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Microplastics as Environmental Pollutants: A Comprehensive Review of Biological and Health Consequences

Janaen Ya'rub. Al-Saeedi[1]   Salwa Abdulzahra. Abduljaleel[1]

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Author affiliation:
Department of Biology, College of Science, University of Basrah, Iraq

shaima.shueayb@uobasrah.edu.iq
salwa.abduljaleel@uobasrah.edu.iq

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ABSTRACT

Microplastic pollution is now a lasting environmental problem. It affects the health of ecosystems and the health of humans. This review synthesizes current knowledge on the sources, environmental distribution, exposure pathways, and biological effects of microplastics across aquatic, terrestrial, and atmospheric systems. Primary microplastics are made on purpose for industry and consumer uses. Secondary microplastics form when big pieces of plastic break down. Both primary and secondary microplastics appear in water, soil, air, food and biological samples. In the water animals and the land animals microplastics often cause trouble eating, slower growth, cell damage from chemicals, inflammation and damage, to tissues. At the cell and molecule level microplastics can kill cells and damage DNA. Microplastics also disturb the system and change how genes work. The ability to adsorb and transport co-occurring contaminants, like metals and persistent organic pollutants makes the contaminants more toxic. The human exposure comes mainly from eating and breathing. The ability to hold onto and move contaminants, such, as heavy metals and persistent organic pollutants creates combined and joint biological effects. The human exposure happens mainly through eating or breathing some microplastics and that interpret found microplastics in stool, blood, and placental tissues. The microplastics risks include cell damage, swelling, hormone disruption and buildup of chemicals.

الدقائق البلاستيكية ملوثات بيئية وآثارها البيولوجية والصحية، مراجعة شاملة

جنائن يعرب محمود   سلوى عبد الزهرة عبد الجليل

يُعدّ التلوث بجسيمات البلاستك دقيق الحبيبات (المايكروبلاستيك) مشكلة بيئية مستمرة. يؤثر هذا التلوث على النظم البيئية وصحة الإنسان. تستعرض هذه الدراسة المعرفة الحالية حول مصادر الجسيمات البلاستيكية الدقيقة، وتوزيعها البيئي، وطرق التعرض لها، وآثارها البيولوجية في النظم المائية والبرية والغلاف الجوي. تُصنع الجسيمات البلاستيكية الدقيقة الأولية خصيصًا للاستخدامات الصناعية والاستهلاكية. أما الجسيمات البلاستيكية الدقيقة الثانوية فتتشكل عند تحلل قطع البلاستيك الكبيرة. وتوجد كلتاهما، الأولية والثانوية، في الماء والتربة والهواء والغذاء والعينات البيولوجية. غالبًا ما تُسبب الجسيمات البلاستيكية الدقيقة للحيوانات المائية والبرية صعوبة في الأكل، وبطء النمو، وتلف الخلايا نتيجة المواد الكيميائية، والتهابات وتلف الأنسجة. على مستوى الخلية والجزيء، يمكن للجسيمات البلاستيكية الدقيقة أن تقتل الخلايا وتُتلف الحمض النووي. كما تُخلّ الجسيمات البلاستيكية الدقيقة بالنظام وتُغير طريقة عمل الجينات. إن قدرة هذه الجسيمات على امتصاص ونقل الملوثات المصاحبة لها، مثل المعادن والملوثات العضوية الثابتة، تجعلها أكثر سمية. ويأتي تعرض الإنسان لها بشكل رئيسي من خلال الأكل والتنفس. تُؤدي قدرة الجسم على الاحتفاظ بالملوثات ونقلها، مثل المعادن الثقيلة والملوثات العضوية الثابتة، إلى آثار بيولوجية مُجتمعة ومُتداخلة. ويحدث تعرض الإنسان لها بشكل رئيسي عن طريق تناول أو استنشاق بعض الجزيئات البلاستيكية الدقيقة، والتي تُوجد أيضًا في البراز والدم وأنسجة المشيمة. وتشمل مخاطر هذه الجزيئات تلف الخلايا، والتورم، واضطراب الهرمونات، وتراكم المواد الكيميائية.

