DOI: 10.5281/zenodo.23728086

CHAPTER 4

The Impact of Animals and Microbial Enzymes on Environmental Sustainability

Pathi Chandra Shekar

Department of Zoology, Government Degree College, Luxettipet, Mancherial District 504215 Telangana State, India

Corresponding author Email: chandrashekarpathi1978@gmail.com

Received: 20 October 2026; Accepted: 26 October 2026; Available online: 28 October 2026

Abstract: Industrial activities, anthropogenic activities, agricultural waste, municipal waste and other mining activities generate toxic substances that disturbs or imbalance the ecosystem and causes health hazardous the human beings. These toxic pollutants posses a major risk to the ecosystem and its linked to some acute and chronic effects on ecosystem as well as human beings. The activities of animal enzymes and microbial enzymes to act in a bioremediative ability is not widely known. These enzymes are rarely preferred for bioremedial activities owing to the ethical concern. Apart from this some specific examples in the science literature enclose that some animal species are effective in removal of heavy metals, hydrocarbons specifically in aquatic environments.

This work is licensed under a Creative Commons Attribution 4.0 International License. This allows re-distribution and re-use of a licensed work on the condition that the author is appropriately credited and the original work is properly cited.

Interdisciplinary Research in Life Sciences: A Path Towards Sustainability (Vol. 4) - Jayvardhan V. Balkhande & Jalander Vaghmare (Eds.)

ISBN: 978-93-49630-02-4 (paperback) 978-93-49630-05-5 (electronic) | © 2026 Advent Publishing.

https://doi.org/10.5281/zenodo.23728086

However untreated veterinary medicines are discharged in to the water which effects majorly on ichthyological ecosystem. The main theme of this review is to reveal detail process by which animal and microbial systems degrades the toxic compounds releases from various pathways (Industries, anthropogenic activities etc..) strategy is to keep central on the mutual acts of Animal and Microbial communities relating with them to degrade and transform the toxic contaminants present in soils, surface water and ground water. Even though previous innovations like chemical physical methods has been developed, but Zoo remediation is the unique or Ideal. Microbes and there enzymes are key roles in reducing and removing hazardous contaminants trough Zoo remediation by their catalytic activities. This review also aims to detail the recent advancements on Zooremediation's.

Keywords: Animal enzymes; microbial enzymes; zooremediation; bioremediation; industrial pollutants; agricultural waste; wastewater treatment; environmental sustainability

Introduction

By promoting bioremediation, lowering industrial carbon footprints, and maximizing agricultural waste, animal and microbial enzymes support environmental sustainability. They use biodegradable, energy-efficient biological catalysts in place of hazardous chemicals.

Plastic Breakdown: Stubborn polymers are broken down into reusable building pieces by specialized microbial enzymes like PETases.

Toxic Waste Removal: Petroleum hydrocarbons, synthetic insecticides, and industrial colors can all be safely broken down by bacterial and fungal enzymes such laccases and peroxidase.

Antibiotic detoxification: By identifying and neutralizing pharmaceutical residues in agricultural runoff, hydro lases reduce soil antimicrobial resistance.

In the face of accelerating global industrialization, climate change, and environmental degradation, [1]the transition toward a sustainable, circular economy has become an urgent global imperative. Traditional chemical and industrial processes have historically relied heavily on fossil fuels, harsh chemical catalysts, high energy consumption, and synthetic agents that generate substantial toxic effluents and greenhouse gas emissions. To mitigate these ecological impacts, environmental biotechnology has increasingly turned to green chemistry solutions. Among the most promising tools in this paradigm shift are enzymes—naturally occurring biological catalysts capable of accelerating chemical reactions with high specificity and efficiency under ambient conditions. While initial research focused broadly on biological processes, contemporary

sustainability science highlights the unique, distinct contributions of animal-derived and microbial enzymes as critical agents for environmental remediation and green manufacturing.

Microbial enzymes, harvested from diverse taxonomies of bacteria, fungi, actinomycetes, and archaea, represent the cornerstone of modern bioremediation and bio energy strategies. Due to their rapid reproduction rates, genetic malleability, and metabolic diversity, microorganisms produce a vast array of specialized enzymes—such as oxidoreductases (e.g., laccases, peroxidases) and hydrolases (e.g., cellulases, lipases). These biocatalysts possess the extraordinary capability to degrade persistent organic pollutants, break down complex agricultural biomass into renewable biofuels, and depolymerize recalcitrant synthetic plastics. Concurrently, animal-derived enzymes and coordinated eco-enzyme fermentation systems offer critical support in optimizing organic waste transformation, enhancing agricultural nutrient cycles, and developing eco-friendly industrial co-products. By substituting traditional chemical catalysts with these targeted animal and microbial enzyme systems, industries can significantly reduce their carbon footprint, lower operational energy requirements, and minimize secondary pollution.

