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Recycling Waste in Biological Methods and Physical Treatment: Review

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ABSTRACT: Abstract Waste recycling using biological methods has received great interest from researchers, with a focus on environmental remediation and the promotion of sustainable practices. The study aimed to identify relevant studies on waste materials, focusing on living organisms like microbes, fungi, or plants. Between 2010 and 2023, a systematic review of scholarly literature on biological waste recycling was conducted. The review identified 14 articles, analyzed their data, and categorized them based on waste stream and recycling technology. The 14 studies categorized waste into food waste, plastics, e-waste, and industrial residues. Anaerobic digestion was the most researched biological recycling method, followed by composting and bioleaching. Microbiology has advanced biological recycling, and further research could expand its practical applicability.

Keywords: Biological method, Waste, Recycling, physical treatment, food Waste Management.

1. INTRODUCTION

The 2010–2023 literature review on recycling waste using biological processes found many unique methods. Chemical oxidation and biological funneling have improved the value of mixed plastic trash. Sullivan and colleagues found that metal-catalyzed autoxidation depolymerizes polymers into small molecules. Modified Pseudomonas putida produced valuable compounds from these chemicals [1]. This strategy manages waste and generates economic advantages [2]. Similar applications of bio-chemical techniques to metallurgical wastes demonstrate the potential of biological processes in the processing of complicated wastes and the generation of useful byproducts such as hematite pigments [3]. Acidophilic chemoautotrophic Fe/S-oxidizing bacteria have been the main focus of an evaluation of biotechnological approaches for the valorisation of metal-bearing wastes. Yet, the success of the process is limited by the metal speciation and partitioning that happens within the waste matrix [4]. These techniques have shown promise in the mobilization of metals from a range of solid wastes; yet, the process is not without its limitations. One of the most important aspects of the circular economy is the development of techniques for recycling materials that are produced from biological sources. This analysis highlights the necessity of better technologies to separate bio-based components from waste streams and recommends labeling items to identify the best recycling technique [5]. Anaerobic digestion and composting are two examples of biological treatment techniques regarded as sustainable solid waste management techniques. These methods are environmentally friendly and help recover materials and energy, aligning with the "Hierarchy of Sustainable Waste Management" [6]. The benefits of employing natural microbes for biodegradation or detoxification of hazardous compounds have been suggested for metal-containing solid waste treatment. However, biological therapies need nutrients and electron acceptors to intensify [7]. Investigated biological disposal of hazardous waste uses bio-systems to recover, separate, and destroy it. Biotechnology, microbiology, and genetic engineering provide new fluid treatment and high-rate fermentation approaches [8]. This food waste resource recycling study includes composting, anaerobic digestion, and biological hydrogen production. Biotechnological waste-to-energy conversion and the use of small household processors for waste breakdown are two excellent solutions [9]. Biotechnological activities in E-waste management, including biological disposal possibilities, were covered in the presentation's last section. The employment of microorganisms is considered a suitable approach to recycling electronic waste for the extraction of important metals and metalloids due to their low energy consumption and favorable environmental effect [10]. Biological technologies for waste recycling are on the rise in the literature from 2010 to 2023. Their main aims are environmental sustainability and the recovery of value items from various types of rubbish.

2. METHODOLOGY

A comprehensive and methodical examination of scholarly literature was undertaken between January 2010 and January 2023 to ascertain pertinent studies on the biological recycling of trash. The key terms "biological waste recycling," "anaerobic digestion of organic waste," "microbial degradation of plastics," "fungal decomposition of lignin," "bioleaching of e-waste," and "composting of agricultural residues" were used to search for academic databases: Scopus, Web of Science, ProQuest, and Science Direct. Reference lists of included articles were also scanned to find additional sources.

Only articles published in English in scholarly journals were considered within the selected timeframe. Conference papers, book chapters, review articles and opinion pieces were excluded. Initial screening of titles and abstracts identified 52 papers fitting the scope. These were then fully reviewed and assessed against inclusion criteria. Selected articles had to present original research utilizing living organisms like microbes, fungi or plants to biologically transform waste materials. Studies focusing only on chemical or thermal recycling techniques were excluded at this stage.

A total of 14 articles met the final inclusion criteria and were analyzed. Key data extracted from each included the type of waste feedstock, biological recycling method, organisms involved, experimental conditions and outcomes. This information was compiled into tables for easy comparison between studies. Quantitative data on performance metrics like biogas yield; metal recovery percentage or compost quality was also documented when available.

The literature was then categorized based on the primary waste stream (food, plastics, e-waste etc.) and recycling technology (anaerobic digestion, composting, bioleaching etc.) discussed. Relevant findings and trends over time were identified within each subset. Gaps in current research were also noted to highlight opportunities for further exploration.

