

Innovative approaches to microplastic and nano-plastic biodegradation

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REVIEW ARTICLE

Microplastics can arise from a variety of places, including bigger plastic trash that breaks down into smaller and smaller fragments of microbeads are extremely small bits of manufactured polyethylene plastic that are used as exfoliants in health and beauty products including cleansers and toothpaste. Microplastics are microscopic plastic particles (less than 1 mm) that form while bigger plastic trash degrades. They are small enough to be consumed by a variety of creatures. Microplastic has been shown to have harmful effects on wildlife in recent studies. These microscopic particles easily slip past water filtering systems and end up in the ocean and the Great Lakes, posing a risk to aquatic life. Because of the cost of removing plastic, it accumulates in the environment, the mechanical of light and heat, plastic breaks into small particles called (microplastic), it affects aquatic not chemically aim to study the biodegrading methods of micro and nano plastics.

Keywords: Microplastic; Nano plastic; Biodegradation; Chemical recycling; Pollution

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INTRODUCTION

If a visitor from 50 years ago came to town, he would most likely notice the amount of plastic in the area. In addition, we often use plastic containers for our food and medicine. In the construction industry, we increasingly use plastic and composite materials to make various products. In 2010, the demand for plastic packaging in the European Union reached 46.4 million tons (Amaral-Zettler et al., 2021). In total, there are around 24.7 million tons of plastic debris that enter the waste stream each year. This figure shows that about 4.8 to 12.7 million tons of waste ends up in the ocean. Despite the alarming environmental impacts, it is still not clear how this widespread and increasing use of plastic will affect human health. For instance, in 2010, almost 14.5 million tons of plastic was used for the packaging of food (Zhu et al., 2021).

The migration of contaminants from plastic packaging into food has been identified as the main route of exposure to harmful substances. Although regulations are in place to prevent the use of harmful substances in the food chain, it is not yet clear how they protect the plastic materials when they are discarded (Moreno-Jiménez et al., 2021). This issue could contribute to the accumulation of toxins in the food chain. Biomonitoring is a technique that can help identify the presence of chemicals in the body. This process involves analyzing the concentrations of pollutants in human tissues and body fluids. It can provide an estimate of the exposure to different sources of contamination (Williams and Osahon, 2021)

This method has revealed that many of the chemicals used in the plastic industry are known to be present in the human population. These chemicals can cause harm to animal models (Vitali et al., 2024). The NICHES is a program of the US Department of Health and Human Services that aims to evaluate the nutritional status of children and adults. According to the National Health Assessment Agency, about 40 chemicals are known to have harmful effects on the human body. Some of these include styrene, acrylamide, and bisphenol A (Rondoni et al., 2021).

This review explores the various kinds of plastic and the possible effects they have on the human body. It also reviews the routes that these materials take when they enter the human body and the potential effects of their consumption on our health. The materials that were identified as the most hazardous were those made from monomers that are carcinogenic or mutagenic. The lack of data on the safety of these chemicals affected the rankings. Unfortunately, there is no hazard class for some of the chemicals that are known to have endocrine-disrupting properties. This limitation could limit the ability of the scientific community to predict the effects of certain plastics on humans. Despite the lack of data, this study was still very useful in trying to identify the various types of polymers that could pose a threat to human health.

PLASTICS AND MICROPLASTICS

Plastic is an umbrella term that refers to various materials made of synthetic organic compounds. These materials can be used for various applications.

Due to their flexible composition, these materials can be molded into various shapes and sizes. Their etymology shows that they originated from Greek words. Most commonly, synthetic plastics are made from petrochemicals. They have long chains and are known as monomers. A good analogy is to see a polymer as a pearl necklace (Yuan et al., 2020).

Through the process of polymerization, these materials are linked to each other. They can be classified as poly-addition, cross-linking, or condensation. Among the various groups that are known to be important are polyesters, acrylics, and halogenated plastics (Wu et al., 2024). Some of these are also known to be useful for various applications. Thermoplastics are materials that can be melted and hardened when heated. They can then be reheated and reused repeatedly. However, thermosets are materials that can't be re-melted and reformed (Amobonye et al., 2021).

