Micro and nano-plastic pollution: Review article on alternatives to solving through biology

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Abstract

The rapid expansion of plastic consumption and the ease of use these cheap, long-lasting chemical compounds, especially in the form of micro and nano particles, has caused pollution of water, soil, and even air resources. Unfortunately, management recommendations to reduce consumption and replacement it by bioplastic have not been very effective, and it seems that the sustainable solution is through biological approaches such as enhance elimination, reduce absorption, or even biologically degrade these particles and finally, some genetic engineering manipulations changing the function of microorganisms such as the production of degrading enzymes or CRISPR engineering, etc., are the only solutions facing humanity. This article reviews these approaches in detail.

Keywords: MPs and NPs pollution, Biodegradation, Bioplastic, Engineering approach

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Introduction

Microplastics (MPs) and nanoplastics (NPs) have indeed become a pressing global environmental and health concern due to their pervasive presence and potential toxicity. A growing concern is their ingestion by organisms and potential infiltration into cells, jeopardizing the health of consumers including humans. Various ways have been proposed to solve the problem of polymer plastic pollution, reducing plastic use, improving recycling, adopting circular economy models and replacing them with bioplastics, which has not been successfully promoted due to the increase in the world population ignorance, easily industrial applications of these cheap plastics and their long-term durability combined with strength. Today's preference is to use the same plastics, approached to solving environmental problems with biological methods such as enhance elimination, reduce absorption, or even biologically degrade these particles and finally, some genetic engineering manipulations changing the function of microorganisms such as the production of degrading enzymes or CRISPR engineering, etc., of course, taking into account some challenges and Ethical Concerns. In these methods, various microorganisms will be used to biodegrade plastics to reduce the longevity of these water, soil and even air pollutants to the shortest possible time.

Here's a breakdown of the key issues and current understanding:

1. Sources of MPs and NPs and Ubiquity (Onyedibe *et al*., 2023)

- Primary Sources: Microplastics (≤5 mm) and nanoplastics (≤1 μm) originate from the breakdown of larger plastic debris, synthetic textiles, car tires, personal care products (microbeads), and industrial waste.
- Secondary Sources: Environmental degradation (UV exposure, mechanical abrasion) of plastics into smaller particles.
- Ubiquity: Found in oceans, freshwater, soil, air, and even remote regions like the Arctic and deep-sea trenches.

2. Ingestion by Organisms (Wang *et al*., 2025)

- Marine Life: Filter feeders (e.g., mussels, plankton), fish, and seabirds ingest MPs/NPs, mistaking them for food.
- Terrestrial Organisms: Earthworms, insects, and mammals (including livestock) consume MPs/NPs via contaminated soil and water (Ge *et al*., 2021).
- Human Exposure (Zhu *et al*., 2024):
  - Diet: Seafood, salt, bottled water, and even fruits/vegetables (via soil uptake).
  - Inhalation: Airborne MPs from synthetic fabrics and dust.
  - Drinking Water: Both tap and bottled water contain MPs.

3. Cellular Infiltration and Toxicity (Mahmud *et al*., 2024).

- Inflammation and Oxidative Stress: MPs/NPs may trigger immune responses and cellular damage.

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- Endocrine Disruption: Some plastics contain/additives like phthalates and BPA, which are known endocrine disruptors.
- Genotoxicity and Metabolic Effects: Possible DNA damage and interference with nutrient absorption.
- Bioaccumulation: MPs/NPs may accumulate in organs over time, though long-term effects are unclear.

Enhance elimination, reduce absorption, or even biologically degrade (Cai *et al*., 2023)

Currently, there is no proven method for humans or animals to fully digest or break down microplastics (MPs) and nanoplastics (NPs) in the body. Plastics are synthetic polymers (e.g., polyethylene, polystyrene) that are highly resistant to enzymatic degradation in the digestive system. However, research is exploring potential ways to enhance elimination, reduce absorption, or even biologically degrade these particles. Here's what we know so far:

1. Natural Elimination (Nayanathara *et al*., 2024)

- Excretion via Feces: Some larger MPs may pass through the gut without absorption, but NPs can cross intestinal barriers.
- Liver/Kidney Clearance: Small NPs may be filtered by the liver and kidneys, but chronic exposure could lead to accumulation.

2. Potential Strategies to Reduce or Degrade MPs/NPs (Mustapha *et al*., 2024)

A. Enhancing Gut Clearance

- Dietary Fiber: High-fiber foods (e.g., psyllium, whole grains) may bind to MPs and promote fecal excretion.
- Probiotics and Gut Microbiome: Some studies suggest certain gut bacteria (e.g., Bacillus cereus, Enterobacter aerogenes) can partially degrade plastics, but this is not yet practical for humans.

