REVISTA OWL (*OWL Journal*)
www.revistaowl.com.br – ISSN: 2965-2634

PLASTICS AND MICROPLASTICS: ENVIRONMENTAL IMPACTS, HEALTH IMPLICATIONS AND PROSPECTS FOR THE CIRCULAR ECONOMY

PLÁSTICOS E MICROPLÁSTICOS: IMPACTOS AMBIENTAIS, IMPLICAÇÕES PARA A SAÚDE E PERSPECTIVAS PARA A ECONOMIA CIRCULAR

DOI: 10.5281/zenodo.23934505

Nicole Delaunay de Souza[1]
Solange da Silva Malfacini[2]
Rayssa de Macedo Rebelo[3]
Marcos Tadeu Varricchio[4]
Jaqueline da Silva[5]
Paulo Sérgio Torres Brioso[6]

1 PhD candidate student in Geology and Geochemistry at the Federal University of Pará (UFPA). Address: Rua Augusto Corrêa, 01. Neighborhood: Guamá. Postal Code: 66075. Belém, Pará. Master's degree in Geosciences from the Federal Rural University of Rio de Janeiro. Email: nicoledelaunay13@gmail.com.

2 PhD candidate student in Environmental Technology at the University of Ribeirão Preto, São Paulo. Medical Doctor with a master's degree in Primary Health Care from the Federal University of Rio de Janeiro (UFRJ). 214 Viúva Dantas Street, room 320. Campo Grande. Rio de Janeiro. Postal Code 23052-090. Email: Campus 1 <0157045@professor.unig.edu.br>

3 Undergraduate student in Electronic and Computer Engineering from Universidade Federal do Rio de Janeiro (UFRJ). Environmental Health, Parasitology, and Bioethics Project of the Immunoparasitology and Toxicological Analysis Laboratory of the Faculty of Pharmacy of the Federal University of Rio de Janeiro (SAPB-LIPAT/FF/UFRJ). Address:Carlos Chagas Filho Avenue, 373, Cidade Universitária da Universidade Federal do Rio de Janeiro, Rio de Janeiro - RJ, Brazil. Zip Code: 21941-170. Email: rr.rayssarebelo@gmail.com.

4 Senior Electrical Engineer, graduate of the Catholic University of Petrópolis (UCP). Environmental Health, Parasitology, and Bioethics Project of the Immunoparasitology and Toxicological Analysis Laboratory of the Faculty of Pharmacy of the Federal University of Rio de Janeiro (SAPB-LIPAT/FF/UFRJ). Address: Carlos Chagas Filho Avenue, 373, Cidade Universitária da Universidade Federal do Rio de Janeiro, Rio de Janeiro - RJ, Brazil. Zip Code: 21941-170. Email: mtvarricchio7@gmail,com.

5 PhD Geriatric Nursing University of San Francisco. Federal University of Rio de Janeiro, Anna Nery School of Nursing. Afonso Cavalcanti Street, 275, Cidade Nova, Rio de Janeiro –RJ, Zip Code: 20211-130. Email: jaquelinedasilva@ufrj.br.

6 Graduated in agronomic engineering. PhD in Sciences – Genetics. Federal Rural University of Rio de Janeiro. Official Laboratory of Phytosanitary Diagnosis – Phytopathology. BR 465, km 07, Rua Itaperuna s/n, Seropédica, Rio de Janeiro, CEP: 23897-095. Email: brioso@bighost.com.br.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

REVISTA OWL (*OWL Journal*)
www.revistaowl.com.br – ISSN: 2965-2634

Ricardo Machado Kuster[7]
Alexandre dos Santos Pyrrho[8]
Simone da Silva[9]
Marcia Cristina Braga Nunes Varricchio[10]

ABSTRACT

Plastics are synthetic materials based on organic polymers, widely used in all sectors of the global economy. World production reached 431 million metric tons in 2024, having grown at a compound annual rate of 4.8% since the beginning of the 21st century. However, only 9% of the total plastic produced up to 2015 had been recycled, while 79% was discarded in landfills or in the natural environment. The progressive fragmentation of these materials gives rise to microplastics (MPs) — particles with a diameter of less than 5 mm — emerging contaminants detected in all terrestrial and aquatic ecosystems, including human tissues. The objective was to conduct a scoping review of the literature (2000–2025) on the definition, classification, and uses of plastics; the origin and environmental dynamics of microplastics; the repercussions on ecosystems and human health; statistics on associated diseases; and biotechnological strategies for biodegradation and circular economy. The methodology adopted was a scoping review using the PubMed/MEDLINE, Web of Science, Scopus, SciELO, and Google Scholar databases, with Boolean operators and MeSH/DeCS controlled descriptors. Coverage period: 2000–2025. Criteria: original articles, systematic reviews, and meta-analyses in English, Portuguese, and Spanish, indexed in peer-reviewed journals. The results identified 7 classes of plastics using the international coding system, distinguishing between thermoplastics and thermosets. Microplastics (MPs) have primary origins (cosmetic microspheres, industrial pellets) or secondary origins (photodegradation, mechanical abrasion, tire wear, synthetic fiber washing). Studies associate exposure to MPs with cardiovascular diseases (accelerated atherosclerosis, myocardial infarction, and stroke), diabetes mellitus, systemic arterial hypertension, endocrine disruption, neurotoxicity, and alterations in the intestinal microbiota. Research by the American College of Cardiology (ACC, 2025) with 555 census tracts in the US confirmed a positive correlation between the concentration of microplastics (MPs) in water bodies and the prevalence of

7 Department of Chemistry, Federal University of Espírito Santo (UFES). Postgraduate Program in Chemistry and Postgraduate Program in Pharmaceutical Sciences. Address: Fernando Ferrari Avenue, 514, 29075-910 - Vitória - ES, Brazil. Email: kusterrm@gmail.com.

8 PhD in Sciences (Biophysics) from the Federal University of Rio de Janeiro (UFRJ). Laboratory of Immunoparasitology and Toxicological Analysis of the Faculty of Pharmacy (UFRJ). Carlos Chagas Filho Avenue, 373, University City of Federal University of Rio de Janeiro, Rio de Janeiro - RJ, Brazil.Zip Code:21941-170. Email: pyrrho@farmacia.ufrj.br.

9 PhD in Sciences (Plant Biology and Biotechnology) from the Postgraduate Program in Plant Biotechnology (PPGBV – UFRJ). Amazon Biobusiness Center (CBA) & Institute of Technology and Education Galileo da Amazônia (ITEGAM). Governor Danilo de Matos Areosa Avenue, No. 690, Industrial District I, Manaus, Amazonas, Brazil. Postal Code 69075-351. Email: simonydasilva@gmail.com.

10 PhD in Sciences (Plant Biology and Biotechnology) from the Postgraduate Program in Plant Biotechnology (PPGBV – UFRJ). Environmental Health, Parasitology, Bioethics Project of the Laboratory of Immune Parasitology and Toxicological Analysis of the Faculty of Pharmacy of the Federal University of Rio de Janeiro (SAPB-LIPAT Project/FF/UFRJ). Address: Carlos Chagas Filho Avenue, 373, University City of the Federal University of Rio de Janeiro, Rio de Janeiro - RJ, Brazil. Zip Code:21941-170. Email: varichio2@gmail.com.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

hypertension, diabetes, and stroke. Enzymes such as PETase, MHETase, laccases, and FAST-PETase, produced by bacteria such as Ideonella sakaiensis, Pseudomonas, and Bacillus, demonstrate potential for polymer biodegradation. PHA and PLA-based bioplastics represent viable alternatives in the circular economy. Conclusion: the microplastic crisis constitutes a global public health and environmental emergency. Although causal relationships with chronic diseases still lack confirmation through longitudinal studies, the associative evidence is growing and robust. Biodegradation biotechnologies and circular economy models represent the most promising strategies for mitigation, requiring convergence between science, regulation, and public policies.