INTRODUCTION

Microplastic pollution has become one of the most widespread and intricate environmental problems of the 21st century that become a real threat to the ecosystem, biodiversity, and even human health. (Geyer *et al.*, 2017; UNEP, 2021). Microplastics are generally defined as plastic particles smaller than 5 mm in diameter and originate either from the fragmentation of larger plastic debris (secondary microplastics) or from intentionally manufactured microscopic plastics used in industrial, cosmetic, and biomedical applications (primary microplastics) (Arthur *et al.*, 2009; Cole *et al.*, 2011). They last a long of time, appear everywhere, and can build up in animals and move up the food chain (Browne *et al*., 2011; Napper & Thompson 2016). more than four hundred million tons of plastic produced yearly from the plastic factories in the world, especially by the developed countries, and a huge part of them gets into the environment (OECD, 2022). Microplastics fall into two groups; primary and secondary microplastica. Primary microplastics are made on purpose, such, as microbeads, pre-production pellets and textile fibers, while secondary microplastics come from the break-up of plastic pieces by forces, sunlight or living organisms (Bläsing & Amelung 2018). Researchers have found microplastics move through a cycle that links the air with the water and the soil (Dris *et al*. 2018). Allen *et al*., 2019; Rillig, 2018). In general, microplastics reduce the growth of the animals, and cause stress, inflammation and tissue damage (Wright *et al*., 2013; Lu *et al*., 2016; Hwang *et al*., 2019). Furthermore, at high levels, microplastics cause DNA damage, and change gene activity (Schirinzi *et al*., 2017; Shen *et al*., 2021). Some researchers referred to importance of the detection of microplastics, in samples, such as stool, blood and placental tissue, and the risks of traveling microplastics through the body and what long-term health effects microplastics could cause (Schwabl *et al*., 2019; Ragusa *et al*. 2021; Leslie *et al*., 2022). Additionally, the microplastics can carry the metals and the persistent organic pollutants (Rochman *et al*., 2013; Andrady, 2011). In contrast, the ways to fix microplastics are still insufficient. This review integrates current understanding of microplastic classification, microplastic distribution, microplastic biological and health effects and the new clean-up methods, for microplastics, and emerging remediation strategies to guide environmental management and policy development.

1. Classification and properties of microplastics

Four factors can be considered as the base of any standardized classification of microplastics; origin, size, shape, and the polymer composition. Therefore, evaluating environmental behavior, exposure pathways, and associated risks of the microplastics can be determined depending on these factors (Frias & Nash 2019).

Table 1. Classification of Microplastics

Classification Criterion	Main Categories	Examples / Notes
Origin	Primary	Microbeads in cosmetics; pre-production pellets (nurdles); textile microfibers.
	Secondary	Fragments from degraded bottles/bags; fibers from synthetic clothing (via washing/wear).
Size	Microplastics (1 µm–5 mm)	Large MPs (1–5 mm); Small MPs (1 µm–1 mm).
	Nanoplastics (<1 µm)	High cellular penetration potential, major analytical challenges.
Shape	Fibers	Dominant in aquatic and atmospheric samples.
	Pellets/Beads	Industrial and cosmetic sources.
	Fragments	Irregular shapes from degraded plastics.
	Films	Derived from packaging and plastic bags.
Polymer Type	PE, PP, PS, PET, PVC	PE and PP are most abundant environmentally.
		Properties (density, rigidity) vary,
		affecting environmental fate.

2. Methodological challenges

Variability in size definitions, distinguishing synthetic fibers from natural ones, and changes due to environmental aging complicate accurate identification (commonly using FTIR or Raman spectroscopy).