Eight thermoplastics are known to be made from various polymers such as Polyethylene, Polyamides, Polyester, and PP. Some of these include Polyurethane, Polyester, and Polystyrene. The fate of the plastic debris in the ocean is the subject of various environmental studies. Many of these studies are conducted in areas where the plastic particles can accumulate. In the North Pacific Ocean, a massive patch of garbage and debris has been estimated to cover a region of about 1.6 million square kilometers. Known as the Pacific trash vortex, it was discovered in 1985 (Islam et al., 2019).

The plastic particles are commonly dispersed over large areas of surface area. In the Great Pacific garbage patch, the concentration of plastic particles is estimated to be about 100 kilograms per kilometer. The garbage patch that's floating around the Pacific Ocean is composed of suspended, dispersed, and small plastic particles. These particles can pose a threat to humans and marine life (Othman et al., 2021).

Studies indicate that the species of organisms found in plastic materials vary greatly from those found in the surrounding marine communities. It's estimated that the total mass of the materials in the garbage patch exceeds 130 thousand tons. In total, that patch has about 1.8 trillion pieces of debris. The other particles, which are known as microplastics, are considered a threat to the environment (Anggiani, 2020).

Due to their large size and the variety of colors they show, microplastics can be classified as primary or secondary. They can be found in various household items such as toothpaste, facial cleansers, and exfoliating creams. It has been estimated that 6% of the cosmetic products sold in the European Union contain microplastics. The particles are mainly found in the raw materials used to make these products. Production issues and accidental loss are also known to contribute to the accumulation of these particles (Zhang et al., 2020).

Air-blasting media are known to use microplastics in their production. After their use, they can reach the environment and contaminate domestic wastewaters. The origin of primary microplastics can be traced to their sources. They can also be identified through the various steps that can be taken to reduce their impact on the environment (Lehmann et al., 2022).

One of these steps is to prevent the accumulation of these materials before they enter the environment. In most cases, this process can be done using special methods and equipment designed to remove microplastics. Unfortunately, this can be very challenging in areas where the existing treatment facilities are not adequate or have inadequate capacity. Aside from this, the efficiency of the treatment process is also affected by the materials' composition (Leifheit et al., 2021).

PLASTIC DEGRADATION

Biodegradable plastics

The concept of bio-based or bioplastics has been presented as a potential solution to the plastic pollution problem globally. However, it is important to note that these are only the first steps in addressing the issue. On the other hand, bioplastics are not the same as traditional plastic materials. They can be classified as either bio-based or biodegradable. Some bio-based polymers include those used in the production of technical performance polymers (Wiedner and Polifka, 2020).

Simultaneously, bio-based and bio-degradable plastics are being produced. These include PLA, PHA, PBS, and starch blends. Regardless of the type of material used, these plastics tend to have the same issues as their conventional counterparts due to their dependence on high humidity and hot temperatures (Riaz et al., 2024).