Keywords: microplastics; synthetic polymers; biodegradation; environmental and sanitary engineering; circular economy; global environmental health.

RESUMO

Os plásticos são materiais sintéticos à base de polímeros orgânicos, amplamente utilizados em todos os setores da economia global. A produção mundial atingiu 431 milhões de toneladas métricas em 2024, tendo crescido a uma taxa composta anual de 4,8% desde o início do século XXI. No entanto, apenas 9% do total de plástico produzido até 2015 havia sido reciclado, enquanto 79% foi descartado em aterros ou no ambiente natural. A fragmentação progressiva desses materiais origina os microplásticos (MPs) — partículas com diâmetro inferior a 5 mm —, contaminantes emergentes detectados em todos os ecossistemas terrestres e aquáticos, inclusive em tecidos humanos. O objetivo foi realizar uma revisão de escopo (*scoping review*) da literatura (2000–2025) sobre a definição, classificação e usos dos plásticos; a origem e dinâmica ambiental dos microplásticos; as repercussões sobre ecossistemas e saúde humana; estatísticas de doenças associadas; e estratégias biotecnológicas para biodegradação e economia circular. Como metodologia adotou-se revisão de escopo com pesquisa nas bases de dados PubMed/MEDLINE, Web of Science, Scopus, SciELO e Google Scholar, com operadores booleanos e descritores controlados MeSH/DeCS. Período de cobertura: 2000–2025. Critérios: artigos originais, revisões sistemáticas e meta-análises em inglês, português e espanhol, indexados em periódicos com revisão por pares. Como resultados foram identificadas 7 classes de plásticos pelo sistema de codificação internacional, com distinção entre termoplásticos e termofixos. Os microplásticos (MPs) têm origem primária (microesferas cosméticas, pellets industriais) ou secundária (fotodegradação, abrasão mecânica, desgaste de pneus, lavagem de fibras sintéticas). Estudos associam a exposição a MPs com doenças cardiovasculares (aterosclerose acelerada, infarto do miocárdio e acidente vascular encefálico), diabetes mellitus, hipertensão arterial sistêmica, disrupção endócrina, neurotoxicidade e alterações da microbiota intestinal. Pesquisa do American College of Cardiology (ACC, 2025) com 555 setores censitários dos EUA confirmou correlação positiva entre concentração de MPs em corpos hídricos e prevalência de hipertensão, diabetes e AVC. Enzimas como PETase, MHETase, laccases e FAST-PETase, produzidas por bactérias como *Ideonella sakaiensis*, Pseudomonas e Bacillus, demonstram potencial para biodegradação de polímeros. Bioplásticos à base de PHA e PLA representam alternativas viáveis na economia circular. Conclusão: a crise dos microplásticos constitui emergência de saúde pública e ambiental de escala global. Embora as relações causais com doenças crônicas ainda careçam de confirmação por estudos longitudinais, a evidência associativa é crescente e robusta. Biotecnologias de biodegradação e modelos de economia circular representam as estratégias mais promissoras para mitigação, exigindo convergência entre ciência, regulação e políticas públicas.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Palavras-chave: microplásticos; polímeros sintéticos; biodegradação; engenharia ambiental e sanitária; economia circular; saúde ambiental global.

INTRODUCTION

Plastics have radically transformed modern civilization since their industrial-scale production began in the second half of the 20th century. Versatile, lightweight, inexpensive, and durable, they have become ubiquitous in sectors such as packaging, construction, medicine, electronics, clothing, and transportation. In 1950, global production was approximately 2 million metric tons; by 2024, this figure had reached 431 million metric tons, representing a growth of over 21.000% in just over seven decades (Statista, 2025; Our World in Data, 2023).

Paradoxically, the very durability that gave plastic its economic utility constitutes the core of the environmental problem it represents. It is estimated that 75% of all plastic ever produced has become waste, of which only 9% has been recycled, 12% incinerated, and 79% deposited in landfills or dispersed in the natural environment (Geyer et al., 2017). In the environment, the combined action of ultraviolet radiation, mechanical stress, and biological agents progressively fragments these materials, generating microplastics—particles with dimensions smaller than 5 millimeters—and nanoplastics (< 1 μm), emerging contaminants whose environmental ubiquity and effects on human health have mobilized increasing scientific and regulatory attention (UNCTAD, 2025).

The detection of microplastics in human tissues, including blood, placenta, lungs, liver, and atherosclerotic plaques, signals that contamination has gone beyond the ecological sphere to reach clinical dimensions. Data presented at the Annual Scientific Session of the American College of Cardiology (2025) revealed a positive correlation between the concentration of microplastics in water bodies and the prevalence of systemic arterial hypertension, diabetes mellitus, and stroke in North American coastal communities, placing microplastics among the top ten predictors of chronic non-communicable diseases (Ponnana et al., 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

This scoping review article aims to consolidate the state of the art of knowledge on plastics and microplastics in the period 2000–2025, addressing: (a) definition and history of plastics; (b) classification and main uses; (c) origin and environmental dynamics of microplastics; (d) ecological and human health repercussions; (e) statistics on associated diseases; and (f) biotechnological strategies for biodegradation and circular economy.

METHODOLOGY

Type of study

Scope review of Literature (2000–2025) (scoping review), conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines and the methodological principles established by the Joanna Briggs Institute (JBI) (Page et al., 2021).

Databases and search strategy

The searches were conducted in the following electronic databases: PubMed/MEDLINE, Web of Science (Clarivate Analytics), Scopus (Elsevier), SciELO (Scientific Electronic Library Online), Google Scholar, and CAPES Journals. The search covered publications from January 2000 to June 2025. The languages included were: English, Portuguese, and Spanish.

Boolean nomenclature used

The search strategy used the following operators and descriptors, structured in thematic blocks:

BLOCK 1 — Plastics and polymers:

("plastic" OR "polymer*" OR "synthetic resin*" OR "thermoplastic*" OR "thermoset*") AND ("classification" OR "properties" OR "uses" OR "applications" OR "polyethylene" OR "polypropylene" OR "PET" OR "PVC" OR "polystyrene")*

BLOCK 2 — Microplastics and nanoplastics:

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

("microplastic" OR "nanoplastic*" OR "micro-plastic*" OR "plastic particle*" OR "plastic fragment*") AND ("origin" OR "source*" OR "formation" OR "degradation" OR "fragmentation" OR "photodegradation" OR "UV degradation" OR "secondary microplastic*")*

BLOCK 3 — Environmental contamination:

("microplastic" OR "nanoplastic*") AND ("environment*" OR "ocean*" OR "marine*" OR "freshwater" OR "soil" OR "atmosphere" OR "air" OR "food chain" OR "ecosystem*" OR "ecotoxicolog*")*

BLOCK 4 — Human health and diseases:

("microplastic" OR "nanoplastic*" OR "plastic pollution") AND ("human health" OR "cardiovascular disease*" OR "diabetes" OR "hypertension" OR "endocrine disruption*" OR "cancer" OR "neurotoxicit*" OR "oxidative stress" OR "inflammation" OR "gut microbiome" OR "respiratory disease*" OR "biomarker*")*

BLOCK 5 — Biodegradation and Circular Economy:

("plastic biodegradation" OR "polymer biodegradation" OR "plastic degrading microorganism*" OR "PETase" OR "microbial enzyme*" OR "bioplastic*" OR "PHA" OR "PLA" OR "polyhydroxyalkanoate*") AND ("circular economy" OR "sustainable" OR "recycling" OR "green chemistry" OR "bioremediation")*

Inclusion and exclusion criteria

Original articles, systematic reviews, meta-analyses, and reports from international organizations (UN, WHO, UNEP, PLASTICS EUROPE) published between 2000 and 2025, indexed in peer-reviewed journals in English, Portuguese, and Spanish, were included. Studies with sample sizes smaller than an = 10 for observational clinical research, conference abstracts without full publication, and articles without access to the full text were excluded.

