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Chapter- 4

Toxicity of microplastics in humans: A search for sustainable alternatives

Prokriti Saha, Riashree Mandal, Punarbasu Chaudhuri and Subarna Bhattacharyya*

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Abstract:

Plastics have become ubiquitous in our daily lives and are a major source of microplastic pollution. Microplastics are plastic particles with a diameter of less than 5mm. It can now be found in all ecosystems, including virgin environments like Antarctica. The main form of microplastics entering the food web is through ingestion and eventually accumulation in a different body part. In this context, the objective of this chapter is to study the toxic effect microplastics have on major systems of humans and to find out existing sustainable alternatives to eliminate microplastics from the environment. The current research focused that microplastics reaching the respiratory, circulatory and gastrointestinal systems through the air, water and food. The toxicity of plastics depends on the particle's size, shape, texture, surface chemistry and charge, which governs its interactions with biological systems. Therefore, scientists partially substituted petrochemical-based polymers with development of bioplastics which are biodegradable in nature and can fight increased environmental and economic challenges. These bioplastics are made from cellulose, potato, corn starch and sugarcane. Though these raw materials are also major food resources, massive production of bioplastics from them may increase the possibility of food crisis.

Introduction:

Plastic means "malleable" or "flexible." Indeed, these synthetic materials can be molded into any form. Plastics are long chains of polymer molecules created from organic and inorganic raw materials, like carbon, silicon, hydrogen, oxygen, and chloride. They are versatile materials that are cheap, lightweight, strong, and durable (do Sul & Costa, 2014). Microplastics are officially defined as heterogeneously mixed plastics having less than five millimeters (0.2 inches) in diameter (Guo et al., 2020). They are loosely classified into two categories: primary

Prokriti Saha
1Department of Forensic Science and Technology, Maulana Abul Kalam Azad University of Technology
Riashree Mandal
School of Environmental Studies, Jadavpur University
Punarbasu Chaudhuri
Department of Environmental Science, University of Calcutta
Subarna Bhattacharyya*
School of Environmental Studies, Jadavpur University
***Corresponding Author:** barna_kol@yahoo.com

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and secondary. Microfiber is a minute piece of plastic utilized in clothes and is thinner than a strand of hair. It passes through washing machine filters and sewage treatment plants and ends up in large water bodies like oceans. 'Nano-plastic' is a term for plastic particles within the submicron range <1 µm (Leslie et al., 2022). Primary microplastics are plastics that are manufactured as tiny particles for commercial use, such as in cosmetics, as well as microfibers shed from fabrics and textiles, such as fishing nets. They can also be released by spilling virgin plastic pellets with a millimetre range diameter.

Degradation is a chemical change that reduces the average molecular weight of a polymer (do Sul & Costa, 2014). Secondary microplastics are created when larger plastics eventually undergo some form of degradation and subsequent fragmentation and breakdown into smaller particles (e.g., water bottles). This breakdown is the result of exposure to environmental factors, such as the sun's radiation, known as photo-degradation and ocean waves, which is mechanical weathering (Chamas et al., 2020). The problem regarding microplastics is intertwined with other global issues like contributing to climate change through greenhouse gas emissions along the life cycle of plastics and microplastics (Garcia-Vazquez & Garcia-Ael, 2021). Microplastics may accelerate biodiversity decline, which is a global issue, because plastic particles cause harm to organisms across the trophic web, from plankton to top predators. Microplastics also pose a threat to human health, which is becoming a global concern. Though not well known yet, the prolonged ingestion of microplastics through diet is thought to enhance inflammatory responses and interrupt the gut microbiome (Eva Garcia-Vazquez, 2021). Microplastics entering the body through inhalation accumulate and are suspected of producing lung cancer. The accompanying toxic molecules which cause chemical and biochemical damage can affect the nervous system adversely (Garcia-Vazquez & Garcia-Ael, 2021).

