microplastics, producing further toxic effects.

C. Epidemiological Investigation

Epidemiological investigation is a good method for demonstrating the correlation between microplastic exposure and adverse health outcomes. However, relatively few epidemiological studies have been conducted on microplastics. Kremer et al. reported that, due to occupational exposure, workers in polymer factories in The Netherlands are more likely to suffer from chronic respiratory diseases. In Canada and the United States, employees of nylon flocking factories are diagnosed with work-related interstitial lung disease. Yan et al. discovered that the faecal microplastic concentration in patients with inflammatory bowel disease (IBD) was significantly higher than that in healthy individuals, and the concentration was positively correlated with the degree of IBD. Horvatits et al. found the existence of microplastics in cirrhotic liver tissues, whose concentration was higher than that in liver samples from healthy individuals. Wu et al. detected microplastics in human aortic dissection thrombus samples and human acute arterial embolism samples. These results suggest that microplastics may be associated with the development of many chronic diseases, which may be harmful to human health.

3. Toxic effects of microplastics on climatic experiments.

Plastic leakage into marine habitats has shown sudden exponential growth in recent years, and by 2040, approximately 23–37 million metric tons of plastic waste will be noticed in marine habitats. The seriousness of this issue of plastic in water bodies is depicted by the fact that the persistence of plastic has been detected in the deepest layer (approximately 11 km below) of the sea in the Mariana Trench (Morelle, 2019). This plastic persistence in oceans releases harmful greenhouse gases, creates an alarming feedback loop, and disturbs the carbon-sink cycle.The unsuccessful management of plastic waste across the world has a direct and indirect impact on the global climate scenario. This is because plastic litter that does not end up in recycling plants is transformed into microplastics and enters rivers and oceans (Sharma and Chatterjee, 2017).

It poses a severe threat to marine biota and the climate, as plastic decomposition is associated with the release of greenhouse gases (carbon dioxide, methane, and ethylene). Research on microplastics suggests that the presence of microplastics in a marine ecosystem affects the ability of marine biota to absorb carbon dioxide and release oxygen, which could accelerate the loss of oceanic oxygen (Edmond, 2022). Waste management is not easy, as only one-fourth of the total plastic produced is recycled, owing to the lack of a functional waste management system. Authorities and industries are innovating different methods for plastic waste management, but some of these methods also contribute to GHG emissions. Incineration is one method that releases a large amount of GHG (mainly CO_2) along with highly toxic chemicals. This waste incineration, also known as waste-to-energy, is the key source of GHG emissions, although electricity generation is also associated with this process.

4. Ecosystem-Level Impacts:

Altered Sediment Properties: Microplastics can alter sediment density and composition, affecting benthic communities.

Changes in Nutrient Cycling: Microplastics can interfere with nutrient cycling processes in aquatic and terrestrial ecosystems.

Food Web Disruption: The transfer of microplastics through the food web can lead to bioaccumulation and biomagnification of associated pollutants.

Potential Human Health Concerns: Although direct evidence is still emerging, potential human health concerns are arising from:

Ingestion via Food and Drinking Water: Microplastics have been detected in various food products (e.g., seafood, salt) and drinking water sources.

Inhalation: Airborne microplastics can be inhaled, potentially affecting respiratory health.

Transfer of Additives and Pollutants: Exposure to plastic additives and adsorbed pollutants through food chain bioaccumulation.

Mitigation Strategies for Microplastic Pollution:

Effective mitigation requires a multi-pronged approach addressing the entire lifecycle of plastics, from production and use to waste management and environmental remediation. Mitigation strategies can be broadly categorized as:

1. Source Reduction: Preventing microplastics from entering the environment in the first place is the most effective approach. At production level, the use of plastics can be reduced by (a) using alternative (e.g., glass), recycled, or biodegradable materials; (b) improving the design to reduce the amount of plastic used, extend product life, allow repair and reuse, and improve recyclability by limiting the number of polymers, additives, and mixtures; and (c) banning certain types of single-use plastics.

Life cycle assessment (LCA) is a tool to assess environmental impact of a product or process from-cradle-to-grave, limited to a specific case study, functional unit, boundaries, and environmental indicators, providing an integrated view that helps producers find the most suitable eco-friendly alternative.

In several LCA of plastics and alternative materials, end-of-life strategies seem to have smaller environmental impacts when compared to eco-design, washing of reusable tableware ,and food loss caused by inefficient packaging. Suggested eco-design improvements include (a) packaging of larger sizes, lower weights, with increased reusability and recyclability; (b) use of lower-energy intensive materials; and (c) eco-friendly means of transportations and efficient shipping configurations. Nonetheless, increasing recycling rates could significantly decrease environmental impacts. For example, increasing recycling in polyethylene terephthalate (PET) bottles by 25–50% would decrease 5–230% in all environmental impacts, whereas a 5% increase in recycling of plastic packaging of legumes would reduce 7% of the global warming potential.

