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RESETIARCH ARTICLE

The Role of Microbial Communities in Bioremediation of Plastic Waste

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ABSTRACT

The fast accumulation of plastic waste happens because insufficient recycling and proper disposal techniques allow only small quantities of plastic to be recycled thus releasing the vast majority into landfills and the environment. The research investigates how microbial collective organisms perform biological recovery of plastic waste. Plastic polymers undergo different enzymatic transformations through bacterial and fungal organisms before these microbes can break down the products to generate cellular metabolic energy. This study examines plastic-biodegrading microbial populations through enzyme research and environmental factor analysis and genetic modification studies focused on plastic degradation enhancement. This paper shows bioremediation operations need appropriate planning by explaining microbial technologies should be implemented during waste management activities. The research shows that plastic pollution management reaches success when applying microbial methods that combine bioplastics with modern biotechnological approaches to support environmental sustainability.

Keywords: *Plastic waste, microbial bioremediation, biodegradation, plastic-degrading microorganisms, enzymatic degradation, environmental impact, biotechnological approaches, genetic engineering.*

INTRODUCTION

Since 2012 the worldwide plastic waste crisis has developed because plastic manufacturing rapidly expanded by 5% every year (et al, 2012; Kumar et al., 2020). Worldwide plastic markets received 367 million tons of plastic products during year 2020 outside polyester polyamide and polyacrylic fiber sectors (Viel et al., 2023). Regarded as among the greatest threats to the environment are the 76% of overall plastic waste output since most plastic products become waste instead of being recycled or incinerated (et al, 2012). Clogging of agricultural land and endangerment of wildlife through plastic entrapment occur due to plastic waste accumulation that damages environmental quality. This resistance to degradation persists through polyethylene as one of the main waste components in municipal solid waste systems due to weight and carbon backbone structures and hydrophobic properties and non-recognition by microorganisms (John & Salim, 2020). Plastic bioremediation research advances quickly because plastic pollutants endure indefinitely in different environmental systems (Oliveira et al., 2020).

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The enzymatic activities of terrestrial bacterial communities utilize strong catalytic enzymes to break down plastic polymers significantly (A. et al., 2019). Weaker microorganisms degrade plastic structures into fundamental elements that enable them to extract carbon-based energy sources (Ali et al., 2021; Malik et al., 2023). Bacteria and fungi together demonstrate promising potential as an alternative way to manage plastic pollution according to Muhonja et al. (2018). Plastic polymer chains undergo decomposition through enzymatic reactions that microorganisms execute for metabolic breakdown. After bacteria attach to the surface the plastic-degrading extracellular enzymes from bacteria cause fragmentation through generation of oligomers and monomers (Muhonja et al., 2018). After microbial cells receive smaller compounds they operate biochemical pathways that produce both carbon dioxide water and microbial biomass. The regular environmental degradation of low-density polyethylene takes more than ten centuries to finish due to its destructive effect on both land-based and marine ecosystems (Nademo et al., 2023). Microorganisms can successfully perform bioremediation operations because they have proper metabolic capabilities for decomposing polymers to establish practical biodegradation systems (Philip et al., 2020).

Microbial Degradation Mechanisms of Plastics

Plastic waste remediation through microbially influenced processes presents an approach which environmental scientists view positively. Plastic-recycling technology improves through genetic modification of microorganisms and enzymes which enables plastic utilization as carbon source along with alkanes production from plastic waste through microbial biological methods (Nisha et al., 2020). Plastic polymers that are difficult to breakdown follow a process of microbial degradation through the combined activities of actinomycetes fungi and bacteria and through isolated enzymes that process plastic chain structures. Microorganisms along with enzymes possess the unique ability to breakdown polyethylene plus additional synthetic plastics such as polystyrene, polypropylene, polyvinyl chloride and polyurethane and polyethylene terephthalate (Ru et al., 2020). The plastic degradation capabilities belong to bacterial genera *Bacillus* along with *Pseudomonas* and *Streptomyces* and *Micrococcus* and among fungal genera are *Aspergillus* followed by *Penicillium* and *Fusarium* which show superior activity in plastic degradation in terrestrial environments (Maroof et al., 2020). The plastic degradation mechanisms of microorganisms experience influence from both plastic material characteristics and additives present in addition to environmental conditions and microbial community attributes (shmi et al., 2020).