2.1 Environmental Fate: Sources, Distribution, and Aging

2.1.1 Sources

Microplastics originate from diverse anthropogenic activities:

- Primary Sources: Personal care products such as Face scrubs and Exfoliating scrubs, industrial pellets such as pellets produced from high density poly ethylene (HDPE) plant and low density poly ethylene (LDPE) plant, tire wear particles, textile fibers released from laundering.
- Secondary Sources: Degradation of larger plastic waste (bags, bottles, fishing gear) by UV radiation, heat, waves and microbial activity (Yousafzai *et al*. 2025).

2.1.2 Environmental Distribution

- **Aquatic systems:** carry microplastics of urban, industrial and agricultural origin to ocean waters. The treatment plants of wastewater also serve as sinks and secondary sources, particularly fibers (Sun *et al*., 2019; Talvitie *et al*., 2017). Heterogeneous distributions are found in marine waters, sediments and marine organisms. The lighter polymers (PE, PP) are accumulated on the surface, whereas the heavier ones (e.g., PVC) settle down to the benthic areas.

- **Terrestrial ecosystems:** Agricultural soils that receive sewage sludge or plastic mulch films collect microplastics. The agricultural soils collect microplastics at levels that can be higher than the levels, in sediments.
- **Atmospheric transport:** Atmospheric transport: microplastics in the urban areas in the rural areas and in the remote areas. Airborne microplastics travel distances. Airborne microplastics land on the land and, on the water surfaces (Allen *et al*. 2019).

2.1.3 Aging and Transformation Processes

- Microplastics are always active in the environment, and their particles go through "aging processes that are driven by:
- • **UV Radiation:** UV radiation breaking bonds, changing the color, making the material brittle, and creating carbonyl and oxide groups on the surface (Andrady *et al*., 2019).
- • **Oxidation and Mechanical Abrasion:** From wave action and sediment movement.
- • **Biological Degradation:** By microorganisms, albeit slowly.
- **Consequences of Aging:** Aging increase the porosity, and specific surface area of the particles. Therefore, the adsorption capacity of these particles enhances drastically toward removing organic pollutants such as pesticides and heavy metals (Wang *et al*., 2022). In addition, aging leads to create nanoplastics that increase the bioavailability of the pollutants and potential toxicity.

3. Analytical and detection techniques: from sampling to identification

3.1 Sampling and Pre-treatment Challenges

Initial steps are critical and impact result accuracy:

- Sampling: sampling methods vary to get a sample, from the water the soil or the air. While grabs can use to get samples of soil, both trawls and grabs use to get samples of water. A filter is used usually to get samples of air.
- • Pre-treatment: Pre-treatment is conducted by removing organic matter using oxidants (e.g., H_2O_2) or enzymes. This process should be done with maintain the plastic particles formation. Mineral matters are separated using density separation (high-density salt solutions).

3.2 Detection and Characterization Techniques

Table 2. Techniques for Microplastic Analysis

Technique	Detection Limit	Advantages	Limitations	Common Applications
Visual Microscopy	> 300 µm	Low cost, rapid	Subjective, does not identify polymer	Preliminary surveys, sorting.
FTIR / µFTIR	10–20 µm	Polymer-specific, spatial mapping	Limited for nanoplastics	Particles in water, sediment, biota.
Raman spectroscopy	< 1 µm	High resolution, analyzes very small particles	Susceptible to fluorescence interference, long analysis time	Nanoplastics, analysis within tissues.
Py-GC–MS	Mass-based	Quantitative, precise polymer mass determination	No particle-level information	Complex samples, organic matrices.
AFM–IR / Nano-FTIR	< 100 nm	Nanoscale resolution, nanoscale chemical analysis	Extremely high cost, purely research-based	Advanced nanoplastic research.

