OPTIMIZATION OF COMPOSTING SYSTEMS USING FOOD WASTE-DERIVED MICROBIAL CONSORTIA FOR SUSTAINABLE ENVIRONMENTAL MANAGEMENT.

ABSTRACT

Global food waste generation poses a significant environmental burden through greenhouse gas emissions, resource loss, and ecosystem pollution, necessitating sustainable waste management solutions. This review focuses on microbial consortia-based compost optimization as an effective strategy for enhancing food waste valorization and environmental sustainability. Key themes include food waste microbiology, microbial community structure and succession, optimization strategies such as pH, temperature, moisture, aeration, and C/N ratio control, engineered and natural microbial consortia, and their roles in accelerating composting efficiency. The review also highlights advances in omics-based technologies and synthetic microbial design for improving compost stability and functionality, alongside environmental applications in soil fertility enhancement, bioremediation, and circular bioeconomy systems. Major insights indicate that optimized microbial interactions significantly improve degradation rates and compost quality. Future directions emphasize smart composting systems and AI-driven microbial management. Overall, microbial consortia-based composting presents a sustainable pathway for integrated food waste and environmental management.

Keywords: Food Waste, Composting, Microbial Consortia, Compost Optimization, Environmental Sustainability.

Introduction

Food waste (FW) has become one of the most pressing environmental challenges worldwide due to its increasing generation rate and its far-reaching ecological and socio-economic consequences. It is estimated that nearly one-third of all food produced for human consumption is lost or wasted annually (Dey et al., 2025). Beyond the direct loss of edible resources, food waste contributes significantly to environmental pollution, depletion of natural resources, and widening social inequalities (Jatoi et al., 2026). Conventional methods of food waste disposal, particularly landfilling and incineration, are increasingly considered unsustainable because of their contribution to greenhouse gas emissions and environmental degradation. During decomposition in landfills, food waste releases methane, ammonia, and volatile organic compounds (VOCs), all of which are associated with air pollution and global warming (Cerda et al., 2018). These concerns have intensified global interest in transitioning from linear waste-disposal systems toward circular economy approaches that promote the recovery and reutilization of organic waste as valuable resources for bioenergy, biofertilizers, and other bioproducts (Huzir et al., 2026).

Among the available waste valorization strategies, aerobic composting has gained considerable attention as an environmentally sustainable and economically feasible method for managing organic waste. Composting involves the biological decomposition and stabilization of organic materials into nutrient-rich compost through the activity of naturally occurring microorganisms (Luo et al., 2024). Compared with physicochemical treatment methods, biological composting is relatively cost-effective, energy-efficient, and environmentally friendly because it minimizes the formation of hazardous by-products (Dey et al., 2025). In addition to reducing the volume of organic waste, composting converts biomass into stable organic fertilizer capable of improving soil fertility, enhancing soil structure, and supporting sustainable agricultural production (Luo et al., 2024). Consequently, composting has emerged as an important component of integrated waste management systems aimed at achieving environmental sustainability.

The efficiency of composting largely depends on the structure, diversity, and metabolic activities of microbial communities involved in the degradation process. Composting occurs through a sequence of mesophilic, thermophilic, cooling, and maturation phases, each characterized by distinct microbial populations adapted to specific environmental conditions and substrate compositions (Luo et al., 2024). These microorganisms play essential roles in the decomposition of complex organic compounds such as cellulose, hemicellulose, starch, lipids, and proteins into simpler and more stable forms (Ansari et al., 2025). The synergistic interactions among bacteria, fungi, and actinomycetes contribute to the metabolic flexibility required for the degradation of heterogeneous food waste substrates (Zhou et al., 2024). Microbial diversity therefore represents a critical factor influencing compost quality, nutrient transformation, organic matter stabilization, and the overall efficiency of the composting process.

Despite its environmental benefits, conventional composting systems are often constrained by several operational and technical limitations. Traditional composting methods are typically characterized by prolonged processing periods and inconsistent degradation efficiency, making them less suitable for the increasing volume of urban food waste generated globally (Ansari et al., 2025). In addition, substantial nutrient losses frequently occur during composting, particularly through ammonia volatilization, resulting in reduced nitrogen content and lower fertilizer quality (Cerda et al., 2018). Other concerns include the emission of unpleasant odors and greenhouse gases, the survival of pathogenic microorganisms, and the persistence of non-biodegradable contaminants in the final compost product (Cerda et al., 2018). These limitations highlight the need for more efficient and controlled composting technologies capable of improving degradation rates, minimizing environmental emissions, and ensuring biosafety and compost maturity (Jatoi et al., 2026).