Table 1: Microbial Communities Involved in Plastic Biodegradation

Microbial Organism	Plastic Type	Key Enzyme(s) Involved	Biodegradation Efficiency	Reference
Bacillus spp.	Polyethylene	Esterase, Hydrolase	High	Maroof et al., 2020
Pseudomonas spp.	Polypropylene	Laccase, Esterase	Moderate	Muhonja et al., 2018
Aspergillus spp.	Polyvinyl Chloride (PVC)	Laccase, Cutinase	High	Tokiwa et al., 2009
Penicillium spp.	Polyethylene Terephthalate (PET)	PETase, MHETase	High	Soong et al., 2022
Streptomyces spp.	Polystyrene	Laccase, Alkaline Phosphatase	Moderate	Nademo et al., 2023

This table gives a summary of microbial organisms and major enzymes, which are engaged in the process of biodegradation of plastics. These microorganisms can degrade different kinds of plastic and the table also shows the efficiency of the microorganisms in biodegradation.

Plastic degradation by microbes occurs through a four-stage process starting from attachment on surfaces and proceeding through chain breakdown then assimilation concludes with mineralization into biomass. The beginning of microbial attachment to plastic surfaces leads to biofilm formation where microorganisms can subsequently unleash extracellular enzymes (Tokiwa et al., 2009). Enzymes named hydrolases and esterases as well as oxidases facilitate plastic polymer chain breakdown thus generating chemical fragments such as oligomers and monomers and dimers (Soong et al., 2022). Through different research investigations scientists have proven the polyethylene degradation capability of *Bacillus* genera to be the most commonly identified species (Muhonja et al., 2018). Microorganisms move plastic molecules into their cellular structures before breaking them down through different metabolic pathways to generate carbon dioxide along with water while simultaneously producing new cellular substances. The ability of microorganisms to deteriorate plastics depends on their synthesis of laccases and alkane hydroxylases for breaking down low-density polyethylene (Muhonja et al., 2018; Maroof et al., 2020). Scientists have not yet proven the degree to which bacterial enzymes work on dissolving plastic as they do cellulose polymers because the process of plastic breakdown by enzymes remains incomplete (Cai et al., 2023). Soil-based bacteria species *Bacillus siamensis* and *Bacillus wiedmannii* indicate low-density polyethylene degradation ability that leads to surface damage while producing carbonyl peaks (Maroof et al., 2020).

The biological decomposition of plastic materials depends on their length and organization and size of exposed surfaces as well as all present additives. Highly crystalline polymers starting from polyethylene show limited environmental breakdown and their marine degradation occurs at such sluggish rates due to minimal oxygen levels and cold temperatures (Nisha et al., 2020). The performance of microbial plastic biodegradation increases through three main strategies that merge enzyme optimization achieved through genetic manipulation along with specific changes to environmental conditions alongside bioconsortium strategies which unite different microorganisms to degrade plastics. The use of multiple microorganism populations in consortia produces superior outcomes than single microorganisms because distinct organisms contain various enzymes which work synergistically to improve cooperative breakdown mechanisms.