2. Policy and Legislation: Banning micro beads in personal care products, implementing extended producer responsibility schemes, and phasing out single-use plastics.

Promoting Sustainable Alternatives: Encouraging the use of biodegradable and compostable materials, bio-based plastics, and reusable alternatives.

Improving Product Design: Designing products for durability, repairability, and recyclability to minimize waste.

3. Reducing Microfiber Release: Developing fabrics that shed fewer fibers, promoting the use of laundry bags that capture microfibers, and installing filters in washing machines.

Waste Management and Recycling: Improving waste management practices to prevent plastic leakage into the environment.

4. Enhancing Waste Collection Infrastructure: Providing adequate waste collection services, especially in developing countries with limited infrastructure.

5. Improving Recycling Rates: Investing in advanced recycling technologies and promoting consumer participation in recycling programs.

6. Developing Waste-to-Energy Technologies: Using plastic waste as a fuel source in well-managed incineration facilities.

7. Nurdle Spills: Implementing strict regulations for the transport and handling of nurdles and developing effective clean up protocols.

8. Remediation and Removal: Cleaning up existing microplastic pollution in the environment.
Wastewater Treatment Upgrades: Installing advanced filtration systems in WWTPs to remove microplastics from effluent.

9. Targeted Removal Technologies: Developing innovative technologies for removing microplastics from aquatic environments, such as filtration, flocculation, and biodegradation.

10. Bioremediation: Exploring the potential of microorganisms to degrade microplastics.
Education and Awareness: Raising public awareness about the problem of microplastic pollution and promoting responsible consumer behavior.

11. Educational Campaigns: Educating consumers about the sources of microplastics and the impact of their choices. Education is a powerful tool in the fight against (micro)plastic pollution, there is a trend for increasing interest in this environmental problem supported by (a) free massive open online courses (e.g., MOOC on Marine Litter) or lectures and activities (e.g., TechWild; The Oceans Nova Scotia); (b) media (e.g., BBC's Blue Planet II; National Geographic's "Planet or Plastic") and apps (e.g., The Marine Debris Tracker, Sea Cleaner) ,(c) beach clean-ups, useful in awareness and remediation (e.g., Great Canadian Shore Clean up) ,(d) and inexpensive but valuable citizen science that could help map marine litter

12.Promoting Sustainable Consumption: Encouraging consumers to reduce their plastic consumption, opt for reusable products, and support sustainable businesses.

13. Labelling and Transparency: Implementing labelling requirements for products containing microplastics and providing information about proper disposal methods.

14. Research and Monitoring: Enhancing scientific understanding of microplastic pollution and its impacts.

15.Developing Standardized Methods: Creating standardized methods for sampling, identifying, and quantifying microplastics in different environmental matrices.
Investigating Pathways and Fate: Studying the transport, distribution, and fate of microplastics in the environment.

16. Assessing Ecological and Human Health Risks: Conducting comprehensive risk assessments to understand the potential impacts of microplastics on organisms and human health.

17. Evaluating Mitigation Strategies: Assessing the effectiveness of different mitigation strategies and identifying areas for improvement.

Challenges and Future Directions:

Despite growing awareness and increasing research efforts, significant challenges remain in addressing microplastic pollution. These include:

1. Complexity of the Problem: The diverse sources, pathways, and impacts of microplastics necessitate a multi-disciplinary approach.
2. Lack of Standardized Methodologies: The lack of standardized methods for sampling, analysis, and risk assessment hinders comparisons between studies and makes it difficult to assess the true extent of the problem.
3. Technological Gaps: Effective remediation technologies for removing microplastics from the environment are still under development.
4. Economic and Political Barriers: Implementing effective mitigation strategies requires significant investment and political will.

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5. Data Gaps: Many aspects of the microplastic cycle, including the fate and transport of microplastics in terrestrial environments, remain poorly understood.

Future research should focus on:

1. Developing more sensitive and reliable methods for detecting and quantifying microplastics in various environmental matrices.
2. Investigating the long-term ecological and human health impacts of microplastic exposure.
3. Developing effective and scalable remediation technologies for removing microplastics from the environment.
4. Promoting the development and adoption of sustainable alternatives to plastics.

Strengthening international cooperation and collaboration to address microplastic pollution globally

II. CONCLUSION

Microplastic pollution represents a significant environmental challenge that demands urgent and concerted action. By understanding the sources, pathways, and impacts of microplastics, and by implementing comprehensive mitigation strategies, we can reduce the flow of these pollutants into the environment and protect ecosystems and human health. A shift towards a circular economy, promoting sustainable consumption patterns, investing in innovative technologies, and strengthening international collaboration are crucial for tackling this global problem and ensuring a more sustainable future. The fight against microplastic pollution is not just an environmental imperative; it is an investment in the health of our planet and future generations.

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