4. Bioaccumulation, biomagnification, and trophic transfer

Microplastic particles build up inside organisms, and move across the food chain. Four factors affect this process; the size of particles, the type of polymer, retention time, and the surface chemistry. The evidence for biomagnification (which means high levels of microplastic particles in the food chain) is still not clear and needs more research.

Table 3. Evidence of Trophic Transfer

Ecosystem	Organism Group	Particle	Key Findings	Reference
Marine	Phytoplankton → Fish	< 50 µm, PS, PE	Trophic transfer	Setälä *et al*., 2014
Freshwater	Zooplankton → Fish	Fibers, fragments	Size-dependent	Wang *et al*., 2022

Terrestrial	Soil invertebrates → Birds	Fibers	Gut accumulation,	Huerta Lwanga *et al*., 2017

5. Molecular and cellular mechanisms of toxicity

Microplastics attach to the cell membrane, taken up by endocytosis, move through the membrane, and triggering a chain of events:

1. **Oxidative Stress and Inflammation:** Particles motivate the cells to produce reactive oxygen species that play a significant role in damaging the lipids, proteins and DNA. The damage turns on signaling pathways such as NF-kB and MAPK which prompts the body to respond and to trigger cell death (Liu et al., 2021).
2. **Genotoxicity:** can cause damage to the DNA by damage a single and/or double strand breaks and mutations.
3. **Endocrine Disruption**: plastic additives (phthalates and bisphenol) which have ability to interfere with the hormonal system act as Endocrine-disrupting chemicals (Campanale *et al*. 2020).
4. **Epigenetic Modifications and Transgenerational Effects:** exposure can cause changes in the histone modifications and DNA methylation. The changes can be inherited by the following generations. The next generations can experience health effects even though they did not have exposure (Wang *et al*., 2022).

6. The plastisphere: microplastics as microbial habitats and vectors

The surface of microplastics is a habitat for microbial communities which very different from those in the surrounding soil or. (Amaral-Zettler *et al*., 2020)

• **Unique microbial communities:** can have three types of bacteria (fermentative, degradative and phototrophic) which affect the carbon cycle and the local nitrogen cycle.

• **Vector, for Pathogens and Antibiotic Resistance:** The "plastisphere" can host the pathogens (for example Vibrio spp.) and the antibiotic resistance genes (ARGs). The plastisphere works as a "Trojan horse" which carries the pathogens and the antibiotic resistance genes for long distances (Yang *et al*., 2022).

• **Ecological impacts:** may change the nutrients that're available and the makeup of the surrounding communities.

7. Interactions with other environmental contaminants

Microplastics act as active carriers for pollutants due to their large surface area and hydrophobic nature:

- • **Contaminant Adsorption:** Heavy metals such as lead and mercury, persistent organic pollutants such as PCBs and pesticides, antibiotics and hormones can stick on the particle surfaces (Akhtar *et al*., 2022).
- • **Combined Toxic Effects:** When the organism ingests some chemicals, the bioavailability of the co-contaminants increases. This increase produces effects that are higher than the toxic effects of each component alone (Rodriguez-Mozaz *et al*., 2020; Bhagat *et al*., 2022).

8. Ecological impacts

8.1 Aquatic Ecosystems

Ingestion across trophic levels reduces the energy intake, impairs the growth and impairs the reproduction, creates oxidative stress, creates inflammation, damages the tissue, and raises the mortality especially in the larval stages (Singh *et al*., 2025).

8.2 Terrestrial Ecosystems

- • **Soil:** Microplastics affect the soil structure, the volume of pores, water- holding capacity, and the cycle of nutrient.
- • **Microbial Communities:** change the composition and function of the soil microbiome.
- • Plants can stop the root growth, the water uptake and the nutrient uptake lowering the productivity.
- • **Invertebrates:** Adversely affect earthworms, soil animals needed for fertility (Mao *et al*., 2025).

8.3 Atmospheric Impacts

Microfibers dominate air samples. Contribute to airborne particulate matter (PM) pollution and may act as cloud condensation nuclei (Hu *et al*., 2025).