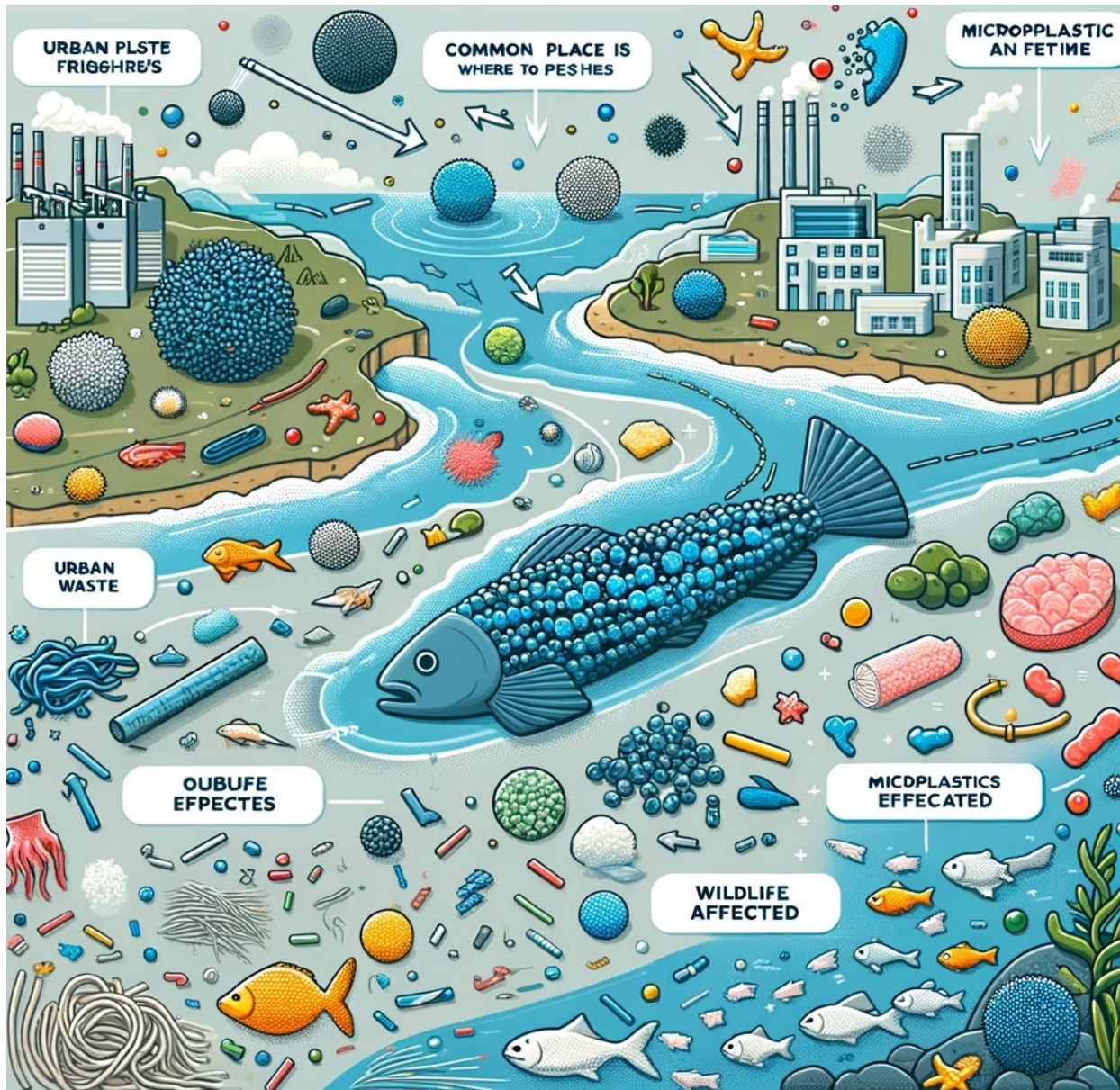


Figure 1. microplastic in the environment (Guo ad Wang, 2019).



Figure 2. Plastic waste management (Glaser, et al., 2022).

Also, these materials can't decompose properly in the environment due to their various properties. For instance, some bio-degradable materials are known to have an oxidizing agent that can cause their disintegration. Due to their properties, these materials can quickly form microscopic fragments. Since they are not suitable for long-term reusable applications, they can't be used for recycling (Yang et al., 2020).

In response to the increasing number of bioplastics, the European Commission has proposed that the EU impose measures against these harmful materials. According to the agency, the use of bioplastics could help reduce greenhouse gas emissions. Despite the advantages of bio-based materials, their commercialization has been very limited due to their high production costs. Despite this, the marketability of PHA has remained limited (Gao et al., 2021).

Despite the advantages of bioplastics, their various characteristics remain unclear. For instance, even though they can reduce greenhouse gas emissions, they are not ideal for food packaging. This issue could require the involvement of various industries to successfully implement bioplastics in their packaging. Also, the various characteristics of bioplastics are not ideal for various applications. For instance, the high strength of bioplastics derived from starch may not be ideal for food packaging.

The easiest way to overcome these issues is by producing copolymers using PCL. Since this is a fossil-based material, it is vulnerable to biodegradation. However, the improved biodegradability of starch-PCL blends can still reduce their malleability and reduce their applications.

Biodegrading organisms

The most urgent issue facing the environment is how to deal with the plastic debris that's floating around. Various actions can be performed to minimize this issue. The concept of biodegradability has been studied to develop strategies that can help minimize the use of plastic-consuming organisms (Han et al., 2024).

Various fungi and bacteria have been identified as possible tools for the biodegradability of plastic. Some of these include the *Streptomyces badius*, the *Rhodococcus ruber*, and the *Butyrivibrio fibrisolvens*. Various fungi have been identified as promising biotechnological agents for the recovery of plastic debris. They can be isolated from various

environments, such as landfill sites, marine water bodies, and plantations (Mbachu et al., 2021).