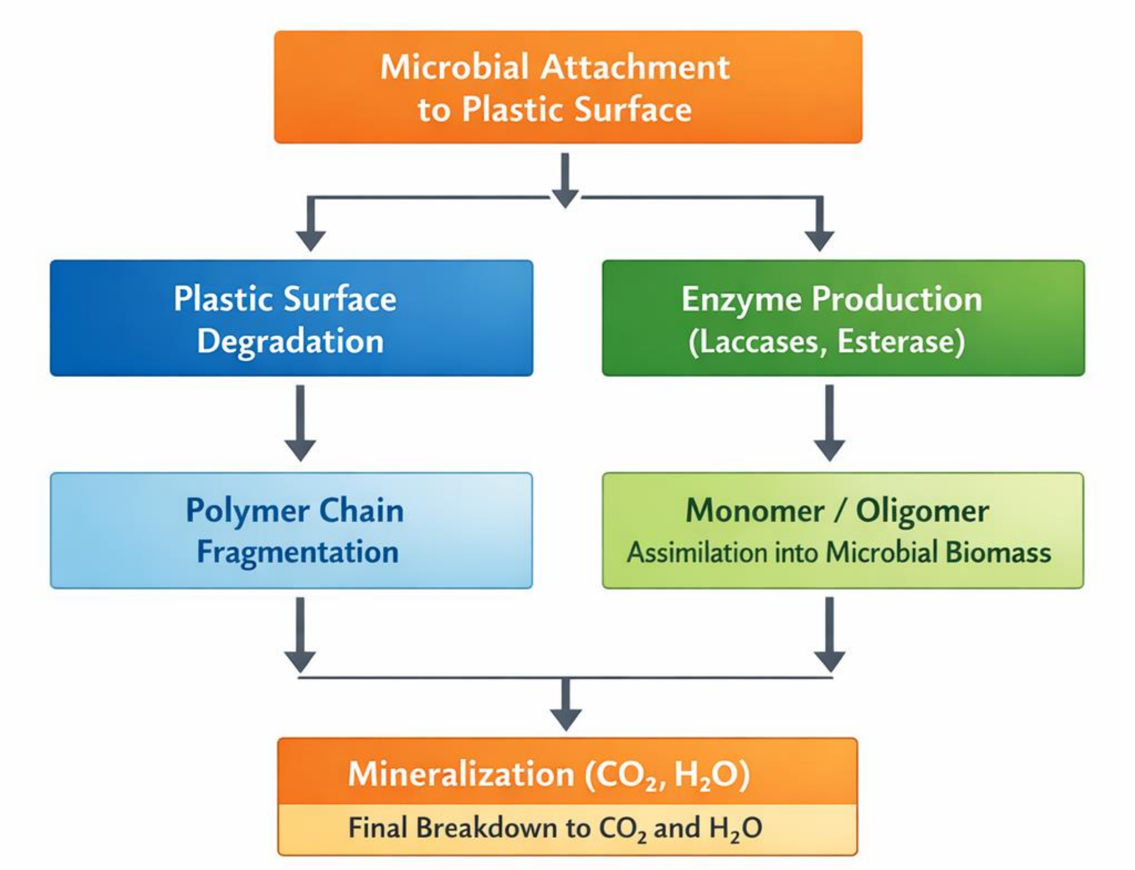

Figure 1: Microbial Biodegradation Pathways for Plastics

This figure presents the overall mechanism of plastic biodegradation by microorganisms. The reaction starts by the microbial attachment of the plastic surface, which is then accompanied by the production of enzymes and the breakdown of polymer chains. The resulting monomers are incorporated into the biomass in microbes and the end mineralization stage results in releases of carbon dioxide and water.

The microbial degradation process mainly depends on environmental factors which temperature proves to be the leading influencing factor. Studies performed in multiple laboratories confirm that low-density polyethylene films achieve optimal degradation during their incubation period within 40-120 days at 30-37°C. A microorganism operates optimally at its specific temperature therefore the operational temperature must align with the best-suvironments for those degrading microorganisms. The functionality of hydrolytic enzymes which break down polymer chains depends on their requirement for water which is influenced by the present levels of moisture. The rates at which microorganisms break down plastic depend strongly upon how microbial networks develop based on different plastic materials across various parts of the world (Viel et al., 2023). Plastic degradation speed and the active phases of responsible microbes depend strongly on how readily available mineral nutrients such as nitrogen and phosphorus are to them. Plastics undergo decomposition through transition metals such as iron and manganese and cobalt and nickel which fragment enormous polymer chains into microscopic fragments so microorganisms can transform the fragments into biomass along with carbon dioxide (Melchor-Martínez et al., 2022).

The use of plastic-digesting microbial enzymes for enzymatic degradation presents a sustainable strategy past current methods as Danso et al., 2019 explored this opportunity. The degradation of polyethene has been shown possible by measuring the activity of laccases produced by particular fungi following the methodology in Muhonja et al. (2018). Diverse plastic materials experience better degradation thanks to the effective plastic degradation process performed by enzymes such as laccases and proteases and cutinases together with PETase and MHETase per Dhali et al. (2024). Scientific studies uncovered polyester hydrolases that researchers successfully modified for better PET ester bond breakdown potential as mentioned in Anuar et al. (2022). A biodegradation system applies abiotic degradation patterns through UV radiation and heat exposure to plastic surfaces which becoming more accessible to microbial decomposition.