Recent advances in microbial biotechnology have shifted attention toward the development and optimization of engineered microbial consortia for enhanced composting performance. Unlike naturally occurring microbial communities, synthetic microbial consortia (SMCs) are deliberately designed to achieve specific functional objectives through synergistic metabolic interactions (Zhou et al., 2024). These engineered consortia possess enhanced substrate degradation capabilities, greater environmental adaptability, and improved metabolic efficiency, thereby accelerating the decomposition of complex organic materials. Through top-down and bottom-up microbiome engineering approaches, researchers can selectively enrich or construct microbial communities with targeted enzymatic and degradative functions (Zhou et al., 2024). Furthermore, the application of advanced molecular techniques such as metagenomics, transcriptomics, and metabolic engineering has improved understanding of microbial succession, functional pathways, and interspecies interactions during composting (Ansari et al., 2025). Such innovations provide opportunities to optimize food waste valorization processes while simultaneously enhancing the recovery of high-value products and reducing environmental impacts.

Hence, the optimization of compost-mediated systems using food waste-derived microbial consortia has emerged as a promising strategy for sustainable environmental management. This study therefore examines current advancements in the application of microbial consortia for improving composting efficiency and food waste bioconversion. Particular attention is given to emerging optimization approaches, including synthetic biology, metabolic engineering, and electro-fermentation technologies, which have demonstrated potential for enhancing microbial activity, accelerating organic matter degradation, and improving compost quality

The aim of the paper is to evaluate the role of food waste-derived microbial consortia in optimizing composting processes for improved waste degradation and compost quality. It seeks to synthesize current knowledge on microbial diversity, succession, and key physicochemical and biological factors influencing compost performance. The review also highlights emerging engineered and omics-based approaches for enhancing sustainable environmental management through efficient composting systems.

Food Waste as a Substrate for Microbial Consortia Development

Food waste (FW) has emerged as a promising organic substrate for the development and application of microbial consortia in sustainable environmental management. The increasing generation of food waste across households, commercial establishments, agro-industrial sectors, and municipal systems has created serious environmental concerns, particularly in relation to greenhouse gas emissions, landfill overflow, and environmental pollution (Cerda et al., 2018). Traditionally, food waste management depended largely on disposal methods such as landfilling and open dumping, which contribute significantly to methane emissions and leachate generation. However, recent waste management strategies increasingly emphasize resource recovery and waste valorization approaches in which microorganisms are employed to convert food waste into valuable products (Jatoi et al., 2026).

1. Composition of Food Waste

Food waste is primarily composed of carbohydrates, proteins, lipids, fibers, vitamins, minerals, and trace elements, although the composition varies considerably depending on the source and type of waste generated (Cerda et al., 2018; Huzir et al., 2026). Carbohydrates usually constitute the dominant fraction of food waste and include starch, cellulose, hemicellulose, and simple sugars. These compounds provide major substrates for hydrolytic and fermentative microorganisms, thereby supporting rapid microbial growth and metabolic activity (Dey et al., 2025). Carbohydrate-rich food residues have also been associated with enhanced hydrogen production and rapid heat generation during composting because of their high biodegradability (Wang et al., 2022). Proteins present in food waste provide essential nitrogen and amino acids required for microbial biomass synthesis and enzyme production. However, excessive protein degradation may result in ammonia accumulation, which can inhibit sensitive microbial populations and contribute to odor generation during composting processes (Cerda et al., 2018; Huzir et al., 2026). Lipids, although generally present in smaller quantities, possess high calorific value and are associated with elevated methane yields during anaerobic digestion because of their energy-rich properties (Wang et al., 2022).