Data selection and extraction

The selection of studies followed these steps: (1) identification by title and abstract; (2) eligibility assessment by full text; (3) final inclusion with structured data extraction. In accordance with the JBI framework for scoping reviews, formal assessment of the methodological quality of individual studies was not a mandatory step; however, a critical

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

mapping of the nature of the study design (observational, experimental, ecological) and the level of evidence for the main associations reported was carried out.

RESULTS

PLASTICS: DEFINITION, HISTORY AND CLASSIFICATION

Definition and chemical composition

Plastics are defined as synthetic or semi-synthetic materials composed of polymers—long molecular chains typically derived from petroleum, natural gas, or, more recently, renewable carbon sources. They are malleable materials that can be molded or shaped when heated and, after cooling, retain their shape and solidify (AMERICAN CHEMISTRY COUNCIL, 2023; AZoM, 2024). The basic structural unit is the monomer, whose polymerization, by addition or condensation, generates macromolecular chains with molar masses typically between 10.000 and 1.000.000 g/mol.

In addition to the base polymer, commercial plastics contain functional chemical additives that include plasticizers (phthalates, adipates), thermal stabilizers (tin salts, zinc compounds), antioxidants (hindered phenols, aromatic amines), pigments, flame retardants (halogenated compounds, phosphates), and nucleating agents. Many of these additives are classified as endocrine disruptors and have recognized toxicity to mammals, including humans (Kannan; Vimalkumar, 2021; PLASTIC POLLUTION COALITION, 2023).

The first synthetic plastic, Bakelite (polyoxybenzylmethyleneglycolanhydride), was patented by Leo Baekeland in 1907. In the following decades, nylon (1938), polyethylene (1939), and PET (Polyethylene terephthalate, 1941) laid the foundations for the modern plastics industry. Large-scale production became viable after World War II, driven by the petrochemical industry. From 2 million tons in 1950, global production has grown virtually uninterruptedly: 213 Mt in 2000, 320 Mt in 2015, and 431 Mt in 2024 (Geyer et al., 2017; STATISTA, 2025). More than half of all plastic ever manufactured was produced after the year 2000 (PLASTIC SOUP FOUNDATION, 2023).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Classification of plastics

Regarding thermal behavior

Plastics are classified, according to their behavior under heat, into two main groups: thermoplastics and thermosets. Thermoplastics, such as polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC), can be melted and remolded repeatedly without significant chemical alteration, making them potentially recyclable (AZoM, 2024; HowStuffWorks, 2023). Thermosets, epoxy resins, bakelite, and cured polyurethane, undergo irreversible cross-linking during curing and cannot be remelted. Table 1 shows a comparison between the groups.

Table 1: Comparison between thermoplastics and thermosets.

Feature	Thermoplastics	Thermosets
Behavior in the heat	They soften and can be reshaped.	They harden permanently.
Recyclability	High (casting and reprocessing)	Very low or zero
Examples	PE, PP, PET, PVC, PS	Epoxy resins, bakelite, thermosetting polyurethane
Structural rigidity	Moderate to high	High
Chemical resistance	Moderate	High
Typical applications	Packaging, piping, fibers	Aeronautics, electronics, structural adhesives

Source: *Prepared by the authors based on AZoM (2024), HowStuffWorks (2023) and Plastic Collective (2024).*

Regarding the resin identification code (SPI)

The international resin coding system, developed by the Society of the Plastics Industry (SPI) and adopted globally, assigns numbers from 1 to 7 to groups of polymers, facilitating sorting for recycling (Table 2). The European Union maintains an expanded list of 9 codes, including ABS and polyamides (WASTE4CHANGE, 2024; A&C PLASTICS, 2023).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Table 2: Classification of plastics by SPI code, type, abbreviation, applications and recyclability.

Code	Polymer Type	Acronym	Main Applications	Recyclable?
1	Polyethylene terephthalate	PET	Beverage packaging, clothing, carpets, surgical sutures	Yes
2	High-Density Polyethylene	HDPE	Milk/detergent bottles, pipes, toys	Yes
3	Polyvinyl chloride	PVC	Hydraulic pipes, flooring, medical packaging, electrical wires	Difficult
4	Low-Density Polyethylene	LDPE	Plastic bags, films, flexible packaging	Limited
5	Polypropylene	PP	Lids, food packaging, automotive parts, medical devices	Yes
6	Polystyrene	PS	Disposable cups, styrofoam, packaging for electronics	Difficult
7	Other polymers (Acrylonitrile-butadiene-styrene, Polycarbonate, Nylon, PLA, etc.)	ABS/PC/PA/PLA	Electronics, water jugs, engineering tools	Variable

Source: *Prepared by the authors based on SPI (2023), WASTE4CHANGE (2024), A&C PLASTICS (2023) and PLASTIC COLLECTIVE (2024).*

Global plastics production (2000–2024)

Analysis of the historical evolution of production reveals virtually uninterrupted growth, with a notable acceleration in the post-pandemic period. In 2023, global production reached 436 Mt, while trade in plastics exceeded US$1.1 trillion, representing 5% of global merchandise trade (UNCTAD, 2025). Asia was the largest producing region in 2023, with China accounting for approximately 30% of world production (WORLD METRICS, 2026), as shown in Table 3.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição *(CC BY)*

Table 3: Evolution of global plastics production (2000–2024).

Year	Production (Mt)	Variation	Context
2000	≈ 213	–	Beginning of accelerated post-industrial growth.
2005	≈ 245	+15%	Expansion in Asia (China and India)
2010	≈ 270	+10%	Global financial crisis slows slightly.
2015	≈ 320	+19%	Stable growth; environmental concerns emerge.
2019	≈ 368	+15%	Pre-pandemic peak; EU proposes ban on single-use plastics.
2020	≈ 370	+1%	COVID-19; increased use of health-grade plastics
2021	≈ 390	+5%	Economic recovery
2022	≈ 460	+18%	Record-breaking global production
2023	≈ 436	-5%	Slight decline; failure at the Global Plastics Treaty (UN)
2024	≈ 431	±0%	Stabilization; intense international regulatory debate

Sources: *Geyer et al. (2017); OUR WORLD IN DATA (2023); STATISTA (2025); UNCTAD (2025); WORLD METRICS (2026). Mt = millions of metric tons.*

Microplastics: Definition, Origin, and Environmental Dynamics

Definition and dimensional categories

Microplastics (MPs) were defined by Thompson et al. (2004) as plastic particles with dimensions smaller than 5 mm. In practice, this category encompasses a huge heterogeneity of sizes, shapes, and polymeric compositions. Hartmann et al. (2019) propose a more granular classification:

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

- Macroplastics (general concept): > 5 mm to 1 cm
- Mesoplastics: 5 mm – 25mm up to 1 cm
- Microplastics: 1 µm to 5 mm
- Nanoplastics: < 1 µm (< 1000 nm)

Classification by origin: primary and secondary

Regarding their origin, microplastics (MPs) are classified as primary and secondary, as shown in Table 4. Primary MPs are deliberately manufactured in reduced sizes for industrial use or in consumer products; they include microspheres used in exfoliating cosmetics, toothpastes, and cleaning products, as well as industrial pellets ("nurdles"), raw material for the manufacture of plastic objects. Secondary MPs result from the fragmentation of larger plastic objects by physical, chemical and biological processes after their disposal in the environment (Shahnawaz et al., 2019; FRONTIERS ENVIRONMENTAL SCIENCE, 2025).