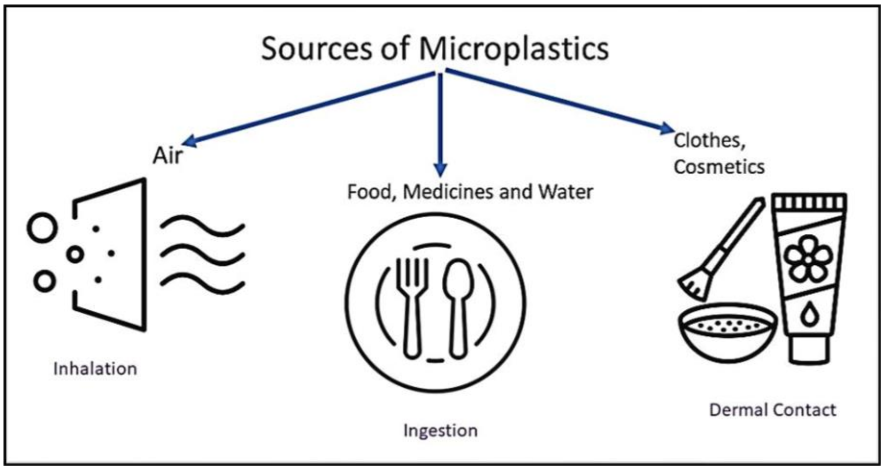

Figure 1. Different sources of Microplastics

Microplastics may come from landfills, sewage treatment plants, tire wear, paint failure, washing clothes and at-sea losses (Hale et al., 2020). Microplastics can be transported through the air (atmospheric) or water (riverine). In surface waters, microplastics weather, befoul, aggregate, and sink, are ingested by organisms and redistributed by currents. Ocean sediments are likely the ultimate destination. Microfibers are continuously shed from the clothes or fabrics we use every day. Micro-beads from personal hygiene products like toothpaste and face scrubs make their way to the water bodies through sewage. Plastics, on degradation, release additives, concentrate environmental contaminants on their surface and work as substrates for biofilms, including exotic and pathogenic species (Hale et al., 2020).

Impact on human health:

Microplastics can be a risk to humans in three ways: physical, chemical and as a host for microorganisms to accumulate and breed on.

While there is no definite evidence currently linking microplastic consumption to human health, results from correlative studies in people exposed to high concentrations of microplastics, model animal and cell culture experiments, propose that effects of microplastics may include provoking the immune and stress responses and inducing reproductive and developmental toxicity.

Research on microplastics by the Food and Agriculture Organization of the United Nations (FAO) and the European Food Safety Authority (EFSA) concluded that large microplastics were likely to be excreted directly through faeces. In addition, the absorption of nano-plastics and chemicals found in plastics, including absorption into the organs, was limited.

Microfibers are consumed by organisms placed at the bottom of the food chain, such as plankton and mussels. It is predicted that microfibers accumulate up the food chain until it reaches humans - although this still needs to be researched.

Raman micro-spectroscopy has been recently applied to the image and identified three polypropylene particles between 5 and 10 μm in human placental tissue (Leslie et al., 2022). Microplastic particles were suggested to be reaching the placenta via inhalation or gastrointestinal translocation (Luís Fernando Amato-Lourenço, 2021). The effects of microplastics on essential human systems like the circulatory, respiratory, and gastrointestinal systems are elaborated in successive sections.

The circulatory system:

Environmental microcontaminant levels observed in venous blood samples are assumed to be representing the measurement of the entire bloodstream, including the microvascular system (Leslie et al., 2022). The distribution of plastic particles in blood differs depending on their sizes. Some tend to be localized in immune cells, while others may adhere to proteins, lipid particles, other plastic particles, or the vascular endothelium (Leslie et al., 2022). The fate of plastic particles depends on the mechanism of their elimination from the body, e.g., by renal filtration or biliary excretion or deposition in the liver, the spleen, or other organs (Leslie et al., 2022).