9. Human exposure and potential health effects

9.1 Exposure Pathways

1. **Ingestion:** Seafood, salt, drinking water (especially bottled), honey, beer, crops grown in contaminated soil.
2. **Inhalation:** Indoor air (from furnishings and textiles) and outdoor air.
3. **Dermal Exposure (Emerging):** Dermal Exposure (Emerging) comes from cosmetics that contain microbeads and from textiles. Emerging does not get through the skin barrier easily (Niebel *et al*., 2025).

9.2 Detection in Human Tissues

Researchers found particles in human stool, lung tissue, blood, placenta, and breast milk, indicating the microplastic particles can cross the body's barriers (Sutkar *et al*., 2025).

9.3 Insights from In Vitro and Animal Studies

These studies indicate potential risks related to:

- **Oxidative stress and chronic inflammation** in intestinal and lung cells.
- **Mitochondrial** dysfunction**.**
- **Reproductive and** developmental **toxicity.**

Gut Microbiome Dysbiosis: Microplastics alter the gut community "dysbiosis" which may link to metabolic disorders and immune disorders (Jin *et al*., 2019).

10. Microplastics and climate change: a two-way interaction

Table 4. Interplay Between Microplastics and Climate Change

Climate Factor	Effect on Microplastics	Environmental Implications / Feedback
UV Radiation	Increases photo-degradation and fragmentation (aging)	Faster production of nanoplastics, increased toxicity potential.
Rising Temperature	Accelerates polymer aging, may increase leaching of additives	Altered particle properties and associated toxicity.
Extreme Events (floods, storms)	Enhances dispersion and transport from land-based sources to aquatic systems.	Wider distribution, accumulation in coastal areas and sediments.
Ocean Acidification	May alter particle surface chemistry (protonation)	Modifies adsorption capacity for other pollutants.

11. Socioeconomic costs and policy frameworks

11.1 Economic Cost Assessment

- The effect of microplastic pollution does not end at the damage of the environment, but at the economic costs (Beaumont *et al*. 2019):
- Fisheries Sector: Lost fisheries, partial destruction of fishing equipment, loss in commercial price of contaminated fish.
- Tourism: The costs of cleaning the beaches, attractiveness of the polluted places. Agriculture: Hypothetical expenses of curing exposure-attributed diseases.
- Healthcare: The possible expenses through the treatment of exposure-attributed diseases..

11.2 Current Policies and Regulatory Gaps

- **Limited Measures:** Restriction on microbeads in cosmetics, and some single-use plastic
- **Challenges:** Lack of a legally binding global treaty, non-standardized monitoring methods, difficulty regulating diffuse sources (e.g., tire wear).
- • **Current Trend:** formal negotiations under the UN Environment Assembly (UNEA) to issue an international, legally binding agreement about plastic pollution.

11.3 The Role of Circular Economy and Innovation

- Transitioning from a "take-make-dispose" model to a circular economy is important, and contain:
- Investing in products for durability, reusability, and effective recyclability.
- Enhancing global waste collection and recycling systems.
- Using biodegradable alternative materials under different alternative materials.

12. Emerging trends in remediation and mitigation

1. **Enhanced Biodegradation:** Determining and designing enzymes and bacteria. (such as *Ideonella sakaiensis* that digests PET) to enhance the breakdown of plastic types (Peng *et al*., 2023).
2. **Photocatalytic Degradation:** Enabling the light-driven degradation of microplastics into less harmful products through the use of photo-catalytic nanomaterials (e.g., TiO_2). (Mohana *et al*., 2023).

3. **Source-Control Preventive Strategies:**

- Install washer machine filters to trap microfibers.
- Reduction in fabric materials to reduce fiber shedding.
- Application of constructed wetlands in wastewater treatment plants to be used in effective particle filtration.
- Increased efforts in waste management so as to reduce losses of plastic to the environment.