Table 4: Sources and characteristics of primary and secondary microplastics.

Type	Source	Typical size	Examples
Primary	Cosmetic microspheres	< 1 mm	Facial scrubs, toothpaste, cleansing products
Primary	Industrial pellets (nurdles)	3–5 mm	Raw material for the manufacture of plastics
Primary	3D printing powder	20–500 µm	Additive manufacturing
Secondary	UV fragmentation (photodegradation)	< 5 mm	Packaging and bags exposed to the sun.
Secondary	Tire wear	20–500 µm	Road traffic, stormwater runoff
Secondary	Cleaning synthetic fabrics	< 1 mm	Polyester, nylon, acrylic in washing machines
Secondary	Mechanical fragmentation in	Miscellaneous	Compression and pressure on solid waste

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Type	Source	Typical size	Examples
	landfills		
Secondary	Paints and coatings	10–200 μm	Maritime structures, buildings, roads

Source: *Prepared by the authors based on FRONTIERS ENVIRONMENTAL SCIENCE (2025), SPRINGER NATURE REVIEWS (2025) and Ahmad et al. (2025).*

Mechanisms of secondary formation

Photodegradation and fragmentation

The main mechanism for generating secondary polymers is photo-oxidation followed by mechanical fragmentation. UV radiation embrittles the polymer chains, inducing the breakage of C-C and C-H bonds, which reduces the molar mass and increases the local crystallinity of the material. Embrittlement facilitates fragmentation by mechanical stress (waves, wind, friction with sediments), generating progressively smaller particles. This process is autocatalytic: as the polymer fragments, a larger surface area is exposed to photo-oxidation, accelerating the cycle (ACS ENVIRONMENTAL SCIENCE & TECHNOLOGY, 2022; PMC CURRENT CONCERNS, 2024).

Tire wear and textile fibers

Two particularly relevant anthropogenic sources are tire wear from motor vehicles and the washing of synthetic fabrics. Tire wear releases synthetic rubber particles (SBR, with diameters of 20–500 μm) into stormwater runoff and receiving water bodies. Estimates suggest that tire wear is responsible for 5–10% of all particulate matter (PMs) found in the global ocean. The washing of polyester, nylon, and acrylic releases between 700.000 and 1.500.000 microfibers per cycle, which escape conventional wastewater treatment systems (SPRINGER NATURE REVIEWS, 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Landfills as reservoirs and sources

Landfills constitute important reservoirs and continuous sources of PMs. Physical compression, temperature variation (60°C–90°C in biodigestion), pH conditions (4.5–9.0), and the local microbiota promote plastic fragmentation even in the absence of light, generating PMs that can be transported to the environment by leaching, percolation, or airborne dispersion (Dehal et al., 2024; FRONTIERS ENVIRONMENTAL SCIENCE, 2025).

Environmental distribution of microplastics

Particulate matter (PMs) is now considered a ubiquitous contaminant, detected in all environmental compartments. Concentrations of up to 4.34 particles per liter have been recorded in drinking water (SPRINGER NATURE REVIEWS, 2025). In the ocean, it is estimated that 1.7 million tons of plastic enter annually as a result of an influx that accumulates in ocean gyres, deep sediments, and marine fauna (Ahmad et al., 2025; OUR WORLD IN DATA, 2023).

In soil, particulate matter (PMs) from irrigation with treated effluents, sewage sludge application, and decomposition of agricultural films compromise soil structure and the terrestrial food chain. The detection of PMs in atmospheric air, in locations as remote as the Arctic and the Himalayas, demonstrates that airborne dispersal is a global vector of contamination (Ahmad et al., 2025; OUR WORLD IN DATA, 2023).

Impacts of Microplastic Contamination on the Environment

Aquatic ecosystems

Microplastics (MPs) affect aquatic organisms at multiple trophic levels. In invertebrates and fish, MP ingestion causes gastrointestinal obstruction, pseudo-satiety, reduced caloric intake, hormonal changes, and transfer of adsorbed contaminants (heavy metals, persistent organic pollutants — POPs). Studies with zebrafish (*Danio rerio*) have documented neurotoxic and reproductive effects of polystyrene nanoparticles, including impaired learning and memory due to acetylcholine depletion (Sarasamma et al., 2020; FRONTIERS PUBLIC HEALTH, 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Microplastics (MPs) act as vectors for the transport of hydrophobic pollutants. The surface of MPs adsorbs compounds such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), DDT and heavy metals with high efficiency, increasing the bioavailability of these toxins to organisms that ingest them — a phenomenon known as the 'Trojan horse effect' (Ahmad et al., 2025).

Terrestrial ecosystems

In agricultural soils, microplastics interfere with porosity, water retention and the activity of earthworms and decomposing microorganisms. Root absorption of nanoplastics in plants has been documented in lettuce, wheat, and soybean crops, raising concerns about the entry of microplastics into the human food chain via vegetables (FRONTIERS ENVIRONMENTAL SCIENCE, 2025).

Climate impacts

Plastic production is responsible for approximately 3.4% of global greenhouse gas emissions. Projections indicate that, if current trends continue, the cumulative carbon equivalent emissions from plastics could exceed the emissions of all US coal-fired power plants by 50 times by 2050 (UNEP, 2023). The incineration of mixed plastics also releases dioxins and furans, extremely toxic and persistent compounds.

IMPACTS OF MICROPLASTICS ON HUMAN HEALTH

Routes of human exposure

Humans are exposed to PMs primarily through three routes: (1) Ingestion — via drinking water, seafood, food packaged in plastic, beverages in plastic bottles, and sea salt; (2) Inhalation — from fibers and particles suspended in ambient air, especially in indoor and occupational settings; and (3) Dermal contact — with plastic materials, cosmetics, and personal care products (Prata et al., 2020; Tandfonline, 2025).

Studies with healthy volunteers and patients have identified food packaging for delivery (takeaway) and bottled water consumption as the main documented sources of

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

exposure (MEDRXIV, 2025). Workers in the plastics industry have additional occupational exposure through inhalation of polymer dusts and mists (Prata et al., 2020).

Bioaccumulation and tissue distribution

Once in the body, MPs cross biological barriers and distribute themselves to multiple tissues. They have been detected in: peripheral blood, lung tissue, liver, kidneys, placenta (including fetal blood), breast milk, atherosclerotic plaques, and thrombi in patients with acute myocardial infarction, ischemic stroke and deep vein thrombosis (LANCET PLANETARY HEALTH, 2025; Ririe et al., 2025). Quantifications in thrombi revealed concentrations of 141.80 μg/g in infarcts and 61.75 μg/g in ischemic strokes (LANCET PLANETARY HEALTH, 2025).

The presence of microplastics (MPs) and nanoplastics in breast milk — detected in up to 75% of some samples — exposes newborns and infants to harmful particles and chemicals. Other recent research has revealed that bottle-fed babies likely ingest millions of microplastics per day and that cow's milk may contain microplastics. The exact effects on humans are still under investigation, but animal models reveal inflammatory responses, hormonal dysregulation and developmental damage. Therefore, the literature recommends storing and heating expressed milk in glass or ceramic containers, avoid plastic bottles and heated utensils that release microparticles.