B. Biodegradation (Experimental)

- Enzymatic Breakdown: PETase and MHETase (discovered in *Ideonella sakaiensis*) can degrade polyethylene terephthalate (PET) (Yoshida *et al*., 2021). Fungal and Bacterial Enzymes (e.g., from *Aspergillus fungi*) show promise in lab settings (Ibrahim *et al*., 2024). But these enzymes are slow, inefficient, and not adapted to human physiology.
- Nanomaterials as Catalysts: Researchers are testing nanozymes (synthetic enzymes) to break down plastics, but safety in humans is unknown (Yu *et al*., 2024).

C. Blocking Absorption

- Mucosal Barriers: Some studies explore chitosan (a natural polymer) to trap NPs in the gut and prevent uptake.
- Activated Charcoal: May bind to some MPs, but evidence is lacking for NPs.

D. Medical Interventions (Future possibility)

- Nanoparticle Scavengers: Synthetic "sponges" (e.g., carbon-based nanomaterials) could theoretically capture NPs in the bloodstream, but this is speculative.

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- Targeted Drug Delivery: Future therapies might use liposomes or other carriers to remove NPs from cells.

3. Prevention is still the best approach

Since it can't yet effectively digest or remove MPs/NPs from the body, reducing exposure is critical:

- Avoid Plastic Packaging: Use glass/stainless-steel containers.
- Filter Water: Reverse osmosis (RO) filters can remove some NPs.
- Limit Seafood Consumption: Especially filter feeders (e.g., mussels, oysters).
- Choose Natural Fibers: Synthetic clothing (e.g., polyester) sheds MPs in laundry.

4. Future research directions

- Synthetic Biology: Engineered bacteria or enzymes for gut-based plastic degradation.
- Detoxification Therapies: Similar to chelation therapy for heavy metals, but for plastics.
- Biomarkers for Exposure: To monitor MP/NP levels in humans.

Here's a detailed look at some plastic-eating organisms (Johnson, 2024) including their mechanisms and potential applications:

Worms:

- Mealworms (*Tenebrio molitor*): Zhong (2022) reported the protocol extracts plastic-degrading bacteria (*Exiguobacterium* spp., *Pseudomonas* spp.) from mealworm guts to create a liquid culture that breaks down polystyrene (PS) and polyethylene (PE).
- Waxworms (*Galleria mellonella*): Bombelli *et al*. (2017) accidentally found that waxworm can eat polyethylene (PE) and discovered that worm's saliva contains demethylenase enzymes oxidized PE into ethylene glycol (detoxified by the liver) and symbiotic gut bacteria" Enterobacter and Bacillus strains further degrade PE. In this research it had been showed that 100 waxworms can degrade 92mg of PE efficiently in 12 hours, however, some limitations still remain, for example byproducts (e.g., glycol) may require detoxification (Bombelli *et al*., 2017).

Superworms (*Zophobas morio*): Sun *et al*. (2022) showed the capability of this worm to digest polystyrene (PS) via gut bacteria (*Pseudomonas*, *Brevundimonas*).

Fungi:

- *Aspergillus tubingensis*: Khan *et al*. (2017) revealed this fungus secretes hydrolases and esterases to break down polyurethane (PU)- based foams in weeks.
- *Pestalotiopsis microspore*: Yale researchers (Biodegradation of Polyester Polyurethane by Endophytic Fungi, 2011) identified that this Amazonian fungus degrades PET and PU anaerobically by serine hydrolase secretion which can be cleave plastic bonds (no oxygen needed).

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- *Fusarium solani*: Khan *et al*. (2017) also reported that this marine fungus strain breaks down polyethylene (PE) in seawater by oxidizing it into ketones.

Marine bacteria and algae

- *Rhodococcus ruber*: The action of this microorganism forms biofilms on PE and metabolizes it into CO_2 + water (Sivan *et al*., 2006). This is a part of the "plastisphere" microbiome in oceans as natural role.
- *Alcanivorax borkumensis*: This microorganism is famous as oil-eating bacterium which Engineered to degrade hydrocarbon-based plastics (e.g., PE) (Zadjelovic *et al*., 2022).
- Microalgae (*Chlorella*): Their action mechanism is adsorbing MPs onto cell surfaces and secrete exopolysaccharides to trap them which will be used for water filtration systems (Fang *et al*., 2024).

Insect larvae

- Black soldier fly larvae (*Hermetia illucens*): This larva can digest PVC-containing waste (though slowly). Klebsiella, Enterococcus two of their gut bacteria play a key role (Wang *et al*., 2024).
- Greater wax moth larvae (*Galleria mellonella*) also degrade PP (polypropylene) in addition to PE (Bombelli *et al*., 2017).