The plastic particles detected in the human bloodstream likely follow the uptake routes via mucosal contact (either ingestion or inhalation). Dermal uptake of fine particles is improbable except if the skin is damaged. Airborne particles between 1 nm and 20 µm are respirable. Ultrafine (<0.1 µm) inhaled particles may become absorbed and accumulate in the lung, while most larger particles are expected to be coughed up and eventually swallowed and have a second chance of absorption via the gut epithelium (Leslie et al., 2022). Microplastics in the blood can cause inflammation, pulmonary hypertension, vascular occlusions, increased coagulability, and blood cell cytotoxicity. They may also reach the liver and kidney through circulation, which is responsible for metabolism and excretion. Continuous accumulation of microplastics in the renal cells after a certain threshold may lead to impaired renal function (Prata et al., 2020).

Respiratory system:

The human respiratory system is an exposure route to microplastics, and the lungs are a site of accumulation (Luís Fernando Amato-Lourenço, 2021). Due to the wide variety of sizes microplastics come in, they likely get inhaled by humans. Microplastics are detected in air and indoor and outdoor dust (Wibowo et al., 2021).

A study was conducted by Amato-Lourenço et al., (2021) by collecting pulmonary tissue samples (parenchymal tissue from the distal and proximal regions of the left lung) from 20 non-smoking adult individuals who underwent routine coroner autopsy at SaoPaulo City Death Verification Service of Sao Paulo University for the verification of cause of death. In thirteen out of twenty decedents, 31 synthetic polymer particles and fibres were observed, along with five natural polymer particles. Polypropylene was the most encountered polymer, followed by polyethene and cotton. Polypropylene and polyethene are in food packaging, automotive parts, sweets and snacks packaging, and currency notes. When used for apparel production, natural fibres are dyed and coated with flame retardants, reducing biodegradability (Amato-Lourenço et al., 2021).

The deposition of exogenous particulates in the lungs depends on size, charge, density, aerodynamic diameter, and flow rate. The number of fibres observed indoors is usually higher than in outdoor environments. Particles of sizes 1- 5 micrometres have the capability to reach the bronchial-alveolar regions (Amato-Lourenço et al., 2021). For fibres, this capability is regulated largely by the actual diameter, length, and density. Only fibres having a diameter smaller than 3 micrometres can reach the alveolar region. Pulmonary translocation to systemic circulation has been demonstrated for fine and ultrafine particles (Amato-Lourenço et al., 2021).

Gastrointestinal system:

The gastrointestinal tract is another possible site of microplastic entry in organisms (Amato-Lourenço et al., 2021). Human faeces were previously analysed with Fourier Transform Infrared spectroscopy (FTIR), providing evidence that microplastic particles can be excreted via the gastrointestinal tract (Leslie et al., 2022). Furthermore, human colectomy specimens analysed using FTIR also detected plastic particles (Leslie et al., 2022). Usually, microplastics accumulate in the gastrointestinal system and larger plastic particles of about 20 µm accumulate across tissues.

Microplastic ingestion in invertebrates and fishes having harmful effects is demonstrated in laboratory experiments. Effects like physical damage and clogging of intestines, cracking of villi, endocrine disorders, immune responses and altered gene expression (Cao et al., 2021).

When exposed to polystyrene or polyvinyl chloride at certain concentrations, organisms like zooplanktons, crustaceans, and fishes show behavioural changes and decreased reproductive output (Cao et al., 2021).

Toxicity:

The toxicity of plastics depends on several factors, such as a particle's size, shape, texture, surface chemistry and charge, which governs its interactions with biological systems, including the formation of a protein corona on the particle surface. It is difficult to weigh the risks microplastics may pose for humans as each plastic is made up of a unique combination of chemicals. The same substance can have different effects depending on the concentration and how a person has been exposed to it (whether the plastic was consumed, inhaled, or injected). The rate at which the chemical is released is controlled by the interactions between the chemical and the plastic as well as its location in the body.

