BACTERIA AS ECOLOGICAL TOOLS: PIONEERING MICROPLASTIC BIODEGRADATION

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ABSTRACT

Objective: Examine through scientific literature the use of the biological process of microplastic degradation by bacteria, as well as discuss the definition, characteristics, and environmental and health impacts caused by these respective particles.

Materials and Methods: Systematic review conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. Searches were performed in the electronic databases and libraries of PubMed, Web of Science, Scopus, and Lilacs, using keywords and Boolean operators: "Environment" AND "Microplastics" AND "Microorganisms" OR "Bacteria" AND "Biodegradation" AND "Xenobiotics.

Results and conclusion: The results have highlighted that microplastics are among the most challenging emerging contaminants regarding their degradation in the environment. Therefore, studies on the biodegradation of microplastics by bacteria have been considered a promising and ecological methodology for reducing the pollution of these particles in the environment.

Originality/ value: This investigation has underscored the significance of both abiotic and biotic degradation processes of microplastics, emphasizing the importance of bacteria in the degradation of these particles and thereby promoting environmental sustainability.

Keywords: Degradation, Plastics, Microorganisms, Environment, Sustainability.

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**BACTÉRIAS COMO FERRAMENTAS ECOLÓGICAS: DESBRAVANDO A BIODEGRADAÇÃO DE MICROPLÁSTICOS**

**RESUMO**

**Objetivo:** Analisar através da literatura científica a utilização do processo biológico de degradação de microplásticos por bactérias, assim como, discutir a definição, características e impactos ambientais e na saúde causado por estas respectivas partículas.

**Materiais e Métodos:** Revisão sistemática realizada de acordo com o protocolo Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). As buscas foram realizadas nas bases e bibliotecas de dados eletrônicos PubMed, Web of Science, Scopus e Lilacs, o qual utilizou-se como palavras-chave e operadores booleanos: “Enviroment” AND “Microplastics” AND “Microrganisms” OUR “Bacteria” AND “Biodegradation” AND “Xenobiotics”.

**Resultados e conclusão:** Os resultados evidenciaram que os microplásticos são um dos principais contaminantes emergentes mais desafiadores no que diz respeito a sua degradação no meio ambiente. Assim, estudos sobre a biodegradação de microplásticos por bactérias tem sido considerada uma metodologia promissora e ecológica para a redução da poluição dessas partículas no meio ambiente.

**Originalidade/valor:** Esta investigação evidenciou a relevância dos processos de degradação abiótica e biótica de microplásticos, enfatizando a importância das bactérias no processo de degradação dessas partículas, promovendo assim a sustentabilidade ambiental.

**Palavras-chave:** Degradação, Plásticos, Microrganismos, Meio Ambiente, Sustentabilidade.

**1 INTRODUCTION**

Anthropogenic activities are considered the main contributors to global plastic pollution, which affects the entire environmental ecosystem. It is estimated that approximately 2 million tons of urban waste are generated each year, and by 2050, this quantity is projected to reach at least 3 million tons (Othman et al., 2021).

This contamination can be driven by inorganic pollutants, such as metals and radioactive elements, as well as organic pollutants like plastics. Plastics are produced using non-renewable resources and have a variety of uses, of which their consumption has increased over the years (Bharagava; Saxena; Mulla, 2020; Wen; Fu; Li, 2021).

Due to poor management and improper disposal, plastics have remained in the environment for long periods of time, primarily due to their low degradability, resulting in the widespread presence of microplastics in water, soil, air, and animals (Silva, 2021).

Microplastics are resilient in the environment, and as a result, they are transported through the food chain. Therefore, studies have been conducted to find better treatments and remediation methods to reduce these particles in the environment. Thus, the biodegradation of microplastics by bacteria has been one of the main targets of research to increase the efficiency of microplastic degradation in the environment (Anand et al., 2023).

Therefore, the present investigation aims to analyze, through scientific literature, the use of the biological process of microplastic degradation by bacteria, as well as discuss the definition, characteristics, and environmental and health impacts caused by these respective particles.
2 MATERIALS AND METHODS

2.1 Protocol

This systematic review was conducted according to the protocol PRISMA.