13. New technological approaches to addressing environmental microplastic

13.1 Advanced Filtration and Removal Systems

- **Biodegradable & Nanocellulose Filters**

Scientists are working on biodegradable filters crafted out of plant materials (e.g. nanocellulose) that can filter out microplastic particles present in wastewater and water runoffs without introducing additional plastics into the ecosystem. They can be fitted in the treatment plants or drainage systems to capture the small particles. (Sayam *et al*., 2026).

- **Natural Material Filters (Ct-Cel)**

A team at Wuhan University created a natural filter (Ct-Cel) from chitin (from squid) and cellulose (from cotton) that removes up to 99.9 % of microplastics from water in lab tests — demonstrating a low-cost, sustainable option.

- **BioCap Tannins-Wood Filter**

In Canada, scientists came up with BioCap filter, which is a combination of plant tannins and wood sawdust designed to remove almost all microplastics in water. This technology employs renewable and biodegradable materials which minimise pollution and contain the pollutants.

- **Washing Machine Microplastic Filters**

Biological inspiration Biological filters are being developed based on the principles of fish gills that can be used to capture microplastics discharged in laundries before being directed into wastewater systems; others of this kind are projected to intercept 99 percent of the fibers.

13.2. Nanotechnology and Advanced Materials

- **Nanofiber and Modified Membrane Filters**

Electrospun PVDF nanofiber membranes modified with biosurfactants and metal oxides show very high removal efficiency (≈99.99 %) for microplastic particles from wastewater while resisting clogging and improving water flow (Acarer, 2023).

- **Magnetic Ferrofluid and Nanomaterials**

Magnetic nanotechnologies—like magnetic ferrofluids that bind microplastics—allow particles to be removed from water easily using magnets, a method developed and refined by researchers and young inventors alike(Ferreira, n.d.).

- **Nanoremediation Approaches**

Nanoparticles are being investigated as a way of environmental cleanup (nanoremediation) to remove such contaminants as microplastics in water and soils, as a chemical/physical approach to remediation..

13.3. Photocatalytic and Chemical Conversion

- Photocatalytic Degradation to Useful Products

Recent studies are using photocatalysts (such as brookite TiO 2) to transform plastic particles into valuable chemicals (via light, e.g. acetic acid) and hydrogen fuel, transforming pollutants into resources and clean energy at the same time. (Guardian Environment 2024).

13.4. Detection and Monitoring Technologies (Support for Treatment)

Although it does not involve direct removal, better surveillance systems facilitate the identification of microplastic hotspots and direct cleanup strategies (which are significant in cleanup projects):

With assistance of AI, sensors are able to quickly identify and categorize plastics in water to help the treatment systems focus more accurately on the problem areas.

Robotic survey machines map the areas of microplastic contamination on the beaches to plan a targeted cleanup (Acarer, 2023).

Machine learning Microwave cytometry is a high throughput detection method and shape analysis that enhances the accuracy of monitoring.

13.5. New Plastic Materials That Prevent Microplastics

- **Plastics That Dissolve Without Leaving Microplastics**

Scientists in Japan developed a new kind of plastic that dissolves in seawater and decomposes fully, leaving no microplastic residues — a proactive strategy to reduce future pollution (Badawi *et al* ,2025).

Table 5. The new technological approaches to addressing environmental microplastic

Technology	Type	What It Does
Biodegradable/Natural Filters	Filtration	Removes microplastics in water sustainably
Nanomaterial Filters	Nanotech filtration	Traps tiny particles efficiently
Photocatalytic Conversion	Chemical/energy recovery	Breaks plastics into useful chemicals + H_2
AI & Automated Detection	Monitoring tech	Helps locate and quantify microplastics
Dissolving Plastics	Material innovation	Prevents microplastic formation