The efficiency of these biotechnological approaches can be enhanced by treating plastic substrates and organisms subjected to different conditions. Although various treatments are available for plastic debris, the effectiveness of these procedures depends on the type of resin used. In most cases, these procedures are not feasible for large-scale operations (Zhong et al., 2024).

Although the results of the experiments have been presented as proof-of-concept, the use of biodegradable organisms in the environment is not feasible. The use of energy recovery as a means of disposal of plastic waste is known to have detrimental effects on the environment. This is because it generates more greenhouse gas emissions and toxic exposure for nearby communities (Liang et al., 2019).

This issue is especially alarming since the amount of greenhouse gas emissions associated with the incineration of plastic waste is equivalent to about 900 kilograms of CO₂ per metric ton of waste. In addition, the process of solid waste incineration produces high levels of microplastics. Although incineration is generally considered an efficient method for recovering plastic debris, the exact composition of the ash may vary depending on the environment and the operation conditions (Khan et al., 2024).

Chemical recycling

Chemical recycling refers to the process of converting plastic materials into their basic components. Various technologies are currently being studied to develop these recycling methods. Usually, high-temperature and solvent-based chemical recycling techniques are used to recover plastic waste. This process is considered an attractive alternative to incineration (Loganathan and Kizhakedathil, 2023).

Various technologies can be used for chemical recycling, some of these are not yet ready for commercial use. Due to their high energy inputs and limited data, these are not suitable for evaluation. Although these techniques are more costly than traditional ones, they can still provide a better final product and a more homogeneous plastic supply. In addition, their ability to reduce the amount of plastic waste in the environment is also key to achieving a comprehensive solution to the plastic waste problem (Leifheit et al., 2021).

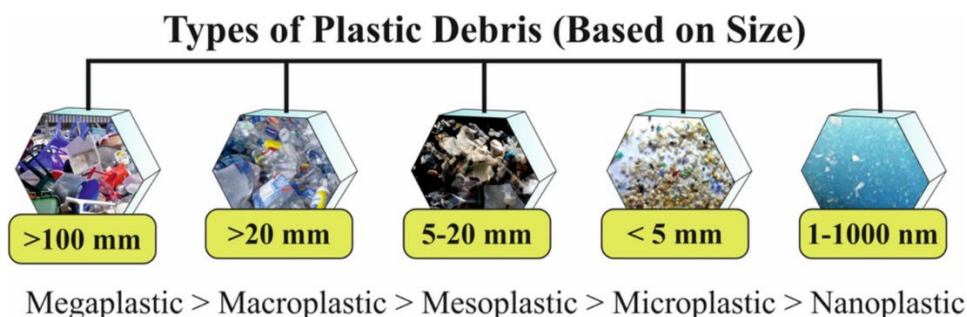


Figure 3. Classification of plastics by size (Debroy et al., 2021).

Most of the challenges in chemical recycling are related to the obtaining of quality feedstock and reducing contamination. Unfortunately, the use of post-consumer plastic feedstocks for chemical recycling doesn't seem feasible. Aside from posing various environmental issues, it consumes a high amount of energy and is not suitable for most used plastics (Kye et al., 2023).

Micro- and Nanoplastics in the Environment

Concerns about the effects of tiny plastic debris particles have been raised. Studies indicate that these objects are known to have detrimental effects on the environment and human health. Microplastics are mainly made up of small objects such as microbeads used in cosmetic products and plastic fragments that are from larger vessels. Aside from oceans, there are also reports of them being present in other environments (Kye et al., 2023).

A study revealed that synthetic polymer fibers and microplastic particles were found in soil and sewage sludge samples. The particles were also detectable for several years after they were applied (Meng et al., 2023). Battistin et al. conducted in 2023a study revealed that the acrylic and polyester fibers used in clothing were very similar to the microplastics found in the sediments of Lake Garda.

The concentrations of these particles were like those found in the Great Lakes. They most likely came from sources such as landfill, litter, and wastewater treatment plants. Although the presence of microplastics in freshwater and agricultural soils is not surprising, the lack of reliable methods for detecting them in aquatic environments is still a bit unclear (Binelli et al., 2020).