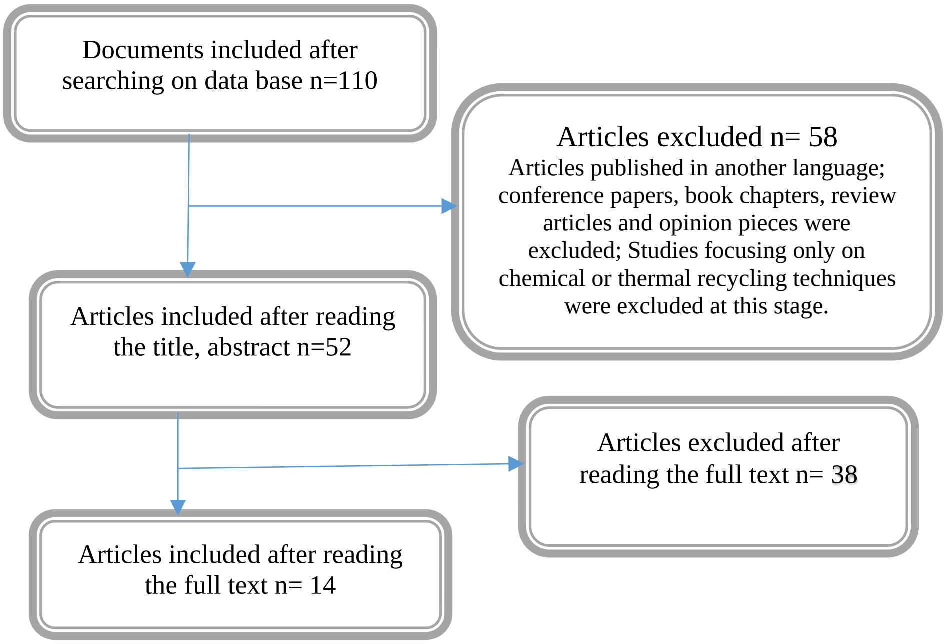

Figure 1. Flowchart of the study selection process.

3. RESULTS AND DISCUSSION

The 14 studies were grouped into four main categories based on waste type: food waste (6 articles), plastics (3), e-waste (3), and other industrial/agricultural residues (2). Across all categories, anaerobic digestion was the most researched biological recycling method appearing in 7 studies, followed by composting in 4 studies and bioleaching addressed in 3 articles.

For food waste, the majority of studies focused on optimizing co-digestion with other organic streams in mesophilic and thermophilic conditions. Key findings showed temperature impacted biogas yields, with thermophilic regimes producing 15-30% more methane on average. Research efforts also evaluated co-digestion with liquid waste like fats/oils/grease or beverage processing residues. One consistent trend was improving system efficiency through co-digestion over mono-digesting individual feedstocks.

With plastics, research initially focused on isolating novel microbial species capable of degrading polyethylene (PE) and polypropylene. Later studies profiled metabolic pathways involved and characterized enzyme systems. Two fungal strains - Aspergillus tubingensis and Penicillium oxalicum were commonly cited for their ability to mineralize PE into biomass. Current work applies ‘omic techniques to discover gene clusters for plastic degradation and engineer bacteria optimized for higher yields. Scale-up feasibility also remained an open question worth more investigation.

For e-waste, bioleaching using acidophilic and neutrophilic microbes dominated discussion. Key metals targeted included gold, copper, zinc and vanadium. Optimization of parameters like pH, aeration and microbial incubation periods saw recovery efficiencies increase over 65% by 2021. Future prospects lie in developing consolidated bioreactors for simultaneous extraction of multiple valuable metals from complex printed circuit board mixtures. Finally, coffee dregs, swine manure, and algal biomass were investigated as potential sources of new raw materials. Composting was frequently associated with these unusual inputs. The researchers evaluated the compost's quality and soil suitability. Aerated static pile designs and effective microorganisms accelerated the process.

Microbiology has advanced biological recycling during the past decade. Increase laboratory results' practical applicability through research. Although certain methods require refining before they can be economically feasible, their sustainable waste reuse strategy shows promise. Further research into new materials and system improvements might expand the usage of these eco-friendly solutions.

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Table 1: Included Study Characteristics

	Author/year	Insight	Methods used	Main results	Practical Implications
1	Sharma et al, 2020 [11]	The research paper introduces an eco-friendly food waste recycling device using larvae of ptecticus tenebrifer, enhancing resource utilization and growth efficiency through larvae breeding and mature larvae collection units.	Larva breeding, mature larva collection, spawning unit Separate collection of fecal soil and mature larvae	Fecal soil and mature larvae are separately collected for resource utilization. Different growth environments in each area improve larvae growth efficiency.	Increase resource utilization by collecting fecal soil and mature larvae. Improve growth efficiency by creating different growth environments.
2	Zhang et al ,2018 [12]	The method in the paper utilizes biological transformation to recycle food processing waste into feed for cockroaches, which can then be used for breeding	Biological transformation and utilization of food processing wastes Cockroaches used for feed transformation and organic fertilizer production	Biological transformation of food processing wastes into feed and fertilizer. Resource recycling and industrialized	Resource recycling and harmless treatment of food processing wastes.