- **Examples of Countries Reducing Microplastic Pollution**

A number of countries have also adopted regulatory and policy-based intervention to mitigate microplastic pollution with a predominant emphasis on source control and waste management. The European Union presented the policy on deliberately added microplastics restrictions in the form of the REACH regulation and encouraged the policies of the circular economy to reduce the production of plastic waste (European Commission, 2023). Likewise, the Netherlands banned the use of microbeads in cosmetics, which will reduce primary microplastic emissions into water bodies by a substantial margin (UNEP, 2018). Canada imposed a countrywide prohibition on some single-use plastic products, which target the deterrence of plastic fragmentation into macroplastics into the soil and water ecosystems (Government of Canada, 2022). China introduced a staged single-use plastic (plastic bags and plastic straws) prohibition as a part of a nation-wide initiative to decrease plastic waste and its downstream effects of microplastics (State Council of China, 2020). Also, other nations, including Rwanda, Kenya, and Bangladesh, have imposed a ban on plastic bags, proving that a powerful legislative response can lead to a decrease in plastic waste that is one of the causes of microplastic pollution in the long term. (UNEP, 2018).

Table 6. Examples of Countries Reducing Microplastic Pollution

Country / Region	Main Strategy	Contribution to Microplastic Reduction	Reference
European Union	Restriction of intentionally added microplastics (REACH)	Prevents direct release of primary microplastics	European Commission, 2023
Netherlands	Ban on microbeads in cosmetics	Reduces microplastics entering wastewater	UNEP, 2018
Canada	Ban on single-use plastics	Limits plastic fragmentation into microplastics	Government of Canada, 2022
China	Phased ban on plastic bags and straws	Reduces sources of secondary microplastics	State Council of China, 2020
Rwanda / Kenya / Bangladesh	Nationwide plastic bag bans	Prevents environmental plastic accumulation	UNEP, 2018

14. Fungi and plastic pollution

Plastic pollution is a long-term ecological issue because of the inertness of synthetic materials containing polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyurethane (PU). Due to their good enzyme systems and the capacity to colonize a solid substrate, fungi have become a promising bioremediation agent of plastics.

Fungi are particularly effective in degrading plastics because they:

- Produce extracellular oxidative and hydrolytic enzymes
- Grow as hyphae, allowing penetration into polymer surfaces
- Tolerate harsh environmental conditions
- Degrade complex natural polymers (e.g., lignin), which are structurally similar to plastics

14.1 Mechanisms of Fungal Plastic Degradation

Fungal degradation of plastics occurs mainly through the following steps:

1. Surface colonization
   Fungal spores attach to plastic surfaces and form biofilms.
2. Enzymatic oxidation and hydrolysis
   Fungi secrete enzymes such as: Laccases, Manganese peroxidase (MnP), Lignin peroxidase (LiP), Cutinases, Esterases.
3. Polymer chain cleavage
   These enzymes break C–C, C–O, and ester bonds, reducing molecular weight.
4. Assimilation and mineralization
   Degradation products are absorbed and metabolized into CO_2, H_2O, and fungal biomass.

Table 7. Major Plastic-Degrading Fungi and Target Polymers

Fungus	Plastic Type	Notes
Aspergillus niger	PE, PS	Surface erosion and weight loss
Penicillium simplicissimum	PE	Oxidative degradation
Fusarium solani	PU	Efficient ester bond cleavage
Phanerochaete chrysosporium	PE, PVC	Strong ligninolytic enzymes
Trichoderma viride	PE	Biofilm-assisted degradation