The practice of genetic engineering delivers vital possibilities to enhance the efficiency of microorganisms while they destroy plastics. Genetic engineering of microorganisms by researchers enables the development of improved bioremediation solutions which enhance microorganisms' plastic degrading potential as well as develop efficient enzymes. The scientific literature confirms how soybean peroxidase acts on polyethylene surfaces yet laccase-mediator systems show effectiveness at breaking down nylon and polyethylene membranes and need testing using membrane polymers independently from standard polyethylene (Santo et al., 2012). Biodegradation rates of polyethylene increase when research teams integrate natural polymers such as starch and chitosan or cellulose substance within the polyethylene matrix according to Sen and Raut (2015). The advancement of new technology depends on complete knowledge about both biological and physical degradation patterns together with exclusive information about these processes' degradation kinetics (Glaser, 2019).

Literature Review

and energy sources through enzyme-generated decomposition operations that break down plastic

The essential role of microbial communities in plastic waste bioremediation processes emerges from recent scientific studies as demonstrated by multiple scientific publications about this matter. Plastics degrade with the help of laccase enzymes that transform complex polymers as per Santo et al. (2012). Maroof et al. (2020) pointed out that low-density polyethylene decomposition occurs efficiently when Enterobacter spp and Brevibacillus borstelensis (along with Pseudomonas aeruginosa and Bacillus cereus) work in a consortium with Brevibacillus spp and Aneurinibacillus spp. Studies conducted on waste dump microorganisms have proven these microorganisms excel at breaking plain polyethylene plastics to present innovative ways for handling plastic waste. To better evaluate research directions researchers need to implement proper assessment techniques during biodegradation investigations according to Matjašič et al. (2020).

Modern research shows that microbial teams using fungal species and bacterial types have shown effective capacity to break down different plastic materials including polyethylene (Muhonja et al., 2018). Plastic-degrading microorganisms exist throughout different environmental regions because they occupy digestive systems of insects and marine sediments as well as the soil environment. The biodegradation levels of polyethylene tests become higher when scientists expose these samples to UV irradiation before conducting the degradation experiment.

Multiple plastic waste items combined with various polymers and additives create a condition where bioremediation processes typically fail to succeed. Modern scientific methods require development to monitor biodegradation since such methods establish essential research standards (Bher et al., 2022). Research shows that properly designed consortium groups advance the pace of plastic degradation and algae serve as an alternative approach to recycle waste plastic items (Ali et al., 2021).

Plastics degrade through various environmental elements where temperature stands as the main factor alongside pH value and oxygen availability and nutrient characteristics. Bioremediative processes experience increased success due to proper adjustments made in environmental conditions which target specific bacterial groups.

Plastic material degradation depends mainly on both microbial population characteristics along with environmental conditions along with plastic material composition. Organisms containing bacteria and fungi utilize plastic to obtain carbon chains (Padmanabhan et al., 2019). Research supported by public and private organizations needs to develop efficient solutions for plastic waste reduction through environmentally safe methods because biodegradation shows promise as a solution platform.

Methodology

The study of microbial influence on plastic waste bioremediation needs a research design which combines field-based work and laboratory testing through sophisticated assessment techniques. Scientists should obtain physical samples from three dissimilar sites that combine between soil environments and marine sediments and freshwater systems because plastic waste exists in all locations. Successful data collection depends on consecutive recording of location-specific sites together with environmental conditions accompanied by detailed plastic waste classification.

Scientists must use DNA extraction methods to acquire microbial community genetic materials before they apply PCR to amplify 16S rRNA genes for sequencing through Illumina MiSeq to establish plastic waste-related microbial relationships (Muhonja et al., 2018).

Laboratory workers must perform complete analysis to measure both physical and chemical alterations that occur to plastic materials throughout degradation.

Genetic modifications after biodegradation processes will enhance microbial degradation capacity thus improving overall efficiency.

Plastic degradation necessitates the detection of suitable microorganisms after their laboratory cultivation for later application to multiple plastic types. Plastic biodegradation development mandates both the identification of perceptive enzymes alongside the determination of purposeful work environments for those enzymes.

Results

The evaluation methods will show essential scientific data about microbes supporting plastic waste bioremediation. A phylogenetic method identified the bacterial types in the sample which matched *Methylobacterium radiotolerans*, *Methylobacterium fujisawaense* and *Lysinibacillus fusiformis* per Maroof et al. (2020). The successful analysis of plastic degradation requires users to perform weight measurements while combining them with scanning electron microscopy assessments of surface modification and Fourier transform infrared spectroscopy observations of chemical alterations. financial evaluation with environmental influences

The scanning electron microscope shows plastic surface degradation through the direct observation of pits and microbial formation of pores and surface flaws (Nademo et al., 2023). The oxidation process becomes verifiable through Fourier transform infrared spectroscopy because it detects new carbonyl, carbonyl, and hydroxyl bonds that emerge during the degradation (Sandt et al., 2021). The acquired data offers crucial information about plastic-breaking microorganisms along with plastic degradation processes and bioremediation assessment techniques.