2.2 Selection Criteria

For this analysis, the PECO strategy was used: Population - Bacteria, Exposure - Microplastics, Comparison - not applicable, and Outcomes - Ecological potential for microplastic biodegradation by bacteria.

Thus, scientific studies that included the role of bacteria in the process of microplastic biodegradation were considered eligible, without restricting the year/language of the studies. In this context, the exclusion of editorial studies, comments, incomplete or insufficient information, duplicates, and titles that did not justify the theme presented in this investigation was applied.

2.3 Sources of Information and Research

To compose the search strategy, searches were carried out in the electronic databases and libraries of PubMed, Web of Science, Scopus and Lilacs, after which the respective descriptors and synonyms were duly defined using Medical Subject Headings (MeSH) and Decks (Descriptors in Health Sciences), as well as keywords and Boolean operators for controlled search, resulting in the terms: “Enviroment” AND “Microplastics” AND “Microorganisms” AND “Bacteria” AND “Biodegradation” AND “Xenobiotics”.

2.4 Study Selection

The inclusion and exclusion of studies involved the participation of two independent reviewers in a blind manner, resulting in three distinct stages. In the 1st stage, a title analysis was conducted, excluding studies that were duplicates. The 2nd, the eligibility criteria were discussed separately by each reviewer according to the PECO strategy mentioned above, which excluded studies that were not related to the proposed strategy. The 3rd and final stage involved the exclusion of studies that could not provide sufficient information for the conduct of this investigation, after a thorough review of abstracts and full texts. Subsequently, information extraction was performed from the eligible studies for this qualitative investigation.

2.5 Risk of Bias

The risk of publication bias in the studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Qualitative Research (Lockwood et al., 2017). This checklist corresponds to three respective classifications: High, Moderate, and Low. In this context, the High-risk classification is obtained with more than 49% scoring 'Yes', Moderate results in a score of 50%–69% 'Yes', while Low consists of a score of 'Yes' ≥ 70%. Thus, after this bias assessment of the studies, those with a high risk of bias were appropriately excluded from this investigation.
3 RESULTS AND DISCUSSION

In this systematic investigation, a total of 845 studies were found in the aforementioned electronic databases and libraries. Subsequently, 32 studies were excluded due to duplication, 571 based on titles, 135 based on abstracts, and 70 for not meeting the eligibility criteria, resulting in a total of 37 studies eligible for systematic review. Figure 1 presents the flowchart showing the main data on the exclusion and inclusion of studies.

The risk of publication bias assessed through the JBI checklist revealed that the majority of responses to the critical questionnaire of the 37 eligible studies resulted in >90% 'Yes' responses, indicating that the studies included in this investigation demonstrated low risk of bias and high methodological quality.

Figure 1: Flowchart with quantitative and qualitative data of excluded and included articles.
Source: Authors, 2024

3.1 Microplastics

Worldwide, approximately 350-400 million metric tons of synthetic polymers are produced every year, some of which have industrial and domestic economic relevance, such as polyurethane (PUR), polyethylene (PE), polyamide (PA), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), and polypropylene (PP) (Danso; Chow; Streit,
2019). Figure 2 presents the major synthetic polymers produced globally in annual production (million tons) corresponding to each aforementioned synthetic polymer.

**Millions of tons**

![Bar chart showing annual production quantities of different synthetic polymers](image)

**Figure 2:** Approximate annual production quantity (million tons) of the main synthetic polymers produced worldwide.  
**Source:** Modified, Danso; Chow; Streit, 2019.

The terminology 'microplastic' was first reported in a study titled 'Plastic and other artifacts on South African beaches: temporal trends in abundance and composition' in 1990 by an African scientist. Following this milestone, the term 'microplastic' gained global recognition and has since been extensively studied and described by scientists worldwide in their research (Alimi et al., 2021).

Microplastics are referred to as small plastic particles, which are generally agreed in the literature to have sizes up to 5 mm. Categorizing their size is considered somewhat challenging due to their morphological variety. Consequently, these particles have been increasingly spreading in terrestrial and aquatic environments each year (Amelia et al., 2021, Khalid et al., 2021, Talbot; Chang, 2022).