Studies show that microplastics may cause reduced energy intake and lead to negative energy balance due to increased energy consumption. They may also cause metabolic changes as secondary effects. In humans, microplastics may increase energy expenditure and decrease nutrient intake. Due to ethical constraints, studies on humans are limited, but the effects are thought to be similar as observed on fish and mice (Prata et al., 2020).

Microplastics have a chemically active, uneven surface with a large surface area which allows it to absorb a variety of toxic contaminants, such as organic compounds and heavy metals from the surroundings. Among the toxic contaminants absorbed by microplastics, heavy metals constitute most of the inorganic nature. Heavy metals interact with the nuclear proteins and DNA, causing damage to specific sites. After entering the environment once via natural or human activities, heavy metals keep accumulating through physical, chemical, and biological migrations (Cao et al., 2021). Microplastics act as vectors for heavy metals, transferring them along food webs and bringing potential hazards to organisms. It has been confirmed that microplastics have a high affinity for heavy metals in an aqueous medium in natural environments and rapidly adsorb heavy metals from nearby available metal sources. Adsorption of heavy metals on virgin microplastics without surface modification is negligible (Cao et al., 2021). The adsorption depends on multiple factors like types and characteristics of microplastics, chemical properties of the heavy metals and other environmental factors like soil pH, salinity, and background concentrations of pollutants (Cao et al., 2021). Additionally, microplastics' dose and particle size play a crucial role in metal absorption.

Two main sources of heavy metals in microplastics are found in the environment. Plastic manufacturing process where heavy metals like Cd and Zn are added to the polymers to improve their properties and performance act as the major source for heavy metals. Another important source is the surrounding environment, where microplastics can absorb heavy metals (Cao et al., 2021). Heavy metals like Cd occurs in association with zinc in nature. Kidneys trap the Cd ingested and eliminate it. Metallothionein, a body protein in the kidneys, effectively binds a small fraction of Cd and the rest in stored in the body, eventually accumulating. In excess ingestion of Cd, it replaces Zn at important enzymatic sites and causes metabolic disorders (Dey, 2022).

Sustainable alternatives:

Plastics have become ubiquitous in our day-to-day life. Plastics is the source of microplastics. The major source of plastics is fossil fuels like petroleum (Steinbuchel, 1992). Plastic manufacturing requires fossil fuels to exhaust the fossil carbon content and cannot be replenished. Also, non-biodegradability causes the accumulation of plastics to pollute the environment. There is an immediate need for sustainable alternatives to plastics to reduce the production of plastics, thus helping the problems it causes.

Scientist partially substituted petrochemical-based polymers with biodegradable ones due to the increasing environmental and economic challenges, forming Bioplastics. They can be made from different sources like cellulose, potato and corn starch, sugarcane and so on (Reddy et al., 2013). Thermoplastic starch is the most widely used bioplastic derived commonly from potatoes and maize. Pure starch can absorb humidity. It is mixed with plasticizers to make it more flexible. Its use in pharmaceutical products is remarkable. It is also used in the production of wrappers (Reddy et al., 2013). PLA or polylactides are bio-polyesters which closely resembles petrochemical-based plastics like polyethene and polypropylene. Lactic acid is the monomer precursor of PLA. It is produced from the fermentation of corn starch and sugarcane. The blends of PLA are used in making medical implants, packaging materials, bottles, cups and more. Poly-3-hydroxybutyrate (PHB) is a thin transparent film very similar to polypropylene, and is used in ropes, banknotes and packaging materials. It is usually made from sugarcane but new research shows water hyacinth can be an effective source of PHB. Polyhydroxy-alkanoate (PHA) are derived products of natural oils and sugars with the help of microbes. They are processed to form a variety of goods like packing materials, fibres, and water-resistant coating. Celluloid is one of the earliest thermoplastics used by humankind. It is a blend of camphor and cellulose nitrate (Steinbuchel, 1992), and is used to produce various articles like artificial textiles, car parts, buttons and many more (Reilly, 1991). Cellulose Xanthate is an inorganic ester of cellulose (Steinbuchel, 1992) where wood pulp (cellulose) is treated with a variety of chemicals in a series of processes and converted into spinnable filaments (Wilkes, 2001). It is used in making cellophane wraps and textile fibres such as rayon, etc. (Bajpai, 2018). Microbial cellulose produced by *Acetobacter xylinum* (Steinbuchel, 1992) closely resembles plant cellulose and is being used for a wide range of products such as conductive membranes, temporary artificial skin, dietary fibres etc. (Mona et al., 2019). A high-fidelity equipment producer also uses it in Japan to manufacture headphone diaphragms (Steinbuchel, 1992). The above-discussed alternatives of plastics are summarized in table 1.