Scientific evidence demonstrates that the polyethylene degradation process performed by bacteria and fungi isolated from waste disposal sites makes them suitable agents for bioremediation purposes. Research has established that microorganisms make both esterase enzymes and laccase enzymes that play a part in polyethene breakdown.

According to Nademo et al. (2023) multiple bacterial strains demonstrate successful virgin polyethylene degradation performance without requiring UV irradiation or chemical oxidation pretreatments. During 120 days of incubation the researchers studied polyethene degradation by different Pseudomonas species (Muhonja et al., 2018). Microorganisms show efficient polymer degradation ability which establishes that pretreatment procedures might accelerate biodeterioration rates.

Discussions

The investigation results require discussion about how identified microorganisms break down plastic while explaining their enzymology and environmental control factors that activate them. Microbiological research on plastic material interaction processes and degradation pathways together with carbon source utilization explains the mechanisms behind biodegradation. LDPE degradation occurs as a slow yet continuous and time-dependent process because of low degradation values and increased percent crystallinity in connection with bacterial isolation of Laccase, Alk1, and Alk2 genes (Maroof et al., 2020).

LDPE degradation was verified by scientist identification of microbial *Bacillus siamensis* and *Bacillus wiedmannii* species together with fungal presence while microscopic analyses revealed surface erosion patterns and confirmed cracks and folds and visible fungal growth on LDPE film surfaces (Nademo et al., 2023).

The discussions need to study large-scale bioremediation execution approaches by combining while following regulatory demands.

Scientists have identified the complete bioremediation system that arises from environmental factors along with microorganism plastic-degrading capabilities.

The study by Rajandas et al. (2012) shows how microorganisms efficiently degrade oxidized polymers through pretreatment methods which allows such organisms to adapt to similar substances.

Conclusion

Scientific research confirms that microorganisms hold strong potential for addressing worldwide plastic waste accumulation problems. Scientific application of plastic-degrading microorganisms which have gone through characterization leads to remarkable advancements in bioremediation projects. The plastic degradation effectiveness increases through new biotechnological approaches combining enzyme engineering with microbial consortia design systems as described by Temporiti et al. (2022). Complete sustainable plastic waste control emerges through logical microbial bioremediation implementation with waste reduction measures and recycling practices.

Complete implementation of microbial bioremediation technologies needs research collaborations between investigators and regulatory bodies along with corporate involvement to establish supportive environments for technology advances and funding while receiving regulatory support.

The future will become sustainable through plastic manufacturing reductions alongside effective waste management and proper use of microbial communities (Orlando et al., 2023).

The circular economic system uses bioplastic production and waste-to-value biotechnology enabled by microorganisms to turn waste material into useful products (García-Depraect et al., 2021; Paço et al., 2018). Global plastic pollution requires international nations to collaborate by creating partnerships at worldwide levels to reduce pollution (Macheca et al., 2024).

Developing countries need substantial financial support toward building waste management systems with built-in source-based waste reduction solutions according to Rahman et al. (2021).

The combination of physical and chemical pretreatments with microbial biodegradation demonstrates high potential for microplastic degradation according to Pan et al. (2022) therefore additional research is essential. Scientific entities must complete ongoing research needs while building new procedures suitable for coastal areas.

The next phase of ecological research should focus on enzyme degradation method enhancements together with consortium development along with quantitative assessments of degradation products on natural ecosystems. The process of plastic contamination at sites allows microbial communities to transform into dense biofilm structures on plastic surfaces where they produce active degradative enzymes (A. et al., 2019).