Mechanisms of toxicity

MPs induce adverse effects through multiple interconnected mechanisms:

- Oxidative stress: generation of reactive oxygen species (ROS) that cause DNA damage, lipid peroxidation, mitochondrial dysfunction, and impaired autophagy;
- Systemic and local inflammation: activation of the NLRP3 inflammasome, release of IL-1β, IL-6 and TNF-α, with macrophage infiltration into the tissues;
- Endocrine disruption: phthalates, bisphenol A (BPA), and alkylphenols released by MPs mimic steroid hormones and interfere with estrogen, androgen and thyroid receptors;

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

- Changes in the gut microbiota: modification of the composition and diversity of the microbiome, with an increase in pathogenic bacteria and a reduction in protective species;
- DNA damage and mutagenic potential: additives such as styrene and vinyl chloride are classified as possible carcinogens (IARC Group 2A/2B);
- Premature cellular senescence: exposure to nanoplastics induces senescence in human lung epithelial cells via ROS signaling (FRONTIERS PUBLIC HEALTH, 2025).

Associated diseases and epidemiological statistics

Table 5 summarizes the main diseases associated with exposure to PMs, the level of evidence available, and the proposed mechanisms.

Table 5: Diseases associated with microplastic exposure - evidence, mechanisms, and references.

System / Disease	Current evidence	Proposed mechanism	Key reference
Cardiovascular (atherosclerosis, heart attack, stroke)	Moderate associative in humans	Oxidative stress, inflammation, accumulation in atherosclerotic plaques.	Marfella et al. (2024)
High blood pressure	Moderate – study of 555 census tracts (USA)	Endothelial dysfunction, endocrine disruption	Ponnana et al. (2025, ACC)
Type 2 diabetes	Moderate – positive correlation with PM in water bodies	Disruption of insulin pathways, oxidative stress	Ponnana et al. (2025, ACC)
Endocrine disruption (obesity, infertility)	High (*in vitro* and animal); Moderate in humans	Hormonal mimicry via BPA and phthalates	Kannan & Vimalkumar (2021)
Neurotoxicity (cognitive impairment)	Low–moderate (predominantly animal)	Cerebral accumulation of nanoparticles, depletion of acetylcholine.	Liu S. et al. (2024)
Respiratory diseases (fibrosis, lung inflammation)	Moderate – documented occupational exposure	Chronic inflammation, epithelial irritation	Prata et al. (2020)
Gastrointestinal disorders /	Moderate – changes in	Dysbiosis, local	Ririe et al. (2025)

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

System / Disease	Current evidence	Proposed mechanism	Key reference
microbiome	intestinal permeability	inflammatory response	
Carcinogenic potential	Low - inconclusive in humans	Mutagenic additives (styrene, vinyl chloride), genotoxic stress	Liu X. et al. (2025)

Source: *Prepared by the authors based on Ponnana et al. (2025), Marfella et al. (2024), Ririe et al. (2025), Liu S. et al. (2024) and Liu X. et al. (2025).*

Cardiovascular diseases

In 2024, Marfella et al. published a prospective study in the New England Journal of Medicine demonstrating that patients with atherosclerotic plaques containing MPs had a 4.5 times greater risk of myocardial infarction, stroke and death from cardiovascular causes over 34 months of follow-up, compared to those without detectable MPs in the plaques. Analyses from Lancet Planetary Health (2025) confirmed the presence of MPs in thrombi of patients with active cardiovascular disease. At the ACC Annual Session (March 2025), Ponnana et al. presented an analysis of 555 census tracts in the US showing that the concentration of PMs in water bodies was positively correlated with systemic arterial hypertension ($p < 0.001$), diabetes mellitus ($p = 0.003$) and stroke ($p = 0.001$), after controlling for 154 socioeconomic and environmental factors (ACC, 2025; AJMC, 2025).

Endocrine disruption

Endocrine disruption is the most studied effect and has the most consolidated evidence. Phthalates, BPA, and perfluoroalkyl substances (PFAS) present in plastics are classified as endocrine disruptors and are associated with endometriosis, breast cancer, hyperthyroidism, obesity, male infertility (reduced sperm count and motility), and polycystic ovary syndrome (Kannan; Vimalkumar, 2021; PLASTIC POLLUTION AND HEALTH, 2023). Elevated BPA levels have been documented in patients with dilated cardiomyopathy compared to healthy controls (PMC, 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Neurotoxicity

Studies in animal models have shown that polystyrene nanoparticles cross the blood-brain barrier, accumulate in brain tissue, and induce cognitive deficits, behavioral changes, anxiety, mood swings and sleep disorders through mechanisms that include acetylcholine depletion and activation of inflammatory pathways similar to those observed in Parkinson's disease. Recent research highlights that fine particles can migrate from the environment directly to the human brain through the olfactory bulb (olfactory nerve), bypassing the blood-brain barrier (Liu S. et al., 2024). Evidence in humans remains limited but growing.

Reproductive and pediatric outcomes

MPs have been detected in human placentas and umbilical cord blood, indicating intrauterine exposure. Prenatal exposure to plastic EDCs is associated with intrauterine growth restriction (IUGR), prematurity and neurological developmental disorders in childhood (MEDRXIV, 2025; Chia et al., 2025).

Natural and biotechnological products for microplastic degradation.

- Microbial biodegradation

The biodegradation of plastics by microorganisms is a multi-step process that involves: (1) adhesion of microbial cells to the plastic surface; (2) colonization and biofilm formation; (3) secretion of extracellular enzymes that cleave the polymer chains into oligomers and monomers; (4) intracellular absorption and metabolism of the degradation products. The efficiency of the process depends on factors intrinsic to the polymer (degree of crystallinity, molar mass, hydrophobicity, presence of additives) and extrinsic factors (temperature, humidity, nutrient availability, microbial diversity) (SPRINGER BIODEGRADATION, 2026; MDPI, 2025).

The main biodegrading microorganisms and enzymes are presented in Table 6. It is important to emphasize that the degradation rates reported in the literature were obtained under heterogeneous experimental conditions (temperature, incubation time, type and form of

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

polymer, presence of oxidative pretreatment), which prevents a direct comparison between the absolute values presented.

Table 6: Microorganisms, enzymes, and biodegradation rates of plastic polymers.

Microorganism / Enzyme	Target polymer	Degradation rate (lab.)	Reference
Ideonella sakaiensis (PETase + MHETase)	PET	~30% in 6 weeks (18°C)	Yoshida et al. (2016)
Pseudomonas putida	LDPE, PP, PET, PLA	3–7% reduction in mass in 60 days	Towards a Circular Economy (2025)
Bacillus subtilis	LDPE, HDPE, PVC (*in silico*), PET	2–8% in 30–90 days	Microbial Sciences (2025)
Aspergillus fumigatus	PVC	5–12% loss of mass in 30 days	El-Dash et al. (2023)
Laccases (*Thermomonospora curvata*)	PS (pre-oxidized polystyrene)	~20% degradation in 7 days	Du et al. (2022)
FAST-PETase (engineered enzyme)	PET	~90% in 1 week (50°C)	Lu et al. (2022)
Rhodococcus ruber+ *Pseudomonas putida* (consortium)	Mixed PE	Greater efficiency than isolated strains.	Manzoor et al. (2022)
Bacterial wax (*Galleria mellonella* – larvae)	PE, LDPE	Oxidative degradation in < 24h (*in vitro*)	Bombelli et al. (2017)

Source: *Prepared by the authors based on Yoshida et al. (2016); Du et al. (2022); MDPI (2025); SCIENCEDIRECT CIRCULAR ECONOMY (2025); SPRINGER BIODEGRADATION (2026).*

PETase and engineered enzymes

The discovery of *Ideonella sakaiensis* 201-F6 by Yoshida et al. (2016), capable of using PET as the sole carbon and energy source via PETase and MHETase, ushered in a new era in plastic degradation biotechnology. Researchers at the University of Texas at Austin

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

developed FAST-PETase in 2022—an engineered version of PETase with five point mutations that increase catalytic activity by 8.600% and allow for the degradation of ~ 90% of PET in one week at 50°C (Lu et al., 2022). Other enzymes of interest include thermostable cutinases, fungal laccases and peroxidases with activity on pre-oxidized PS, PE and PP (SPRINGER BIODEGRADATION, 2026; ACS ENVIRONMENTAL AU, 2025).