Table 1: Status of bioplastics and their application

Alternative	Abbreviation	Plastic it resembles	Source	Use	Reference
Thermoplastic starch	-	Polyethene	Potatoes, maize	Drug capsules, wrappers	(Reddy et al., 2013)
Polylactides	PLA	Polyethene, polypropylene	Corn starch, sugarcane	Medical implants, bottles	(Reddy et al., 2013)
Poly-3-hydroxybutyrate	PHB	Polypropylene	Sugarcane, water hyacinth	Ropes, bank notes, car parts	(Reddy et al., 2013)
Polyhydroxy-alkanoate	PHA	Polypropylene	Natural oils and sugar	Water-resistant coating, moulded goods	(Reddy et al., 2013)
Celluloid	-	Polyethene	Nitrocellulose + camphor	Photographic films, artificial textiles	(Steinbuchel, 1992); (Reilly, 1991)
Cellulose xanthate	-	Polyesters	Cellulose	Cellophane wrap, textile fibres like rayon	(Wilkes, 2001); (Bajpai, 2018)
Microbial Cellulose	-	Cellulose	*Acetobacter xylinum*	Temporary artificial skin, Headphone diaphragm	(Steinbuchel, 1992); (Mona et al, 2019)

Present day challenges:

Several types of raw materials are used to make bioplastics like plants, animals and microbial biomass. Scientists, engineers and business personnel are now dealing with some limitations in utilizing raw materials like the non-availability of high biomass, food crisis, and refinement of natural resources. Instead of all limitations, biodegradation and less human toxicity answer all challenges, no doubt.

Advantages:

Smaller Carbon Footprint:

The carbon footprint of a bioplastic is highly dependent on whether the plastic permanently stores the carbon extracted from the air by the growing plant. Plastic made from a biological source seizes the CO_2 captured by the plant in the photosynthesis process. Usually, bioplastic degrades into CO_2 and water in the natural environment with the influence of decomposers. But a permanent bioplastic, made to be similar to polyethene or other conventional plastics, stores the CO_2 forever. Even if the plastic is recycled many times, the CO_2 initially taken from the atmosphere remains sequestered (Arikan & Ozsoy, 2015).

Renewable resource:

Bioplastic is made from renewable resources like corn, sugarcane, soy and other plant sources, as opposed to common plastics, which are made from petroleum (Chen 2009).

Lower energy costs in manufacturing:

Bioplastic production uses less energy than conventional plastics. Generally, plastics are made from about 4% of the oil the world uses yearly. The manufacture of plastics becomes increasingly exposed to fluctuating prices of crude oil worldwide (Chen et al.,, 2021).

Eco-safety:

Bioplastic contains zero toxins and generates fewer greenhouse gasses (Chen et al., 2020). It helps reduce the global warming potential as bioplastics contribute clearly to the goal of mitigating GHG emissions with only 0.49 kg CO_2 being emitted from producing 1 kg of resin. This can be compared with the petrochemical counterparts, where 2 to 3 kg of CO_2 is produced from one plastic production unit (Chen, 2008).