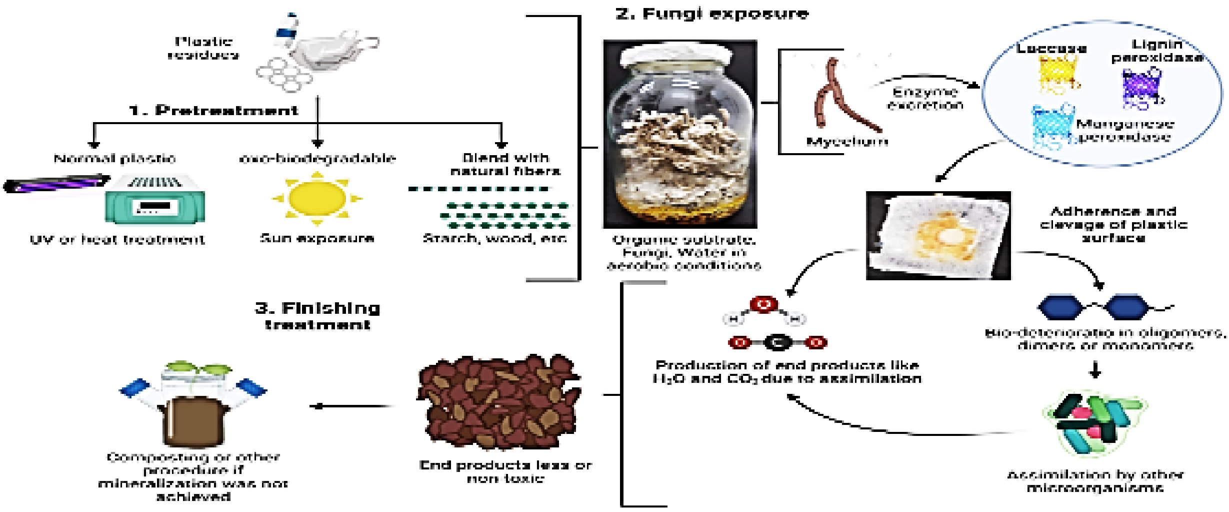

Fig. 1. Bioremediation of plastic polymers by fungi (white root fungi) (Mohanan *et al*,2023)

.CONCLUSION

Plastic pollution is a multi-boundary and multi-faceted environmental problem. It is directly associated with the trends of plastic production and consumption in the world. The review illuminated the origin of microplastic contamination, modes of distribution, and the impact of the same on the living organisms, starting with the cells and all the way to the entire ecosystem. The identification of microplastics in the environment and human body is the matter that should be paid significant attention to contact with other pollutants and climate change also adds to the complexity and hazards. Microplastic pollution has become a widespread environmental hazard that has found its way into terrestrial systems, freshwater systems, and marine systems and has had compounding effects on human and ecological health. Small size, persistence and chemical interactions of microplastics make conventional waste management and water treatment strategies ineffective to a large extent.

Protecting environment and human health from the thread demands requires an integrated strategy that unit scientific research, policy development, societal engagement, and technological innovation. The ultimate objective is to move toward a sustainable economy within planetary limits. High tech interventions such as membrane filtration, advanced oxidation, electrocoagulation and new bio-based remediation methods have shown positive prospects of reducing microplastic contamination. Nonetheless, these remedies are usually limited by high costs of operation, energy requirements and total elimination of nanoscale particles. Future policy should, however, incorporate multi-tier solutions, which is a combination of policy enforcement, source reduction, material innovations, and scale technological treatments. In addition, sustained surveillance, standard screening procedures, and trans different research is needed to be able to comprehend microplastic behavior, environmental fate, and adverse long-term health effects in their entirety. To conclude, microplastic pollution will require an interdisciplinary approach between innovative technology and environmentally friendly management to ensure the integrity of the ecosystem and human wellbeing. Thus, the application of the knowledge in coordinated action with practical steps is significant in the predictable future. This requires:

• Promoting the rapid development and implementation of effective policies from local to global levels, focusing on source prevention strategies.

• Encouraging the investment in innovative approaches, which include alternative materials, circular product design, and effective remediation technologies.

• Mobilizing communities and utilizing citizen science for environmental monitoring and driving sustainable solutions.

• Bridging essential knowledge gaps through investment in innovative, cross-disciplinary research.

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