Human health risks associated with the presence of microplastics are associated with their potential to accumulate in the food chain. There are various aquatic organisms that can be commonly found in the

marine food web because of the ingestion of plastic particles. Some of these include seabirds, fish, and turtles (Lamichhane et al., 2023).

Most studies show that microplastics are found in the guts of organisms, which are not consumed by humans. Some exceptions include certain seafood species, such as mussels and certain shrimps (Alberghini et al., 2023; Meng et al., 2023; Saud et al., 2023). In addition to their harmful effects on the environment, ingesting microplastics could also have detrimental effects on the human body. The particles' surface area could allow pollutants to cling to them and enter human tissue.

This topic is covered in various studies published in the past couple of years. These studies show that the particles can be transferred to tissues by wildlife organisms (Anand et al., 2023; Li et al., 2023). Currently, there is no evidence supporting the effects of microplastics on the biological or physical properties of humans.

Plastics derivatives and its effect on human health

In addition to their physical properties, plastic particles can also contain additives that can improve their chemical composition. This could result in their leaching into the surrounding environment. Even though the particles do not have long-term effects, they could still enter the body through their leaching. Many of the chemicals found in plastic particles have short half-lives. Their migration into the human body could be a major source of exposure to the population (Sun et al., 2023). The migration rates of plastic particles can be estimated using various solvents and various partitioning models. These methods can simulate the environment where they're being transported. The European Food Safety Authority has a total migration limit of 10 mg/dm² for various additives within plastic food packaging. For certain chemicals of concern, this limit is lowered to 0.01 mg/kg (Kabir et al., 2023).

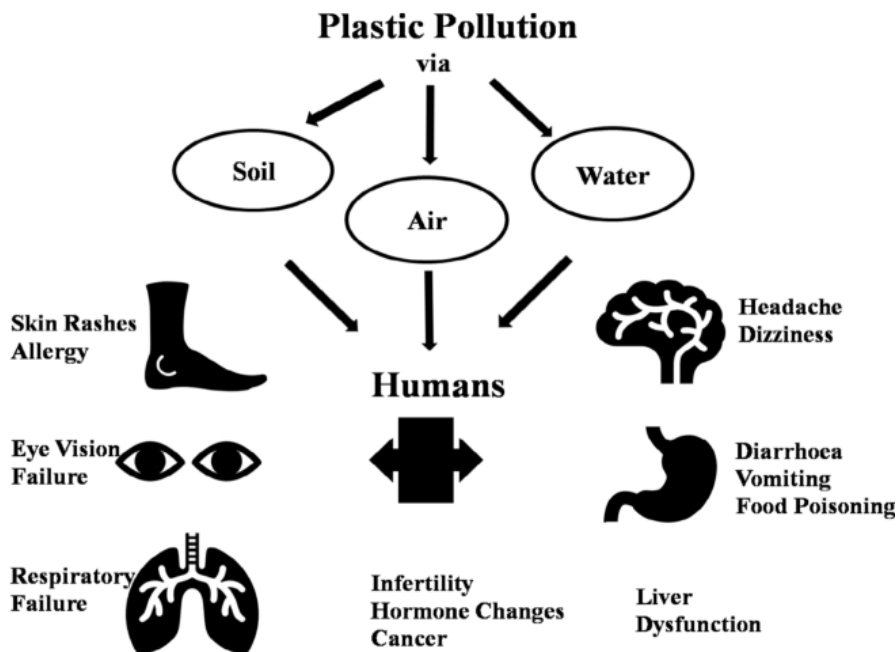


Figure 4. Effect of plastic on human health (Anuar et al.2023).

Bisphenol and Human Health

Although the exact effects of additives on the human body are not yet clear, one chemical known as Bisphenol A has been widely focused on due to its human health effects. This chemical is a high-volume chemical that's used as a monomer to produce plastic bottles and food cans. Studies suggest that exposure to BPA can occur through the consumption of soft drinks and foodstuffs. It is also known that the chemical can migrate out of polycarbonate and enter the human body through the inhalation of household dust. Studies have shown that Bisphenol A is widely known to enter the human body through its exposure to over 95 percent of the population in various countries. The chemical is known to exert its biological effects through its interaction with certain hormone receptors (Pan et al., 2023).