Technical benefit

Bioplastics have improved printability, the ability to print a highly legible text or image on the plastic. Engineered bioplastics surfaces are smoother and printer-friendly than conventional plastics. It imparts less likelihood of imparting a different taste to the product contained in a plastic container. For example, milk will acquire a new taste in a styrene cup, but the bioplastic alternative has no such effect. Generally, bioplastics cannot tolerate much greater water vapour than common plastic can. As a result, bioplastic can not use to pack warm sandwiches, patties etc. In the case of newly baked bread, a bioplastic container will offer a significant advantage in letting out excess vapour or steam. A bioplastic can feel softer and more tactile. For applications such as cosmetics packaging, this can be a major perceived consumer benefit. Furthermore, Bioplastics can be made clearer and more transparent (Jannah et al., 2019).

Disadvantages:

High costs:

It is considered that bioplastics cost two times more than conventional plastics. However, the amount of large-scale industrial production of bioplastics which will be more common in the future with the implementation of cost reduction, is expected.

Recycling issues:

Bioplastic material might actually contaminate the recycling process if not separated from conventional plastics. Infrared rays are used in plastic waste separation systems where bioplastics cannot be separated. These mixed plastics might be contaminated the system and bioplastics are not be recycled.

Reduction of raw materials:

Renewable resources are used to produce bioplastics which might reduce raw material reserves. Common starch food resources like potatoes, maize, etc., are valuable; utilising those food crops for bioplastic may initiate a food crisis (Lagaron & Lopez-Rubio, 2011).

Misunderstanding of terms:

The name bioplastics and related items are often misused by various companies to market their products. Usually “environmentally friendly”, “non-toxic”, and “degradable/totally degradable” like slogans are being used by manufacturers as a trick to sell the materials to the uninformed and overwhelmed consumers (Arikan and Ozsoy, 2015). All bioplastics are not compostable at home, like organic food waste. They usually require an industrial composting treatment that is unavailable at every composting site (Barker & Safford, 2009).

Lack of legislation:

Production of bioplastics is projected to increase to over 6.7 million tons by the year 2018, but still, now many countries have not used any law or legislation about their production, usage or waste management (Arikan and Ozsoy, 2015).

Current status of the bioplastics market in India:

Bioplastics play an important role in developing bioeconomy. Bioplastic is a growing market; it increases by about 20%~25% per year globally, and by 2020 it will increase to 25%~30% of the total plastic market. Developing countries like India's use of bioplastics will create new job opportunities. But Currently, the Bioplastics market in India is in an infant stage. Very few companies are operating in the bioplastic segment in India. Environmental awareness programs, easy feedstock availability and government backing give major support to Bioplastics manufacturers in India. However, more initiative is needed for production, raw materials and technology development. The National Green Tribunal's state-level committee has set an August 31, 2019, deadline for the government to enforce the ban on plastic. Scientists across India were working on the development of bioplastics. A very recent development came from IIT-Guwahati, and the new bioplastic is under commercial production. Biogreen India’s 1st Biotechnology Company for Bio-degradable Products. Truegreen, Plastobags, Ecolife, and Envigreen are already producing bioplastics in India. Many technological discoveries have boosted the Indian Bioplastics market and significant growth in the industry has been observed (Arikan and Ozsoy, 2015).

Conclusion:

Since the beginning of bulk plastic production in the 1940s, microplastic contamination of the environment has been a growing concern. Microplastics are in everyday products like face scrubs, toothpaste, and textiles. It is necessary to understand the role of microplastics and their contribution to human life to evaluate their potential contribution to the global disease burden. Although there are several studies conducted on the toxic effects of microplastics on model organisms like microorganisms, fishes and mice, there is very limited study on humans because of ethical and legal constraints. Plastic waste management is no doubt initiated lots of problems like increased greenhouse gas emissions, microplastic entering the human food chain, etc. Bio-plastics are considered a unique, sustainable alternative to plastic management. Thus, research and development in bio-plastics are much needed for better management of this problem. Policymakers, business houses and politicians have to play a crucial role in regularly using bioplastics.

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