[2]Despite their immense potential, the widespread industrial and environmental deployment of these enzymes faces notable technical hurdles. Natural enzymes are frequently sensitive to the harsh, fluctuating conditions of real-world polluted sites and industrial reactors, including extreme pH, high thermal gradients, and heavy metal toxicity. Furthermore, the economic viability of large-scale production, downstream purification, and catalyst recovery presents ongoing challenges. To overcome these limitations, current research focuses heavily on innovative engineering techniques, such as enzyme immobilization on advanced nanomaterial supports and recombinant DNA technology to synthesize highly stable, robust mutant enzymes.

The Role of Animals and Microbial Enzymes in Sustainability

Enzymes as Green Biocatalysts

Enzymes derived from animal and microbial sources represent a cornerstone of green chemistry and circular bioeconomy strategies. Unlike traditional industrial catalysts, which often require extreme temperatures, high pressure, and toxic heavy metals, enzymes operate efficiently under mild physiological conditions (low temperatures, neutral pH, and atmospheric pressure). Their high substrate specificity minimizes the formation of unwanted byproducts, significantly reducing the environmental footprint of industrial manufacturing and waste management.

***Key Types and Mechanisms of Action**

- Microbial Enzymes (The Bioremediation Engines): Microorganisms (bacteria, fungi, and archaea) are the primary source of industrial enzymes due to their rapid growth, ease of genetic manipulation, and ability to survive in extreme environments.
- Oxidoreductases (Laccases, Peroxidases): These enzymes catalyze electron transfer, allowing them to break down stable, toxic aromatic structures found in synthetic dyes, plastics, pharmaceuticals, and agricultural pesticides. [1,2]
- Hydrolases (Lipases, Cellulases, Proteases): [3]These enzymes use water molecules to cleave chemical bonds. They are critical for liquefying oil spills, breaking down plant biomass into fermentable sugars, and degrading complex organic pollutants.
- Agricultural and Waste Stabilization: Animal-derived digestive enzymes (like trypsin or pepsin) and complex fermented "eco-enzymes" (produced from organic fruit/vegetable waste and microbes) are utilized to accelerate the composting of organic municipal waste, suppress pathogens, and neutralize volatile organic compounds (VOCs) that cause foul odors.

Major Sustainability Applications

- Advanced Bioremediation: Enzymes are deployed directly into contaminated ecosystems to degrade persistent organic pollutants (POPs), microplastics (such as PET using engineered PETases), and heavy industrial effluents, converting them into harmless metabolites like water, carbon dioxide, and simple salts.
- Cleaner Industrial Manufacturing: In the textile, paper, and leather industries, enzymes replace hazardous substances. For instance, cellulases replace pumice stones for denim washing, and microbial amylases replace harsh acids for fabric desizing, which slashes wastewater toxicity by up to 80%.
- Biofuels and the Circular Bioeconomy: Microbial cellulases and hemicellulases break down non-food agricultural waste (like corn stover or straw) into simple sugars. These sugars are then fermented into bioethanol. Similarly, lipases catalyze the conversion of waste cooking oils into biodiesel, providing a renewable alternative to fossil fuels. [4]

Mechanisms of Enzymatic Microplastic Degradation

The accumulation of synthetic polymers in global ecosystems has triggered an urgent need for biological recycling alternatives. Enzymes break down these tough, crystalline plastics through a targeted multi-step biochemical process.

The discovery of the bacterium Ideonella sakaiensis revealed a specialized two-enzyme system capable of breaking down Polyethylene Terephthalate (PET), the plastic widely used in single-use bottles and synthetic textiles.

1. Surface Absorption: [4]The engineered enzyme PETase (IsPETase) binds to the hydrophobic surface of the PET solid polymer via a specialized substrate-binding cleft.
2. Primary Hydrolysis: IsPETase cleaves the internal ester bonds of the long PET chain. This breakdown turns the solid plastic into smaller, water-soluble molecules, primarily MHET (mono-2-hydroxyethyl terephthalate), alongside trace amounts of BHET, ethylene glycol, and terephthalic acid.
3. Secondary Hydrolysis: A second outer-membrane enzyme, MHETase, quickly grabs the remaining MHET molecules and hydrolyzes them into two benign, foundational monomer units: Terephthalic Acid (TPA) and Ethylene Glycol (EG).
4. Intracellular Assimilation: The host microbes safely absorb the released TPA and EG, using them as carbon and energy sources to fuel normal cellular respiration, leaving behind nothing but carbon dioxide and water.