References

1. A., G. K., Anjana, K., Hinduja, M., Sujitha, K., & Dharani, G. (2019). Review on plastic wastes in marine environment – Biodegradation and biotechnological solutions [Review of Review on plastic wastes in marine environment – Biodegradation and biotechnological solutions]. Marine Pollution Bulletin, 150, 110733. Elsevier BV. https://doi.org/10.1016/j.marpolbul.2019.110733
2. Ali, S. S., Elsamahy, T., Al-Tohamy, R., Zhu, D., Mahmoud, Y. A. -G., Koutra, E., Metwally, M. A., Kornaros, M., & Sun, J. (2021). Plastic wastes biodegradation: Mechanisms, challenges and future prospects [Review of Plastic wastes biodegradation: Mechanisms, challenges and future prospects]. The Science of The Total Environment, 780, 146590. Elsevier BV. https://doi.org/10.1016/j.scitotenv.2021.146590 Hydrolases and Efforts in Tailoring Enzymes
3. Ali, S. S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M. M., Abdelkarim, E. A., Zhu, D., & Sun, J. (2021). Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal [Review of Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal]. The Science of The Total Environment, 771, 144719. Elsevier BV. https://doi.org/10.1016/j.scitotenv.2020.144719
4. Anuar, N. F. S. K., Huyop, F., Ur-Rehman, G., Abdullah, F., Normi, Y. M., Sabullah, M. K., & Wahab, R. A. (2022). An Overview into Polyethylene Terephthalate (PET) Hydrolases and Efforts in Tailoring Enzymes for Improved Plastic Degradation [Review of An Overview into Polyethylene Terephthalate (PET) for Improved Plastic Degradation].

International Journal of Molecular Sciences, 23(20), 12644. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ijms232012644

5. Bher, A., Mayekar, P. C., Auras, R., & Schvezov, C. E. (2022). Biodegradation of Biodegradable Polymers in Mesophilic Aerobic Environments [Review of Biodegradation of Biodegradable Polymers in Mesophilic Aerobic Environments]. International Journal of Molecular Sciences, 23(20), 12165. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ijms232012165
6. Cai, Z., Li, M., Zhu, Z., Wang, X., Huang, Y., Li, T. J., Gong, H., & Yan, M. (2023). Biological Degradation of Plastics and Microplastics: A Recent Perspective on Associated Mechanisms and Influencing Factors [Review of Biological Degradation of Plastics and Microplastics: A Recent Perspective on Associated Mechanisms and Influencing Factors]. Microorganisms, 11(7), 1661. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/microorganisms11071661
7. Danso, D., Chow, J., & Streit, W. R. (2019). Plastics: Environmental and Biotechnological Perspectives on Microbial Degradation [Review of Plastics: Environmental and Biotechnological Perspectives on Microbial Degradation]. Applied and Environmental Microbiology, 85(19). American Society for Microbiology. https://doi.org/10.1128/aem.01095-19
8. Dhali, S. L., Parida, D., Kumar, B., & Bala, K. (2024). Recent trends in microbial and enzymatic plastic degradation: a solution for plastic pollution predicaments. Deleted Journal, 1(1). https://doi.org/10.1186/s44316-024-00011-0
9. et al, Y. (2012). Bioremediation & Biodegradation.
10. García-Depraect, O., Bordel, S., Lebrero, R., Santos-Beneit, F., Börner, R. A., Börner, T., & Muñoz, R. (2021). Inspired by nature: Microbial production, degradation and valorization of biodegradable bioplastics for life-cycle-engineered products [Review of Inspired by nature: Microbial production, degradation and valorization of biodegradable bioplastics for life-cycle-engineered products]. Biotechnology Advances, 53, 107772. Elsevier BV. https://doi.org/10.1016/j.biotechadv.2021.107772
11. Glaser, J. A. (2019). Biological Degradation of Polymers in the Environment. In IntechOpen eBooks. IntechOpen. https://doi.org/10.5772/intechopen.85124
12. John, N., & Salim, R. (2020). Biodegradation of plastics by microbes-A review. AIP Conference Proceedings, 2263, 20003. https://doi.org/10.1063/5.0016828
13. Kumar, P., Lee, J., Brown, R. J. C., & Kim, K. (2020). Micro- and nano-plastic pollution: Behavior, microbial ecology, and remediation technologies. Journal of Cleaner Production, 291, 125240. https://doi.org/10.1016/j.jclepro.2020.125240
14. Macheca, A. D., Mutuma, B. K., Adalima, J. L., Midheme, E., Lucas, L. H. M., Ochanda, V. K., & Mhlanga, S. D. (2024). Perspectives on Plastic Waste Management: Challenges and Possible Solutions to Ensure Its Sustainable Use. Recycling, 9(5), 77. https://doi.org/10.3390/recycling9050077
15. Malik, S., Maurya, A. C., Khare, S. K., & Srivastava, K. R. (2023). Computational Exploration of Bio-Degradation Patterns of Various Plastic Types. Polymers, 15(6), 1540. https://doi.org/10.3390/polym15061540
16. Maroof, L., Khan, I., Yoo, H. S., Kim, S., Park, H.-T., Ahmad, B., & Azam, S. (2020). Identification and characterization of low density polyethylene-degrading bacteria isolated from soils of waste disposal sites. Environmental Engineering Research. https://doi.org/10.4491/eer.2020.167
17. Matjašič, T., Simčić, T., Medvešček, N., Bajt, O., Dreo, T., & Mori, N. (2020). Critical evaluation of biodegradation studies on synthetic plastics through a systematic literature review [Review of Critical evaluation of biodegradation studies on synthetic plastics through a systematic literature review]. The Science of The Total Environment, 752, 141959. Elsevier BV. https://doi.org/10.1016/j.scitotenv.2020.141959
18. Melchor-Martínez, E. M., Macías-Garbett, R., Alvarado-Ramírez, L., Araújo, R. G., Sosa-Hernández, J. E., Ramírez-Gamboa, D., Parra-Arroyo, L., Alvarez, A. G., Monteverde, R. P. B., Cazares, K. A. S., Reyes-Mayer, A., Lino, M. Y., Iqbal, H. M. N., & Parra-Saldívar, R. (2022). Towards a Circular Economy of Plastics: An Evaluation of the Systematic Transition to a New Generation of Bioplastics [Review of Towards a Circular Economy of Plastics: An Evaluation of the Systematic