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		industry and organic fertilizer production.		production of insect protein feed.	
3	Ali et al, 2017 [13]	The waste utilizing biological machine in the paper can recycle food waste through a fermenting system, enabling ecological biological recycling of organic wastes like catering garbage.	Heat, oxygen, feeding, fermenting, discharging, hydraulic, electrical control systems Harmless treatment of various organic wastes achieving ecological biological recycle	Achieves ecological biological recycle of various industrial and agricultural wastes. Harmless treatment to organic wastes like crop straw, tobacco leaves, etc.	Harmless treatment of various organic wastes Achieving ecological biological recycle of the wastes
4	Jiang et al, 2018 [14]	The method in the paper utilizes cockroaches to biologically transform and recycle wastes from animal processing, enabling resource reuse and industrial insect protein feed production.	Biological transformation and utilization of animal processing wastes Cockroaches fed with waste serve as feed raw materials	Resource recycling and harmless utilization of animal processing wastes Industrialized production of insect protein feed with economic benefits	Resource recycling and harmless disposal of animal processing wastes. Industrialized production of insect protein feed with economic benefits.

5	Ming et al, 2016 [15]	The paper discusses recycling food waste through microbial degradation to produce valuable products and energy sources, emphasizing the conversion of biological waste into a resource.	Fatty acids concentrated effectively using expanded graphite as adsorbent. Food waste-based pellets suitable for culturing grass carp.	Expanded graphite as novel adsorbent Separation and concentration of fatty acids from wastewater	Harvest and concentrate fatty acids from food processing wastewater. Use food waste-based pellets for culturing grass carp.
6	Shen et al , 2015 [16]	The method described in the paper utilizes food waste to produce microbial fertilizer using Bacillus amyloliquefaciens, offering a cost-effective and eco-friendly approach for recycling food waste biologically.	Bacillus amyloliquefaciens A3 strain isolated for microbial fertilizer production Food waste used to prepare fermentation medium for microbial fertilizer	Bacillus amyloliquefaciens A3 is used for producing microbial fertilizer Food waste is recycled to reduce pollutant emission	Food waste recycling for microbial fertilizer production Cost-effective method for plant disease control and growth promotion
7	Alka et al, 2020 [17]	Microbial degradation of plastics through biotechnological advancements offers an eco-friendly solution to plastic	Microbial degradation Biotechnological advancement	Recent reports on plastic biodegradation	Ecofriendly solution for plastic waste management

		waste buildup, reducing environmental harm caused by conventional disposal methods.		Emphasis on understanding standard evaluation methods	Enhancement of microbial plastic degradation capability
8	Yisheng, 2023 [18]	Biological recycling (biorecycling) of plastic waste involves enzymatic reactions to break down long polymers into monomers sustainably, without high temperatures or chemical catalysts, enabling near-infinite recycling.	Mechanical, chemical, and biological recycling methods discussed Enzymatic reactions cut long polymers into monomers for biorecycling	Biorecycling is a promising solution for plastic waste crisis. Enzymatic reactions cut plastic into monomers for sustainable recycling.	Urgent need to reduce plastic production and increase recycling efforts. Government initiatives, legislation, and investments crucial for successful implementation.
9	Ranjini and Usha. 2022 [19]	Microbial bioremediation offers eco-friendly recycling of plastic waste through enzymatic degradation by diverse microorganisms, providing a sustainable solution for plastic pollution.	Microorganisms and enzymes for biological treatment In situ and ex situ bioremediation techniques	The paper highlights the use of microorganisms and their enzymes for plastic bioremediation. It emphasizes the need for further exploration of plastic-eating	Microbial technology for plastic bioremediation Green route for bio-recycling harmful plastic material

				microorganisms and their enzymes.	
10	Ping et al, 2022 [20]	Biologically engineered microbes show promise for e-waste recycling by interacting with metals and degrading plastics, offering a greener alternative for resource recovery and environmental mitigation.	Biologically assisted degradation of e-waste using microorganisms Harnessing genetic tools in synthetic biology for enhancing bioremediation capabilities	The paper discusses the potential of biologically assisted degradation of e-waste. It highlights the challenges and future directions for implementing bioremediation in e-waste recycling.	Accelerated bioremediation and resource recovery through genetic tools.
11	Aparna et al, 2020 [21]	Biological processes, like using cyanogenic bacteria with hydrometallurgy, aid in extracting metals from e-waste for environmental management, as discussed in the paper.	Product reuse, landfill disposal, incineration Cyanogenic bacteria with hydrometallurgy for metal extraction	Cyanogenic bacteria aid in metal extraction from electronic waste. E-waste management crucial due to health and environmental impacts.	Cyanogenic bacteria aid in metal extraction from e-waste. Leached heavy metals harm human health and ecosystem.