Degrading Other Synthetic Polymers

- Polyethylene (PE) and Polypropylene (PP): Because these plastics lack easily cleavable ester linkages, they require initial physical oxidation (like UV exposure). Following this step, microbial alkane hydroxylases and laccases target the newly oxidized carbon-carbon backbone to gradually break the material down.
- Polyurethanes (PU): Esterases and proteases target the urethane links, breaking the plastic back down into its original polyols and isocyanates.

Advanced Waste water Treatment via Microbial Enzymes

Municipal and industrial wastewater treatment plants are under immense pressure to remove emerging contaminants that slip past conventional filters. Enzymes act as precise molecular scalpels, neutralizing dissolved toxics right in the water.

Current Challenges and Future Engineering Directions

Despite their immense potential, natural enzymes often lack stability when exposed to harsh industrial environments, such as highly acidic wastewater or elevated processing temperatures. Additionally, isolating and purifying these enzymes at a commercial scale can be costly.

To overcome these barriers, modern sustainability research focuses on two main breakthroughs

1. Enzyme Immobilization: Attaching enzymes to solid, inert matrices or nanomaterials. This shields their structure, increases their thermal stability, and allows them to be recovered and reused across multiple operational cycles, drastically lowering costs.
2. Genetic and Protein Engineering: Using tools like CRISPR and directed evolution to modify the genetic codes of microbes. This allows scientists to design "super-enzyme" with enhanced structural resilience, higher catalytic speeds, and the specific ability to target man-made pollutants that do not naturally degrade in the environment.

Future Perspectives

As research moves forward, the widespread industrial use of animal and microbial enzymes will rely on combining biotechnology with digital design and advanced materials.

- [5]AI-Driven Enzyme Design: Using artificial intelligence platform engines (like AlphaFold and structural machine learning models) allows researchers to bypass slow laboratory trials. Scientists can now design synthetic enzymes completely from scratch, accurately predicting how stable they will be and how they will interact with new, man-made pollutants before ever testing them in a physical lab.
- Multi-Enzyme Cascades: Instead of relying on single enzymes, future treatment plants will use automated, multi-step enzyme systems. Mimicking natural metabolic pathways, these systems will process complex waste mixtures simultaneously, turning hazardous industrial effluents into valuable chemical building blocks in a single, continuous loop.
- Smart Bio-Composite Systems: [5]Researchers are embedding immobilized enzymes directly into the manufacturing materials of commercial filters and pipes. These self-cleaning, bio-active materials will automatically break down trapped microplastics and organic pollutants, preventing biofilms from forming and eliminating the need for harsh chemical cleaning cycles.

Conclusion

The integration of animal and microbial enzymes into environmental engineering marks a fundamental shift toward sustainable industrial chemistry and environmental remediation. As highly specific, eco-friendly biocatalysts, these enzymes offer a viable path to move away from energy-intensive, chemically toxic manufacturing processes. Their ability to target and break down stubborn, man-made pollutants—demonstrated by the engineered enzymatic degradation of microplastics and the targeted removal of emerging contaminants in wastewater—highlights their potential to clean up global ecosystems.

However, moving these biological tools from laboratory benches to large-scale industrial operations requires overcoming challenges related to structural stability, high production costs, and environmental sensitivity. Future breakthroughs in this field depend on the continued advancement of protein engineering (such as directed evolution) and nanomaterial immobilization techniques. By enhancing the resilience and reusability of these enzymes, modern science can establish a truly circular bioeconomy. This approach turns industrial waste streams into renewable resources and secures long-term ecological balance.

References

1. Singh, A., Singh, R., and Bilal, M., Environmental Science and Pollution Research, 2023, 30, 31045.
2. Saratale, R. G., Saratale, G. D., Chang, J. S., and Govindwar, S. P., Journal of the Taiwan Institute of Chemical Engineers, 2011, 42, 138.
3. Lu, H., Diaz, D. J., Marasi, H., Webb, A. J., and Ellington, A. D., Nature, 2022, 604, 662.
4. Srivastava, N., Rawat, R., Oberoi, H. S., and Ramteke, P. W., Renewable and Sustainable Energy Reviews, 2018, 92, 508.
5. Zdarta, J., Meyer, A. S., Jesionowski, T., and Pinelo, M., Critical Reviews in Biotechnology, 2018, 38, 1251.