The categorization of microplastics in the environment is divided into two groups: primary microplastics and secondary microplastics, which are distinguished based on their respective point of origin. Primary microplastics are any plastic particles ≤ 5 mm that enter the environment for the first time and originate from industrial activities. On the other hand, secondary microplastics result from chemical, physical, and biological activities, meaning they are the outcome of the fragmentation and degradation of plastic products in the environment (Botterell et al., 2020, Suardy; Tahrîm; Ramli, 2020, Dong et al., 2021, Shi et al., 2022).

Microplastic pollution is primarily caused by anthropogenic activities, as they are frequently used by humans, ranging from industrial sectors to domestic usage. One of the major industrial sectors contributing to the dispersion of these particles is the production of raw plastic and textile services (Tang et al., 2021).

### 3.1.1 Environmental and Health Impacts

Microplastics are considered emerging contaminants, as these particles have the capacity for bioaccumulation, with their risk increasing as their size decreases. Therefore, they...
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are a significant indicator of generalized risk to both the environment and health (Anbumani; Kakkar, 2018). Consequently, microplastics can generate both direct and indirect impacts, which have raised growing concerns due to their low biodegradability and the difficulty of recycling (Zhang et al., 2022).

In this context, microplastics can be found in both terrestrial and aquatic ecosystems, causing impacts on both fauna and flora. It has also been shown that these particles can affect nutrient absorption and accumulate in the roots, shoots, and leaves of plants, as well as negatively alter the physical and chemical properties of the soil, consequently harming soil organisms, such as soil microbiota (Othman et al., 2021).

In aquatic ecosystems, microplastics can be ingested both directly and indirectly by aquatic animals, such as fish, aquatic birds, and aquatic mammals. Thus, the cumulative effect of these particles in the digestive system of these aquatic organisms can cause alterations in their normal physiological functions, such as a decrease in immune system capacity, necrosis of hepatic cells, reduction in reproduction, and survival (Zhao et al., 2023).

Furthermore, this ability to bioaccumulate microplastics can also occur in humans, considering that they can be ingested, which enter the food chain and can accumulate in organs and tissues. Although their direct implications are not yet fully understood, it is known that these particles can impact human health by triggering inflammatory and immune responses, due to their hydrophobic properties (Vethaak; Leslie, 2016, Leslie et al., 2022, Sahu et al., 2023). Figure 3 includes examples of impacts caused by microplastics in living organisms.

In aquatic organisms, microplastics can cause intestinal obstruction, changes in nutrient absorption, endocrine disruption, immunological and neurological effects and loss of reproductive functions.

Microplastics can damage the cell walls of plants and microalgae, cause metabolic dysfunctions and impair photosynthesis due to shading effects.

The main routes of human exposure to microplastics are identified as ingestion, inhalation and dermal contact, triggering inflammatory and immunological reactions.

Figure 3: Examples of living organisms impacted by microplastics.
Source: Modified, Anand et al., 2023.

In this context, due to the gradual deterioration of microplastics that can take thousands of years, it is of paramount importance to treat and remove these particles from the environment, especially due to their toxic nature. Therefore, their degradation can be achieved through both biological and non-biological means (Othman et al., 2021, Sahu et al., 2023).
3.2 Microplastic Degradation

Plastics in general can undergo various degradation processes of both biotic and abiotic origin, such as ultraviolet radiation, physical wear, chemical oxidation, and even biodegradation, which result in the loss of their physical integrity. Consequently, this process can create surface cracks, leading to the fragmentation of these materials into smaller particles, referred to as microplastics (Luo et al., 2023).

Among the abiotic processes, there are physical and chemical methodologies for microplastic disposal, such as thermal degradation, photodegradation, and mechanical degradation. Degradation through biotic processes is primarily associated with enzymes, in which microorganisms have played a crucial role in the degradation of microplastics, leading to their mineralization (Anand et al., 2023, Luo et al., 2023). Figure 4 depicts the main processes of microplastic degradation.