Transition to a New Generation of Bioplastics]. Polymers, 14(6), 1203. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/polym14061203

19. Muhonja, C. N., Magoma, G., Imbuga, M., & Makonde, H. M. (2018). Molecular Characterization of Low-Density Polyethene (LDPE) Degrading Bacteria and Fungi from Dandora Dumpsite, Nairobi, Kenya. International Journal of Microbiology, 2018, 1. https://doi.org/10.1155/2018/4167845
20. Nademo, Z. M., Shibeshi, N. T., & Gemeda, M. T. (2023). Isolation and screening of low-density polyethylene (LDPE) bags degrading bacteria from Addis Ababa municipal solid waste disposal site "Koshe." Annals of Microbiology, 73(1). https://doi.org/10.1186/s13213-023-01711-0
21. Nisha, M., Montazer, Z., Sharma, P., & Levin, D. B. (2020). Microbial and Enzymatic Degradation of Synthetic Plastics [Review of Microbial and Enzymatic Degradation of Synthetic Plastics]. Frontiers in Microbiology, 11. Frontiers Media. https://doi.org/10.3389/fmicb.2020.580709
22. Oliveira, J., Belchior, A., Silva, V. D. da, Rotter, A., Petrovski, Ž., Almeida, P. L., Lourenço, N. D., & Gaudêncio, S. P. (2020). Marine Environmental Plastic Pollution: Mitigation by Microorganism Degradation and Recycling Valorization. Frontiers in Marine Science, 7. https://doi.org/10.3389/fmars.2020.567126
23. Orlando, M., Molla, G., Castellani, P., Pirillo, V., Torretta, V., & Ferronato, N. (2023). Microbial Enzyme Biotechnology to Reach Plastic Waste Circularity: Current Status, Problems and Perspectives [Review of Microbial Enzyme Biotechnology to Reach Plastic Waste Circularity: Current Status, Problems and Perspectives]. International Journal of Molecular Sciences, 24(4), 3877. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ijms24043877
24. Paço, A., Jacinto, J., Costa, J. P. da, Santos, P. S. M., Vitorino, R., Duarte, A. C., & Rocha-Santos, T. (2018). Biotechnological tools for the effective management of plastics in the environment. Critical Reviews in Environmental Science and Technology, 49(5), 410. https://doi.org/10.1080/10643389.2018.1548862
25. Padmanabhan, L., Varghese, S., Patil, R. K., Rajath, H. M., Krishnasree, R. K., & Shareef, M. I. (2019). Ecofriendly Degradation of Polyethylene Plastics Using Oil Degrading Microbes. Recent Innovations in Chemical Engineering (Formerly Recent Patents on Chemical Engineering), 13(1), 29. https://doi.org/10.2174/2405520412666190725114137
26. Pan, Y.-S., Gao, S.-H., Ge, C., Gao, Q., Huang, S., Kang, Y., Luo, G., Zhang, Z., Lü, F., Zhu, Y., & Wang, A. (2022). Removing microplastics from aquatic environments: A critical review [Review of Removing microplastics from aquatic environments: A critical review]. Environmental Science and Ecotechnology, 13, 100222. Elsevier BV. https://doi.org/10.1016/j.ese.2022.100222
27. Philip, J., ja, T., Michael, H., Verma, V., & Rahman, A. M. (2020). Effect of Fungi Isolated from Different Plastic Polluted Sites on Low Density Polyethylene Material Degradation with Reference to SEM Analysis. International Journal of Current Microbiology and Applied Sciences, 9(6), 3149. https://doi.org/10.20546/ijcmas.2020.906.377
28. Rahman, Z., Ishtiaq, G., & Amanat, A. (2021). Assessment of Solid Waste Management and Sustainability Practices in District Swat, Pakistan.
29. Rajandas, H., Parimannan, S., Sathasivam, K. V., Ravichandran, M., & Yin, L. S. (2012). A novel FTIR-ATR spectroscopy based technique for the estimation of low-density polyethylene biodegradation. Polymer Testing, 31(8), 1094. https://doi.org/10.1016/j.polymertesting.2012.07.015
30. Ru, J., Huo, Y., & Yang, Y. (2020). Microbial Degradation and Valorization of Plastic Wastes [Review of Microbial Degradation and Valorization of Plastic Wastes]. Frontiers in Microbiology, 11. Frontiers Media. https://doi.org/10.3389/fmicb.2020.00442
31. Sandt, C., Waeytens, J., Deniset-Besseau, A., Nielsen-LeRoux, C., & Réjasse, A. (2021). Use and misuse of FTIR spectroscopy for studying the bio-oxidation of plastics. Spectrochimica Acta Part A Molecular and Biomolecular Spectroscopy, 258, 119841. https://doi.org/10.1016/j.saa.2021.119841
32. Santo, M., Weitsman, R., & Sivan, A. (2012). The role of the copper-binding enzyme laccase in the biodegradation of polyethylene by the actinomycete Rhodococcus ruber.
33. Sen, S. K., & Raut, S. (2015). Microbial degradation of low density polyethylene (LDPE): A review [Review of Microbial degradation of low density polyethylene (LDPE): A review]. Journal of Environmental