Various models have shown that exposure to the chemical can alter a cell's function and promote weight gain. Exposure to BPA at concentrations found in the general population is associated with increased risk of various chronic diseases such as diabetes and heart disease (Hawke et al., 2024).

Other studies have also shown that exposure to Bisphenol A can lead to an increase in the number of neurodevelopmental disorders and cancer among male offspring. Although it's widely believed that exposure to nanoplastics or micro-plastics directly into the body can contribute to human exposure, the

exact level of exposure to the body is still not known (Wu et al., 2024).

It has also been suggested that exposure to high concentrations of BPA can occur through the consumption of food and drink. Although the chemical can be absorbed through the gut, it can also be taken across various body surfaces. A study revealed that Bisphenol A can be absorbed with high efficiency through a process known as sublingual absorption. Another study conducted by scientists revealed that the chemical can be transported into aquatic organisms (Binelli et al., 2020).

Polymer Formulations

Due to the wide variety of applications of nanoplastics and microplastics, the risks posed by their accidental entry into the food chain can be assessed through existing risk assessments. In a study, the European Food Safety Authority noted that the uncertainties involved in detecting and identifying contaminants in food are significant. The agency's recommendations help minimize the risk posed by nanoplastics and microplastics (Stapleton et al., 2023).

Based on the recommendations of the FDA, it's widely believed that the risks posed by nanoplastics and microplastics to humans can be assessed through their chemical composition and properties. The factors that can influence their uptake and exposure levels are also known. A modeling study conducted by

scientists suggested that the migration of nanoparticles from low dynamic viscosity polymers would be limited to particles with diameters of less than 1 nm (Saud et al., 2023).

Although the nanoparticles did migrate out of the food matrix, their concentrations were well below the safety limit. The agency noted that their entry could lead to toxicity. The scientists noted that the characteristics of nanoplastics and microplastics, such as their reactivity and the presence of toxic chemicals, could pose a hazard to human health (Li et al., 2023).

Biodegradation of micro-Plastics

Many microorganisms can degrade plastic materials such as polypropylene, polyester, and PS. They can also be isolated from the open environment through the soil, marine water, and waste of plastic-containing materials (Anand et al., 2023).

Polyethylene (PE)

In the 1970s, an experiment was carried out to determine the microbial degradation rate of ¹⁴C-labeled PE by introducing three different soil microorganisms. When ¹⁴C-labeled polyethylene was extracted with cyclohexane, the bacterial degradation rate dropped to less than a percent. This study revealed that the release of ¹⁴CO₂, which was produced by the microbial degradation of ¹⁴C-labeled PE, was mainly caused by the low molecular weight of the material. In 1999, a study presented by scientists stated that the maximum molecular weight of microorganisms that can cause the degradation of PE is 2,000 Da (Sun et al., 2023).

Although the high molecular weight of PE was considered a key factor in the microbial degradation of the material, other factors such as the use of oxidizing agents and UV radiation could help in the depolymerization of the product. This process led to the development of low molecular-weight products from resin. It was also interesting to study how microorganisms could be degraded from nature's sources, such as landfill sites, marine water, and soil-contaminated sewage. The results of this study revealed that numerous strains could be isolated from these environments (Kabir et al., 2023).

Some of the strains isolated from these sources were able to generate a carbon source from unpretreated PE. For instance, the *Serratia marcescens* strain exhibited a significant weight loss after being degraded for 70 days. In addition, two cyanobacteria that live in soil exhibited the capability of

degranulating 30% of tested PE. However, these reports were not supported by the evidence supporting the weight loss caused by the degradation of the resin (He et al., 2022).

Various studies have shown that the wax worm, which to digest and feed on wax, can also consume films made from PE (Russell and Webster, 2021; Yang et al., 2022; Yu et al., 2022). The biodegradation of the resin was detected through the interaction with the wax worm's homogenate or through the gut of another animal. Further studies are needed to analyze the effects of the depolymerization on the waxworm's gut. It has been theorized that the presence of certain microbial symbionts in the wax worm's gut can contribute to the depolymerization of PE (Tirkey and Upadhyay, 2021).

A pair of bacterial strains isolated from the gut of a wax worm known as the *Enterobacter asburiae* YT1 and the *Bacillus* sp. YP1 exhibited the capability to degrade PE. The results of the study indicated that the microbes could be used as a source for further studies related to the depolymerization process. Although it's been known that various microbial enzymes can contribute to the depolymerization of PE, only four known enzymes are responsible for the degradation of the resin (L. Yang et al., 2021a).