![Figure 4: Primary processes of microplastic degradation through combined abiotic and biotic factors. Source: Anand et al., 2023.](image)

The thermal degradation process is a chemical abiotic pathway focused on oxidation and is dependent on the wear of free radicals. Therefore, high temperatures lead to the dissociation of bonds and result in bond breakage. Similarly, photodegradation is also a chemical abiotic degradation pathway with characteristics parallel to thermal degradation. Through the absorption of ultraviolet energy, free radicals are formed, characterized by the breaking of chemical bonds, ultimately resulting in inert products (Liu et al., 2020, Bacha; Nabi; Zhang, 2021, Luo et al., 2023).

Mechanical degradation is considered a chemical abiotic pathway and can be caused by various factors such as sand, rocks, waves, tides, and even other particles. Thus, this type of degradation can be generated by human activities, when in terrestrial environments, in aquatic environments it can occur through freezing and thawing cycles, which consequently the sand and waves together can accelerate this physical process of degradation of microplastics and further reduce their size to nanoplastics (Enfrim et al., 2020, Duan et al., 2021, Alimi et al., 2022).
Biodegradation, also known as biotic degradation, involves the degradation of microplastics by organisms in the environment through the ingestion and digestion of these particles. Microorganisms such as bacteria, fungi, and algae are the primary organisms involved in the biodegradation of microplastics, thereby modifying the properties and structures of the functional groups of microplastics (Porter; Smith; Lewis, 2019, Cau et al., 2020).

### 3.3 Bacteria and Microplastics

Microplastics are not just inert surfaces; they can adsorb nutrients and organic matter from their surroundings, facilitating the formation of microbial biofilms due to the provided substrate. Therefore, biofilms formed on microplastics are considered a microbial niche in the environment (Yang et al., 2020).

Studies have addressed the physical interactions of microorganisms colonizing microplastic surfaces, which have shown potential effects such as the formation of biofilms on microplastics, which can promote horizontal gene transfer between bacteria, as well as carbon cycling by bacteria (Rummel et al., 2017, Arias; Jimenez; Grossart, 2019, Kettner et al., 2019).

The colonization of microplastic surfaces is referred to as the 'plastisphere,' which can harbor a wide microbial diversity. This diversity aids in adhering to the surfaces of microplastics through polysaccharide structures, as well as providing nutrition and support for other microorganisms (Du et al., 2022). Figure 5 illustrates the process of biofilm formation on microplastics, leading to the plastisphere.

![Figure 5: Process of biofilm formation and plastisphere.](source)

**Figure 5:** Process of biofilm formation and plastisphere.

MP: Microplastic.

*Source:* Zhai; Zhang; Yu, 2023.

Thus, the selection of bacterial communities in the colonization of microplastics to form the plastisphere depends mainly on the physical properties of plastics, such as particle morphology, crystallinity, hydrophobicity, roughness, and surface charge. As bacteria occupy their surface, the first layer of the initial biofilm is formed, which consequently reduces the hydrophobicity of the microplastic surface over time due to bacterial colonization (Tu et al., 2020).

In addition to providing physical support, nutrients, and habitat, microplastics also help bacteria resist adverse environmental conditions. Consequently, following the formation of the plastisphere, processes that catalyze metabolic reactions occur, including the degradation of compounds associated with microplastics. This biofilm formation can assist as an oxidative pathway for the biodegradation of microplastics through processes of biodeterioration, biofragmentation, bioassimilation, and biomineralization, resulting in an ecological effect on the destination of these particles (Zhai; Zhang; Yu, 2023).
3.3.1 Bacterial biodegradation of microplastics as a strategy for environmental sustainability

The microorganisms considered the most abundant and important organisms in the environment are bacteria, as they exist in water, soil, and even in the atmosphere. Consequently, several species have been discovered and recognized for their ability to degrade pollutants. Therefore, studies have been intensified to investigate the usefulness of bacteria in the degradation of microplastics (Yuan et al., 2020).

In this context, plastic biodegradation is a process by which microorganisms can digest and break down plastic fragments into sources of carbon, altering their functional structure, molecular weight, and other characteristics, with microplastics being the primary candidates for this process (Ren; Ni, 2023).