Synergistic microbial consortia

Instead of isolated strains, researchers have explored microbial consortia that act synergistically to decompose polymers more efficiently. Studies with *Rhodococcus ruber* and *Pseudomonas putida* have demonstrated that mixed cultures degrade PE significantly faster than individual strains (Manzoor et al., 2022). Bacillus and Pseudomonas show remarkable versatility, being able to degrade LDPE, HDPE, PP, PET, PLA, and PS (Manzoor et al., 2022; SCIENCEDIRECT, 2025, 2025a).

Macroscopic organisms: *Galleria mellonella*

Bombelli et al. (2017) documented that wax moth larvae (*Galleria mellonella*) can oxidize and fragment polyethylene in less than 24 hours, through a mechanism mediated by enzymes in the wax produced by the larvae. The industrial potential of this finding remains under investigation, but it represents a biologically inspired approach to PE degradation.

- Chemical Action of Plants

In general, plant species do not destroy microplastics through direct chemical reactions. They mitigate this environmental pollution mainly through phytoremediation (the use of plants to contain or extract pollutants). The main highlight in this area is the water hyacinth (*Eichhornia crassipes*) (Yin et al., 2025).

In addition to water hyacinth, which is highly efficient at removing contaminants from aquatic environments due to its extensive root area (Yin et al., 2025), other terrestrial and semi-aquatic species are being studied for soil decontamination: Trees such as poplar

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

(Populus) and willow (Salix); Grasses such as vetiver besides lemongrass; also Ground cover: jack bean (*Canavalia ensiformis*) and crotalaria.

Recent investigations also point to the potential of lignocellulosic residues, such as sugarcane bagasse, as the low-cost bioadsorbents for removing particulate matter from effluents, given their high porosity and availability of reactive functional groups (Yuan et al., 2024).

Specifically to plastics, mainly laticifers plant species may act in morphological forms of PP at room temperature, frequently explained by their hydrophobicity, but indeed the mechanism of action still remains unknown and needs to be methodologically investigated (Delaunay; Rangel, 2019; Delaunay de Souza et al., 2023; 2023a; De Souza et al., 2026).

Circular Economy: Strategies for Sustainable Plastics

Current overview of plastic waste management

Despite regulatory advances and growing public awareness, plastic recycling accounts for less than 10% of global plastic waste management (STATISTA, 2025). The production of fossil fuel-based plastics grew by 300% between 1999 and 2019, reaching approximately 400 Mt/year, with only 9% recycled (UNEP, 2023). Business-as-usual projections indicate that even tripling the volume recycled by 2040, recycling would only represent 14% of the waste generated that year, with landfilling remaining the dominant method (STATISTA, 2025).

Contemporary circular economy strategies are shown in Table 7.

Table 7: Circular economy strategies for plastics: description and examples.

Strategy	Description	Recent examples and advances
Chemical recycling / enzymatic depolymerization	Conversion of polymers into reusable monomers via biological catalysis.	FAST-PETase (UT Austin); LanzaTech (captured carbon → polymers)
Bioplastics (PHA, PLA, PHB)	Biodegradable polymers synthesized by bacteria or derived from biomass.	PHA production by *Cupriavidus necator*; PLA from NatureWorks

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

Strategy	Description	Recent examples and advances
Circular Economy of Packaging	Systems for the return, reuse, and recycling of plastic packaging.	Loop Industries; Deposit Return Scheme (EU, 2024)
Pyrolysis / Gasification of plastic waste	Conversion of non-recyclable plastics into fuels or monomers.	Plastic Energy; Renewlogy; Agilyx
Replacement with biomaterials	Polysaccharides (cellulose, chitosan, starch), algae, and lignin as substitutes.	Notpla (algae packaging); functional papers
Filters and barriers for microplastics	Technologies for retaining particulate matter (PM) from industrial and domestic wastewater.	Guppyfriend backwash filters; tertiary water treatment systems

Source: *Prepared by the authors based on SCIENCEDIRECT CIRCULAR ECONOMY (2025), PHYS.ORG (2023), MDPI (2025) and UNCTAD (2025).*

Bioplastics as a structural alternative

Bioplastics represented only 2.42 million tons (0.6% of fossil plastic production) in 2021, with projected growth to 7.59 Mt by 2026 (EUROPEAN BIOPLASTICS apud UNEP, 2023). Polyhydroxyalkanoates (PHAs), synthesized by bacteria such as *Cupriavidus necator* and *Pseudomonas putida*, are completely biodegradable in natural environments, without generating residual material residues, and represent the alternative with the greatest potential for replacing single-use plastic packaging (PHYS.ORG, 2023).

Global regulatory policies

In 2024, UN member states failed to finalize the text of the Global Plastics Treaty, with disagreements centered on production limits and the elimination of specific products. The European Union banned ten categories of single-use plastics through Directive (EU) 2019/904 (EUROPEAN UNION, 2019) and implemented the Deposit Return Scheme (DRS) in 2024. Average MFN tariffs on fossil-based plastics have fallen from 34% to 7.2% over the past three decades, making them artificially cheaper than natural alternatives (average tariff of 14.4% for paper, bamboo and natural fibers), representing a structural market distortion (UNCTAD, 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

DISCUSSION

The data consolidated in this review reveal a picture of global environmental contamination on an unprecedented scale. The ubiquity of microplastics, detected from the deepest ocean trenches to the human placenta, constitutes what some researchers call the 'Great Plastic Acceleration', parallel to the Great Economic Acceleration of the post-war period, but with environmental and health consequences that are still incompletely understood.

With regard to human health, it is imperative to distinguish between associative evidence and established causality. The systematic review by Ririe et al. (2025) classifies the certainty of evidence for inflammatory and endocrine biomarkers associated with MP exposure in humans as moderate, and low for specific chronic disease outcomes including diabetes mellitus and cardiovascular diseases. The widely cited study by Marfella et al. (2024) establishes a correlation between MPs in atherosclerotic plaques and greater severity of cardiovascular outcomes, but does not allow for inferring direct causality, given the observational nature of the design. The ACC analysis (Ponnana et al., 2025), while comprehensive in population terms, is ecological in nature — correlating environmental concentrations with disease prevalence without measuring individual exposure.

These methodological limitations do not diminish the health relevance of the findings: the precautionary principle, enshrined in International Environmental Law by the Rio Declaration on Environment and Development (UN, 1992), justifies proportionate preventive action even in the absence of definitive causality. The scale of human exposure — estimated at tens to hundreds of thousands of particles per person per year — and the detection of PMs in fetal tissues reinforce the urgency of regulatory and technological measures.

In the field of solutions, enzymatic biodegradation biotechnologies show remarkable progress, but still lack industrial scaling. FAST-PETase demonstrates impressive efficiency in the laboratory, but its *in situ* application faces challenges of thermostability under real environmental conditions, GMO regulation, and the cost of enzymatic production. Circular

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

economy approaches, including chemical recycling, bioplastics, and packaging return systems, represent the most promising frontier for systemic reduction of material generation.

CONCLUSION

This systematic review demonstrates that microplastics constitute emerging contaminants of global environmental and health sanitary relevance. In 75 years of industrial-scale production, plastic has transformed from a technological solution into a civilizational crisis: more than 8.3 billion metric tons produced (Geyer et al., 2017), 79% accumulated in landfills or the natural environment, with continuous fragmentation into particles that permeate all ecosystems and reach the human body.