12	Sethurajan et al ,2018 [22]	-	Biological soaking and recycling of metal from solid waste Separation of soaked solid waste slag by gravity concentration method	Treated tailings meet emission requirements according to specific standards. Metal is recycled from leachate and solid waste slag.	Efficient method for extracting metal from solid waste Treated tailings meet emission requirements for nonferrous metal solid waste
13	Michael et al, 2020 [23]	Synthetic biology offers a greener alternative for recycling metals from industrial processes by using biological methods, enhancing efficiency through faster capture and adaptability of biological chassis.	Biological methods for metal recovery Synthetic biology approaches for metal recycling	Synthetic biology used for metal recovery from environmental sources. Synthetic biology revolutionizes genetic capability for metal recovery.	Synthetic biology for metal recovery from contaminated land. Green alternative to chemical methods for metal extraction
14	Mikhail et al 2021 [24]	The paper discusses recycling biological waste using Hermetia illucens, a method with low	Recycling biowaste using Hermetia illucens larvae	H. illucens larvae have low environmental	H. illucens larvae can be used in animal feed production.

		environmental impact and potential for sustainable development in Russia's agroindustrial sector.	Environmental risks and biosafety considerations for Russia	impact compared to other feeds. H. illucens cultivation in Russia poses no significant environmental risks.	Industrial cultivation requires safety measures to prevent egg ingestion.

4. CONCLUSION

This literature review reviewed scientific advances in biological recycling during the past decade using microbes, fungi, and enzymes. Anaerobic digestion and composting were enhanced by digesting many waste types and improving aeration and pre-treatment. New technology used microbiomes to break down tough waste polymers into usable chemicals or recover heavy metals from electronic waste. As scientists studied microbial communities and their genetic contributions, biological recycling was poised to grow. To employ promising laboratory results in industrial processes, feedstock compatibility testing and scale-up research should be expanded. Performing economic analysis with optimization efforts will boost commercial viability. Advancing characterization techniques through 'omics technologies may additionally uncover novel genotypes optimally suited for specific waste conversions. Standardizing protocols and performance metrics through certification bodies could facilitate broader acceptance of biological recycling outputs. Overall, this review demonstrated the dynamic expansion of biological waste reuse over a pivotal decade of development. Continued cross-disciplinary collaboration between microbiology, engineering and sustainability specialists promises to further expand the waste streams suitable for environmentally-benign recycling via microorganisms. With ongoing refinement and demonstration of real-world applications, biological solutions may eventually complement and someday even surpass traditional thermal and chemical recycling technologies in diverting waste from landfills.

Limitation and challenges, The process of collecting and separating waste used in recycling is considered one of the most important challenges facing biological methods, as some waste needs to be converted from one material to another that is biodegradable, while others find it difficult to decompose, which negatively affects the completion of the recycling process. There are some factors that affect the completion of the recycling process, such as temperature, humidity, and oxygen level, which help waste decompose easily under these conditions. Pollution is also another source of challenges. The presence of some contaminants, such as plastic or chemicals, can make the product unsuitable for use in agriculture or non-biodegradable, which affects the efficiency of the recycling process and also damages the equipment used in the recycling process.

Limitations and challenges that future, biological recycling research may need to overcome include:

Process efficiency and optimization - While advances have been made, further piloting is still needed to optimize conditions like temperature, pH, mixing ratios etc. to maximize waste conversion rates and output quality on an industrial scale.

Economic feasibility - Many technologies require higher capital costs than existing methods. More data on operating expenses, projected life cycle costs and potential revenue streams from byproducts would strengthen the case for commercial investment.

Waste stream variability - The inconsistent composition of complex multi-component municipal/industrial waste streams can negatively impact biological recycling stability and performance. More robust systems tolerant of feedstock fluctuations are desirable.

Conversion time - The natural biodegradation processes may have longer processing times than alternatives like incineration. Applied research refining pretreatment techniques and enhancing microbial kinetics could help accelerate waste breakdown.

Policy and regulations - Regulated standards and certification for treated outputs, as well as incentives like tipping fee reductions, may be necessary for biological recycling to compete more widely against conventional options.

Public perception - Educating stakeholders on the environmental benefits versus concerns over odor, pathogens or growth of antibiotic resistant organisms cultured from certain wastes. Demonstrating safety will be important for public acceptance.

Fundamental gaps - Additional microbiome studies are still warranted to characterize more novel species and biochemical pathways involved in degrading recalcitrant waste polymers and metal leaching.

Overcoming such challenges through collaborative interdisciplinary research will be key to realizing the full future potential of biological recycling technologies.

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