Due to the presence of extracellular enzymes such as esterases, lipases, lignin peroxidases, laccases, hydrolases, cutinases, and manganese peroxidases, along with abiotic factors, microplastics are biodeteriorated and biofragmented into oligomers and monomers. Subsequently, these particles are properly internalized by bacteria, which use them as a source of carbon, ultimately resulting in the mineralization process of microplastics (Anand et al., 2023). The main products obtained after the mineralization of microplastics are CO$_2$ and H$_2$O, as illustrated in Figure 6 below.

![Figure 6: Example of microplastic mineralization process by bacteria. Source: Anand et al., 2023.](image)

Thus, in its complete mineralization of the microplastic, the CO$_2$ particle is released together with other intermediate compounds, which can be used by bacteria as a source of energy, entering different metabolic pathways. Consequently, the role of extracellular enzymes in bacteria is significant as they assist in making microplastics more hydrophilic and even contribute to the formation of fissures, leading to their degradation and the subsequent entry of these microplastic monomers into the cytoplasm of bacteria (Taniguchi et al., 2019).
With that in mind, several factors are considered for the optimal degradation of microplastics. These include the availability of microorganisms that possess efficient enzymes and metabolic pathways, as well as the necessity for other environmental factors to be included, such as temperature, pH, salinity, and moisture content (Lin et al., 2022, Miri et al., 2022).

Hence, the main bacterial genera involved in microplastic degradation are still relatively basic, considering that each day new genera and species are discovered as microplastic biodegraders. The main bacterial isolates associated with water, soil, and landfill environments for microplastic degradation include: *Achromobacter, Acinetobacter, Arthrobacter, Bacillus, Comamonas, Delftia, Micrococcus, Nesiotobacter, Paenibacillus, Pseudomonas, Rahnella, Staphylococcus*, and *Stenotrophomonas* (Zhai; Zhang; Yu, 2023).

Thus, bacterial degradation has been considered a promising and environmentally friendly methodology, as it removes microplastics from the environment without causing harm. Therefore, the identification of genera and species and the screening of bacteria with the ability to degrade different types of microplastics can contribute to the process of bioremediation and the cleaning of ecosystems, as these bacteria can adapt to various environments and transform various compounds, including plastic compounds (Ren; Ni, 2023).

4 CONCLUSION

It is concluded that microplastics are important emerging contaminants that have caused environmental impacts throughout ecosystems. Due to long-term concerns about these particles in the environment, studies have been motivated to contribute to the understanding and promotion of microplastic reduction through biodegradation, including that carried out by bactería. The degradation of microplastics by bacteria involves various factors, including both abiotic and biotic ones. Extracellular enzymes play an important role in biodeterioration and biofragmentation, enabling microplastics to be internalized by bacteria and properly biodegraded, resulting in the production of CO$_2$ and H$_2$O particles at the end of the process. This process is considered ecologically beneficial for the environment. Ultimately, it is necessary to further develop studies for microplastic treatment through biodegradation to significantly reduce microplastic pollution in the environment.

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REFERENCES


Amelia, T. S. M., Khalik, W. M. A. W. M., Ong, M. C., Shao, Y. T., Pan, H. J., & Bhubalan, K. (2021). Marine microplastics as vectors of major ocean pollutants and its hazards to the...
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Cau, A., Avio, C. G., Dessì, C., Moccia, D., Pusceddu, A., Regoli, F., ... & Follesa, M. C. (2020). Benthic crustacean digestion can modulate the environmental fate of microplastics in the deep sea. *Environmental Science & Technology*, 54(8), 4886-4892. doi: [https://doi.org/10.1021/acs.est.9b07705](https://doi.org/10.1021/acs.est.9b07705)


Duan, J., Bolan, N., Li, Y., Ding, S., Atugoda, T., Vithanage, M., ... & Kirkham, M. B. (2021). Weathering of microplastics and interaction with other coexisting constituents in terrestrial and
Bacteria as Ecological Tools: Pioneering Microplastic Biodegradation


Vethaak, A. D., & Leslie, H. A. (2016). Plastic debris is a human health issue. doi: [https://doi.org/10.1021/acs.est.6b02569](https://doi.org/10.1021/acs.est.6b02569)