Chemical Engineering, 3(1), 462. Elsevier BV. https://doi.org/10.1016/j.jece.2015.01.003

34. shmi, R., Kumar, R., & Pathak, D. (2020). Approaches for Enhancing Microbial Degradation of Synthetic Plastics: A Review [Review of Approaches for Enhancing Microbial Degradation of Synthetic Plastics: A Review]. International Journal of Current Microbiology and Applied Sciences, 9(1), 910. Excellent Publishers. https://doi.org/10.20546/ijcmas.2020.901.101
35. Soong, Y. V., Sobkowicz, M. J., & Xie, D. (2022). Recent Advances in Biological Recycling of Polyethylene Terephthalate (PET) Plastic Wastes [Review of Recent Advances in Biological Recycling of Polyethylene Terephthalate (PET) Plastic Wastes]. Bioengineering, 9(3), 98. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/bioengineering9030098
36. Temporiti, M. E. E., Nicola, L., Nielsen, E., & Tosi, S. (2022). Fungal Enzymes Involved in Plastics Biodegradation [Review of Fungal Enzymes Involved in Plastics Biodegradation]. Microorganisms, 10(6), 1180. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/microorganisms10061180
37. Tokiwa, Y., Calabia, B. P., Ugwu, C. U., & Aiba, S. (2009). Biodegradability of Plastics [Review of Biodegradability of Plastics]. International Journal of Molecular Sciences, 10(9), 3722. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ijms10093722
38. Viel, T., Manfra, L., Zupo, V., Libralato, G., Cocca, M., & Costantini, M. (2023). Biodegradation of Plastics Induced by Marine Organisms: Future Perspectives for Bioremediation Approaches [Review of Biodegradation of Plastics Induced by Marine Organisms: Future Perspectives for Bioremediation Approaches]. Polymers, 15(12), 2673. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/polym15122673