Polystyrene (PS)

In 1974, researchers first assessed the microbial degradation of PS using two different types of ¹⁴C-PS. They discovered that the concentration of microbes that degraded the resin was less than 0.01%. After analyzing the data, they learned that the PS degradation rate was only 1.5 to 3% during the 16-week. Aside from the microbes that live in the soil, researchers also tried to isolate microorganisms that can depolymerize PS. Wu., 2024 researchers discovered that soil microorganisms can also reduce the resin's molecular weight. Also, three fungi and three bacterial strains were isolated from soil-buried PS films. Although these organisms exhibited low biodegradation rates, they did not cause noticeable physical or chemical changes in the resin (Wu et al., 2024).

Polypropylene (PP)

In 1993, cultures were analyzed to determine the microbial degradation of PP. The concentration of the degraded products consumed about 40% of the resin's initial weight. The researchers discovered that most of the degraded products were phenolic compounds that were added to plastic to improve its

flexibility and workability. Although the hydrocarbons were identified as non-natural, the sandy soil microorganisms degraded the plasticizers. Various studies have been performed on the effects of soil microorganisms on PP. For instance, after 12 months, the residual PP content increased 33% and 0.4% weight loss was observed. The results indicate that the resin could be degraded by the microbes living in the soil (Uheida et al., 2021).

The mixed consortia of bacterial strains isolated from waste management facilities and sewage treatment plants could also reduce the PP resin's weight loss. These organisms caused a weight loss of 44.2 to 56.3% after about 140 days. It's not clear if the weight loss caused by the microbes came from the depolymerization of the resin or the degradation of its low molecular weight components (Zhong et al., 2024).

The *Stenotrophomonas panacihumi* PA3-2 strain, which was isolated from the soil of a waste storage yard, can reduce the molecular weight of two kinds of PP. However, it only degraded the low molecular weight fraction and not the long-chain PP. Until now, there's been no evidence that enzymes can effectively depolymerize PP. However, several such as the use of UV radiation and thermo-oxidation can help the resin's microbial degradation.

Polyvinyl chloride (PVC)

Due to the properties of its plasticizers, which can be used by fungi and bacteria as sources of nutrients, plasticized PVC is considered a vulnerable material to bacterial or fungal attack. For instance, some of the plasticized bathmats and shower curtains that were made from PVC were found to be damaged by fungi (Zhong et al., 2024).

Various fungal isolates isolated from soil, plasticized sheets in the atmosphere, and waste disposal sites were found to be capable of causing the plastic to deteriorate. The bacterial strains isolated from various environments such as landfill sites, garden soil, and marine environments were also able to degrade the plastic.

Although the microorganisms can successfully depolymerize PVC, they only degraded a component of the plasticizer instead of its core. This suggests that the enzymes involved in the degradation of plasticizers are still undiscovered. The strains that can depolymerize long-chain molecules of PVC must be able to do so using virgin plastic. This method involves

extracting low molecular weight components from the resin using a solvent (Wu et al., 2024).

Polyurethane (PUR)

The term PUR refers to the plastic resin that's produced from the condensation of polyisocyanate and polyester polyols. In 1968, scientists Robert Kaplan and Geoffrey Darby discovered that seven fungi can live on the surface of polyester PUR. Since then, various fungi have been able to successfully depolymerize the resin (Uheida et al., 2021).

In 2010, a fungus known as *Alternaria sp.* PURDK2 was able to reduce the weight of polyether PUR foam by almost 30% after about 70 days. The ability to reduce the resin's molecular weight has been regarded as a key step in the evolution of fungi that can depolymerize plastic. In 2016, eight fungal strains were able to grow in the mineral medium and degraded 65% of polyether PUR foams. A study revealed that three bacteria and one yeast could cause a weight loss of up to 10% within 5 months after deactivating commercial polyether PUR films (Wu et al., 2024).

The role of enzymes and genes in the depolymerization of polyester PUR has been studied extensively. In 1994, scientists from the University of Maryland discovered that an esterase produced by a polyester PUR-degrading fungus can cleavage the resin's ester bonds. The scientists involved in the study cloned a gene encoding a polyester PUR-degrading esterase. They also purified various esterases from different bacteria and successfully used a lipase from *Bacillus subtilis* (Uheida et al., 2021).