The available scientific evidence — still predominantly associative for the most serious clinical outcomes — points to relationships between exposure to PMs and cardiovascular disease, endocrine disruption, neurotoxicity, reproductive disorders, and alterations in the gut microbiome. The level of certainty ranges from moderate to low for most clinical associations in humans, requiring longitudinal studies with individual exposure measurements.

In the field of solutions, microorganisms and biotechnological enzymes — especially PETase, FAST-PETase, and consortia of Pseudomonas and Bacillus — represent promising approaches for polymer biodegradation. Bioplastics (PHA, PLA) and circular economy strategies (chemical recycling, return systems, substitution with biomaterials) shape the transition horizon towards a production model less dependent on persistent fossil polymers.

The convergence of materials science, microbiology, epidemiology, toxicology, and public policy is essential for reversing the current trajectory in the coming decades. The failure to conclude the Global Plastics Treaty by 2024 underscores the political difficulty of the challenge, while also highlighting its urgency to environmental health besides global sustainable economy and development.

The authors declare no conflict of interest. This study received no funding.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

REFERENCES

AHMAD, OA et al. **Microplastic pollution in the marine environment: sources, impacts, and degradation**. Journal of Advanced Veterinary and Animal Research, vol. 12, no. 1, p. 893, 2025. DOI: 10.5455/javar.2025.l893.

AMERICAN CHEMISTRY COUNCIL. **Plastics: Material and Properties.** Washington: ACC, 2023. Available at: https://www.americanchemistry.com/industry-groups/plastics. Accessed on: June 5, 2025.

AMERICAN COLLEGE OF CARDIOLOGY (ACC). **New Evidence Links Microplastics with Chronic Disease**. Press Release, March 25 2025. Available at: https://www.acc.org/About-ACC/Press-Releases/2025/03/25. Accessed on: 5 June. 2025.

AMERICAN JOURNAL OF MANAGED CARE (AJMC). **Health Risks of Microplastics Highlighted at Recent Medical Conferences**. AJMC Online, May 2025. Available at: https://www.ajmc.com/view/health-risks-of-microplastics-highlighted-at-recent-medical-conferences. Accessed on: 5 June. 2025.

AZOM. **What Are the Different Types of Plastics?** AZoM, August 14, 2024. Available at: https://www.azom.com/article.aspx?ArticleID=23894. Accessed on: June 5, 2025.

BOMBELLI, P. et al. **Polyethylene bio-degradation by caterpillars of the wax moth Galleria *mellonella***. Current Biology, vol. 27, no. 8, p. R292–R293, 2017. DOI: 10.1016/j.cub.2017.02.060.

CHIA, RW et al. **Microplastic and human health with focus on pediatric well-being: a comprehensive review and call for future studies**. Clinical and Experimental Pediatrics, vol. 68, no. 1, p. 1–15, 2025. DOI: 10.3345/cep.2023.01739.

DE SOUZA, M.P.; VARRICCHIO, M.T.; BRIOSO, P.S.T.; PYRRHO, A. DOS S.; DA SILVA, S.; KUSTER, R.M.; VARRICCHIO, M.C.B.N.; DE FREITAS, F.A. **Circular Economy: State of the Art, Conceptual Understanding and Application in Brazil – An Integrative Systematic Review (2000–2025).** Campina Grande (PB). *OWL Journal.* Volume 4, Número 9 (2026). Published online 2026. doi:10.5281/zenodo.22549358.

DEHAL, B. et al. **Long-term production and discharge of microplastics from landfills**. Environmental Science Letters, 2024. (cited in Frontiers Environmental Science, 2025).

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

DELAUNAY, N.; RANGEL, B. **A contaminação do solo via atividades industriais e agrícolas e seus danos à saúde humana.** Apresentação: N. Delaunay. Aula no Curso de Extensão: Geofarmacobotânica e Bioprodutos. Centro Cultural FMPFase. 2019.

DELAUNAY DE SOUZA, N.; MACÊDO REBELO, R. de; NIGRI, A. I.; GASPAR, S.A.; BRIOSO, P.S.T.; VARRICCHIO, M.C.B.N.; DA SILVA, S. ***Euphorbia tirucalli:*** **potential plastic digester and bioeconomy.** Brazilian Journal of Development. 2023. Available at: https://ojs.brazilianjournals.com.br/ojs/index.php/BRJD/ article/view/62666/45093

DELAUNAY DE SOUZA, N.; FREIRE SOUZA SILVA, F.; GASPAR, S.A.; GORINI, C.C.; VARRICCHIO, M.C.B.N.; PYRRHO, A. dos S.; BRIOSO, P.S.T.; DA SILVA, S. ***Euphorbia tirucalli*** **elicitor in** ***Vigna unguiculata*** **cultivation: Bioprocess, Bioproduct and Biotechnological Potential Plastic Digester.** Contemporânea: Journal of Ethics and Political Philosophy. v. 3, n. 10, p. 16713-16730. 2023a, out. Available at: https://ojs.revistacontemporanea.com/ojs/index.php/home/issue/view/20

DU, Y. et al. **Oxidative degradation of pre-oxidated polystyrene plastics by dye decolorizing peroxidases from Thermomonospora curvata and Nostocaceae**. Journal of Hazardous Materials, vol. 436, p. 129265, 2022. DOI: 10.1016/j.jhazmat.2022.129265.

EL-DASH, HA et al. **Optimizing eco-friendly degradation of polyvinyl chloride (PVC) plastic using environmental strains of Malassezia species and *Aspergillus fumigatus*.** Journal of Hazardous Materials Advances, vol. 6, p. 100076, 2023. DOI: 10.1016/j.hazadv.2022.100076.

EUROPEAN BIOPLASTICS. **Bioplastics market data 2022**. Berlin: European Bioplastics, 2022. Available at: https://www.european-bioplastics.org/market/. Accessed on: June 5, 2025.

EUROPEAN UNION. **Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on reducing the environmental impact of certain plastic products.** Official Journal of the European Union, L 155, p. 1–19, 12 June 2019.

FRONTIERS IN ENVIRONMENTAL SCIENCE. **Landfills as a potential source and origin of microplastics: Formation, composition, and environmental risks**. Frontiers in Environmental Science, vol. 13, 1 Dec. 2025. DOI: 10.3389/fenvs.2025.1689154.

FRONTIERS IN PUBLIC HEALTH. **Microplastics and human health: unraveling the toxicological pathways and implications for public health**. Frontiers in Public Health, vol. 13, 30 May 2025. DOI: 10.3389/fpubh.2025.1567200.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

GEYER, R.; JAMBECK, JR; LAW, KL **Production, use, and fate of all plastics ever made.** Science Advances, vol. 3, no. 7, e1700782, 2017. DOI: 10.1126/sciadv.1700782.

HARTMANN, NB et al. **Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris**. Environmental Science & Technology, vol. 53, no. 3, p. 1039–1047, 2019. DOI: 10.1021/acs.est.8b05297.

HOWSTUFFWORKS. **Types of Plastics**. August 18, 2023. Available at: https://science.howstuffworks.com/plastic4.htm. Accessed on: June 5, 2025.

KANNAN, K.; VIMALKUMAR, K. **A review of human exposure to microplastics and insights into microplastics as obesogens**. Frontiers in Endocrinology, vol. 12, p. 724989, 2021. DOI: 10.3389/fendo.2021.724989.

LANCET PLANETARY HEALTH. **Microplastic and nanoplastic pollution and associated potential disease risks**. The Lancet Planetary Health, 17 Dec. 2025. DOI: 10.1016/S2542-5196(25)00268-2.