Synthetic biology solutions

- Engineered *E. coli*: Modified to produce PETase + MHETase enzymes for PET degradation. Some strains can convert plastic waste into vanillin (Sadler and Wallac, 2021).
- Biohybrid Systems: Combining algae + bacteria to create self-sustaining MP cleanup systems (Abate *et al*., 2024):

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Key Takeaways

Organism	Plastics Degraded	Mechanism	Potential use
Mealworms	PS and PE	Gut degrading bacteria	PE waste treatment and PS foam recycling
Waxworms	PE	Saliva enzymes + gut bacteria	PE waste treatment
Superworms	PS	Gut microbiome shift	PS foam recycling
Aspergillus tubingensis	PU	Secreted hydrolases	Myco-remediation of foams
Pestalotiopsis microspore	PET and PU	degrades PET and PU anaerobically by serine hydrolase secretion	Cleave plastic bonds
Fusarium solani	PE	breaks down polyethylene (PE)	Marine plastic cleanup
Rhodococcus ruber	PE	Biofilm formation + oxidation	Marine plastic cleanup
Alcanivorax borkumensis	PE	degrade hydrocarbon-based plastics	oil-eating bacterium
Microalgae (Spirulina, Chlorella)	MPs	adsorbing MPs onto cell surfaces and secrete exopolysaccharides to trap them	Water filtration
Black soldier fly larvae (*Hermetia* illucens)	PVC	gut bacteria	PVC waste
Greater wax moth larvae (*Galleria mellonella*)	PP	degrade PP and PE	PE and PP waste treatment
Engineered *E. coli*	PET	Synthetic PETase production	Industrial upcycling
Biohybrid Systems: Combining algae + bacteria	MP	self-sustaining MP cleanup systems	MP pollution

5. Challenges and ethical concerns

Releasing engineered organisms could disrupt ecosystems or incomplete plastic degradation may release harmful intermediates and byproduct toxicity (e.g., styrene). However, there is also the limitation that the performance of microorganisms will be very slow for industrial use.

6. Future Prospects

- Consortium approaches: Combining fungi, bacteria, and insects for mixed plastic waste.
- Enzyme cocktails: Blending PETase, FAST-PETase, and fungal enzymes for broader plastic coverage. For example by CRISPR editing, it can be knock in PETase genes to expand plastic range.
- Urban bioremediation: Deploying worm/fungal farms near landfills.

While these organisms excel in environmental cleanup, adapting them for human MP/NP detox remains distant. However:

- Enzyme pills: Oral doses of PETase/MHETase could one day target PET MPs in the gut.
- Probiotic therapies: Genetically modified gut bacteria might eventually break down NPs.

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While most plastic-degrading organisms break polymers into harmless byproducts (CO_2, water, or biomass), some microbes and engineered systems can convert plastic waste into fuels (e.g., biodiesel, methane, or crude oil analogs). Here's how it works:

Natural plastic-to-fuel converters

A. Bacteria

Pseudomonas aeruginosa: This bacterium oxidizes plastics into fatty acids then fermented into biodiesel. Lab tests show ~30% conversion to methyl esters (biodiesel precursors) (Yang, 2021; Mehmood *et al*., 2023).

Clostridium (Anaerobic bacteria): This bacterium Ferments plastic into volatile fatty acids (VFAs) then upgraded to biogas (methane) or biohydrogen. It can be used for Landfill biogas recovery from plastic waste (Beschkov and Angelov, 2025).

B. Fungi

Aspergillus flavus and *Fusarium* spp.: These fungi secrete lipases and oxidases to break plastics into hydrocarbons resembling crude oil and produce up to 40% liquid fuel (similar to pyrolysis oil) (Gajendiran and Abraham, 2016).

Engineered bio-systems for plastic-to-fuel

A. Engineered *E. coli* and *Yarrowia lipolytica*[1]: These microorganisms broken plastic (PET/PE) into terephthalic acid (TPA) or fatty acids and by suing engineered microbes TPA van be converted into biodiesel or jet fuel. Scientists at University of Edinburgh (Beschkov and Angelov, 2025) modified *E. coli* to turn PET into vanillin (flavoring) and fatty alcohols (biofuel precursors).

B. Algal-bacterial hybrid systems: These bacteria break down plastics into ethylene glycol or VFAs. Microalgae (e.g., *Chlorella*) consume byproducts and produce lipid-rich biomass for biodiesel. Ine of the most advantage in this process is zero-waste cycle (CO_2 from degradation feeds algae):

Pros of Biological Methods:

- Lower energy input than pyrolysis
- Can work at ambient temperatures
- Produces fewer toxic byproducts

Cons:

- Slower than industrial methods
- Limited to specific plastics (PET, PE, PS)

[1] Yarrowia lipolytica is a non-pathogenic, dimorphic yeast with significant biotechnological potential. It is known for its ability to thrive in hydrophobic environments and metabolize triglycerides and fatty acids, making it useful in bioremediation and various industrial applications. Furthermore, it is a source of valuable nutrients, including proteins, essential amino acids, and vitamins, and has been approved as a safe food supplement.

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Comparison to Traditional Methods

Method	Organism Involved?	Fuel Output	Scalability
Pyrolysis	No (thermal)	Crude oil, diesel	High
Gasification	No	Syngas (H_2 + CO)	High
Bacterial Conversion	Yes	Biodiesel, biogas	Medium
Fungal Conversion	Yes	Hydrocarbon liquids	Low-medium

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