Stages of microplastic biodegrading

To break down plastic fragments, microorganisms have evolved to develop enzymes that can convert them into carbon sources. This process has been observed in various ecosystems. Various enzymes are involved in the depolymerization and degradation of various types of plastic. They can vary widely in their substrate scope and their efficiency (Bai et al., 2021).

Since the inception of plastics, it has been assumed that they would never be discarded. This paradigm is now being challenged by the development of enzymes that can break down these materials. Following are the steps necessary for the biodegradation of plastic. The first one involves introducing a microbial community on the polymer's

surface. This step can be followed by the growth of bacterial communities on the surface (Bajt, 2021).

After introducing the plastic substrate, secreted enzymes are required to break it down into lower molecular weight oligomers. This step is considered the most challenging part of the biodegradation process. As the plastic is degraded, the bacteria take up the fragments and produce usable energy. These products can then be used to mineralize the environment. The resulting products can be used as useful products (Piyawardhana et al., 2022).

The bottlenecks in the biodegradation process can be addressed to increase its throughput and make it a feasible solution to plastic pollution. Bio-fragmentation is a process that occurs when the biofilm grows and causes plastic fragments to crack and get pitted. During this step, the bacteria attack the fragments with their nonspecific enzymes (Tsering et al., 2021).

After the fragments are pitted, they are further degraded by the presence of intracellular enzymes, which can convert them into waste products. The ocean is awash in microbial life. Many of these life forms are formed by the interactions between organic and inorganic debris. When mixed with plastic, the resulting surface can quickly become contaminated (Huang et al., 2022).

Studies reveal that many of the marine communities that live on plastic surfaces are closely related to petroleum-derived organisms. These species could be involved in the plastic degradation process. Further studies are needed to establish the stages of biodegradation on marine microplastics (Yang et al., 2021b).

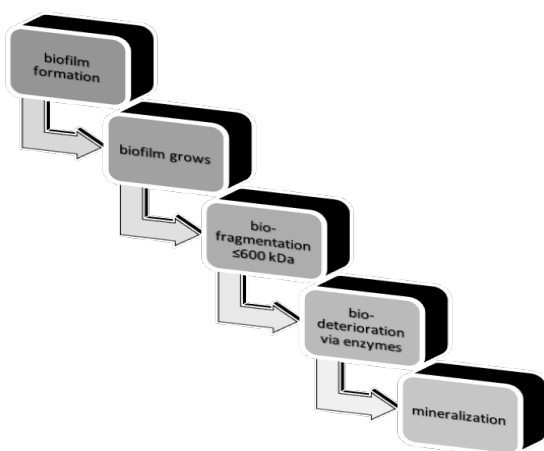


Figure 5. Stages of microplastic biodegrading.

CONCLUSION

Various types of plastic additives are commonly encountered in everyday use. The hazards they pose to human health are discussed. The concept of contamination by nanoplastics and microplastics is still in its infancy. Despite this, many unanswered questions remain regarding the environmental impacts of these materials. If so, what species are most at risk from the effects of plastic additives? How does the aging of plastic affect its physico-chemical properties and toxicity?

Various techniques such as field flow fractionation, multi-angled light scattering, ICP-MS, and bioimaging have been studied to extract nanoplastics and microplastics. The increasing number of legislative and regulatory actions related to plastic additives are usually affected by the lag time between the gathering of data and their implementation. This review aims to develop science-based strategies that are focused on addressing the various aspects of plastic pollution. Aside from regulations, policies, and tools that can be used to address plastic pollution also need to be considered. In the long term, education and outreach are considered the most effective way of addressing plastic pollution. Doing so can help children develop a better understanding of the environmental impacts of plastic pollution. Despite the various problems associated with the increasing use of plastic additives, the issue is not only related to one cause. It also has a common solution.

AVAILABILITY OF DATA

This investigation offers all the data collected.

CONFLICT OF INTEREST

All authors proclaim that there is no conflict of interest.

AUTHORS' CONTRIBUTION

Naser Ahmed Alkenani constructed the framework, data collection, data representation, writing, reviewing, and editing.

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