LIU, S. et al. **Neurotoxicities induced by micro/nanoplastics: A review focusing on the risks of neurological diseases.** Journal of Hazardous Materials**.** Vol. 469, 5 May 2024, 134054. Elsevier. DOI:https://doi.org/10.1016/j.jhazmat.2024.134054. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0304389424006332.

LIU, X. et al. **Microplastics, plastics, and their products exposures and cancer: a pooled analysis**. International Journal of Surgery, vol. 111, p. 5593–5605, 2025. DOI: 10.1097/JS9.0000000000002631.

LU, H. et al. **Machine learning-aided engineering of hydrolases for PET depolymerization**. Nature, vol. 604, p. 662–667, 2022. DOI: 10.1038/s41586-022-04599-z.

MANZOOR, S. et al. **Synergistic biodegradation of polyethylene by mixed cultures of *Rhodococcus ruber* and *Pseudomonas putida*.** Polymer Degradation and Stability, 2022. (cited in ScienceDirect Circular Economy Review, 2025).

MARFELLA, R. et al. **Microplastics and nanoplastics in atheromas and cardiovascular events**. New England Journal of Medicine, vol. 390, p. 900–910, 2024. DOI: 10.1056/NEJMoa2309822.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

MDPI — MICROORGANISMS. **Biodegradation of Petrochemical Plastics by Microorganisms: Toward Sustainable Solutions for Plastic Pollution**. Microorganisms (Biodivers), v. 4, no. 3, p. 44, 1 set. 2025. DOI: 10.3390/microorganisms4030044.

OUR WORLD IN DATA. **Plastic Pollution**. Hannah Ritchie; Veronika Samborska; Max Roser, 2023. Available at: https://ourworldindata.org/plastic-pollution. Accessed on: June 5, 2025.

PAGE, M. J.; MCKENZIE, J. E.; BOSSUYT, P. M.; BOUTRON, I.; HOFFMANN, T. C.; MULROW, C. D. et al. **The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.** BMJ, v. 372, n. 71, 2021.

PHYS.ORG. **Using microbes for sustainable plastic production and biodegradation**. December 11, 2023. Available at: https://phys.org/news/2023-12-microbes-sustainable-plastic-production-biodegradation.html. Accessed on: June 5, 2025.

PLASTIC COLLECTIVE. **Types of Plastic: Guide to Different Plastic Types**. April 17, 2024. Available at: https://www.plasticcollective.co/types-of-plastic-guide-to-different-plastic-types/. Accessed on: June 5, 2025.

PLASTIC SOUP FOUNDATION. **Plastic Facts & Figures**. Amsterdam, 2023. Available at: https://www.plasticsoupfoundation.org/en/plastic-facts-and-figures/. Accessed on: June 5, 2025.

PONNANA, SR et al. **Microplastic Concentration, Social, and Environmental Features and Their Association with Chronic Disease Prevalence: An Analysis Across US Census Tracts**. In: AMERICAN COLLEGE OF CARDIOLOGY ANNUAL SCIENTIFIC SESSION, 2025, Chicago. Abstract. Chicago: ACC, 2025.

PRATA, JC et al. **Environmental exposure to microplastics: an overview on possible human health effects.** Science of the Total Environment, vol. 702, p. 134455, 2020. DOI: 10.1016/j.scitotenv.2019.134455.

RRIIE, K. et al. **Impact of Microplastic Exposure on Human Health: A Systematic Review of Mechanisms, Biomarkers, and Clinical Outcomes**. Cureus, 2025. DOI: 10.7759/cureus.84551.

SARASAMMA, S. et al. **Nanoplastics cause neurobehavioral impairments, reproductive and oxidative damages, and biomarker responses in zebrafish: throwing up alarms of**

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

widespread health risk of exposure. International Journal of Molecular Sciences, vol. 21, no. 4, p. 1410, 2020. DOI: 10.3390/ijms21041410.

SCIENCEDIRECT. **Rethinking plastics through microbial biodegradation and circular economy innovation: a review**. Resources, Conservation & Recycling, v. 217, p. 108188, 2025. DOI: 10.1016/j.resconrec.2025.108188.

SCIENCEDIRECT. **Towards a circular economy: Harnessing bacteria for sustainable plastic waste degradation.** Biochemical Engineering Journal, 2025a. DOI: 10.1016/j.bej.2025.109437.

SHAHNAWAZ, M. et al. **Plastic degradation by microorganisms: a review**. Annals of Microbiology, 2019. (cited in Frontiers Environmental Science, 2024).

SOCIETY OF THE PLASTICS INDUSTRY (SPI). **Resin identification code — guide**. Washington: SPI, 2023. Available at: https://www.plasticsindustry.org/. Accessed on: June 5, 2025.

SPRINGER NATURE REVIEWS. **Microplastic Pollution: Sources, Degradation Mechanisms, Analytical Advances, and Mitigation Strategies for Environmental Sustainability. Reviews of Environmental** Contamination and Toxicology, 2025. DOI: 10.1007/s44169-025-00098-0.

STATISTA. **Global plastics industry — statistics & facts**. Hamburg: Statista, 2025. Available at: https://www.statista.com/topics/5266/plastics-industry/. Accessed on: June 5, 2025.

THOMPSON, RC et al. **Lost at sea: where is all the plastic?** Science, vol. 304, no. 5672, p. 838, 2004. DOI: 10.1126/science.1094559.

UNCTAD — UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT. **Global Trade Update (August 2025): Mobilising trade to curb plastic pollution**. Geneva: UNCTAD, 2025. Available at: https://unctad.org/publication/global-trade-update-august-2025. Accessed on: June 5, 2025.

UNEP — UNITED NATIONS ENVIRONMENT PROGRAMME. **Turning off the tap: how the world can end plastic pollution and create a circular economy**. Nairobi: UNEP, 2023. Available at: https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy. Accessed on: 5 June. 2025.

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)

UNITED NATIONS (UN). **Rio Declaration on Environment and Development.** Rio de Janeiro: United Nations Conference on Environment and Development, 1992.

WASTE4CHANGE. **7 Types of Plastic: The Different Materials and Grades**. February 6, 2024. Available at: https://waste4change.com/blog/7-types-plastic-need-know/. Accessed June 5, 2025.

WORLD METRICS. **Global Plastic Production Statistics: 2026 Edition**. February 12, 2026. Available at: https://worldmetrics.org/global-plastic-production-statistics/. Accessed on: June 5, 2025.

YIN, J. et al. **Phytoremediation of microplastics by water hyacinth.** Environmental Science and Ecotechnology.Vol. 24 March 2025. DOIhttps://doi.org/10.1016/j.ese.2025.100540. Available at https://www.sciencedirect.com/science/article/pii/S2666498425000183.

YOSHIDA, S. et al. **A bacterium that degrades and assimilates poly(ethylene terephthalate)**. Science, vol. 351, no. 6278, p. 1196–1199, 2016. DOI: 10.1126/science.aad6359.

YUAN, W. et al. The power of green: Harnessing phytoremediation to combat micro/nanoplastics. Eco-Environment & Health.Vol. 3, Issue 3, September 2024, Pages 260-265. DOIhttps://doi.org/10.1016/j.eehl.2024.04.001. Available at: https://www.sciencedirect.com/science/article/pii/S2772985024000292.

ZHENG, H. et al. **Microplastics and nanoplastics in cardiovascular disease: a narrative review with worrying links.** Frontiers in Toxicology, vol. 6, p. 1479292, 10 Oct. 2024. DOI: 10.3389/ftox.2024.1479292.

Recebido em: 28/09/2026
Aprovado em: 21/10/2026
Publicado em: 03/11/2026

A Revista OWL Journal está licenciada com uma Licença Creative Commons Atribuição (CC BY)