2 Physicochemical Characteristics

The physicochemical properties of food waste strongly influence microbial growth, metabolic interactions, and the efficiency of compost-mediated bioconversion systems. Moisture content is one of the most important characteristics because food waste generally contains water levels exceeding 70–80% (Cerda et al., 2018; Huzir et al., 2026). Although sufficient moisture is necessary for microbial metabolism, excessively high moisture levels can reduce porosity and limit oxygen transfer, thereby promoting anaerobic conditions within compost piles (Cerda et al., 2018). Such conditions may result in the accumulation of volatile fatty acids, unpleasant odors, and reduced composting efficiency. To maintain favorable aerobic conditions, moisture content is commonly adjusted to an optimal range of 50–65% through the addition of bulking agents such as rice straw, wheat straw, sawdust, or dry leaves (Huzir et al., 2026). These amendments improve aeration and structural stability while supporting the proliferation of aerobic decomposer microorganisms.

3 Microbial Colonization Potential

Food waste naturally contains diverse indigenous microbial communities that contribute to the initiation and progression of decomposition processes. These communities include bacteria, fungi, yeasts, and actinomycetes capable of degrading the wide variety of organic compounds present within food residues (Luo et al., 2024). Indigenous microorganisms function as primary decomposers by secreting extracellular enzymes such as cellulases, proteases, lipases, and amylases that hydrolyze complex polymers into simpler compounds suitable for microbial assimilation (Dey et al., 2025). The succession of microbial populations during composting is a key determinant of process efficiency and compost maturity. This succession occurs in response to changes in environmental conditions including temperature, pH, oxygen concentration, and substrate availability (Luo et al., 2024).

Microbial Diversity in Composting Systems

Composting is a dynamic, controlled ecological process driven by the coordinated activity of diverse microbial communities that progressively transform organic wastes into stable, nutrient-rich soil amendments (Huzir et al., 2026). This transformation occurs through a succession of interacting microbial groups, including bacteria, fungi, actinomycetes, and archaea, whose synergistic and sometimes competitive relationships regulate the efficiency of organic matter degradation and nutrient stabilization (Luo et al., 2024). The overall performance of composting systems depends on maintaining environmental conditions that support these functional groups across different stages of decomposition, ensuring effective breakdown of organic substrates and formation of stable humus (Ansari et al., 2025).

1 Bacterial Communities

Bacteria represent the most abundant and metabolically active group in composting systems, largely due to their rapid growth rates and ability to adapt to fluctuating environmental conditions (Luo et al., 2024). They initiate the decomposition process by breaking down readily available organic substrates and generating heat that drives subsequent microbial succession.

Mesophilic bacteria dominate the early stage of composting when temperatures are close to ambient conditions. These microorganisms, mainly from the phyla Bacillota (formerly Firmicutes), Pseudomonadota (formerly Proteobacteria), and Bacteroidota, actively metabolize simple compounds such as sugars, amino acids, and organic acids (Ansari et al., 2025; Cerda et al., 2018). Their intense aerobic respiration generates metabolic heat, which gradually increases the temperature of the compost mass and triggers a transition to thermophilic conditions (Huzir et al., 2026; Luo et al., 2024).

As temperatures rise above 45–50°C, thermophilic bacteria replace mesophilic populations. Genera such as Bacillus, Geobacillus, Ureibacillus, and Thermobifida dominate this stage due to their ability to withstand high temperatures through heat-stable cellular structures and enzymes (Luo et al., 2024). This phase is critical for sanitation, as sustained high temperatures eliminate pathogens and weed seeds, thereby improving the safety and quality of the final compost product (Cerda et al., 2018; Huzir et al., 2026).

2 Fungal Communities

Fungi play a crucial role in composting systems, particularly under conditions of moderate moisture and slightly acidic pH, where they complement bacterial activity by targeting more complex and resistant organic structures (Luo et al., 2024).

Their most important contribution lies in the degradation of lignocellulosic materials such as plant residues and woody biomass. Fungal hyphae physically penetrate solid substrates, increasing surface area and facilitating deeper microbial access to otherwise resistant plant. This structural disruption is coupled with strong oxidative and hydrolytic processes that enable fungi to access carbon trapped within lignin, cellulose, and hemicellulose complexes (Huzir et al., 2026).

3 Role of Actinomycetes

Actinomycetes, belonging to the phylum Actinomycetota, are filamentous, slow-growing bacteria that resemble fungi in their structure and ecological function. They become particularly dominant during the later thermophilic phase and persist through the cooling and maturation stages of composting (Luo et al., 2024).

A key ecological function of actinomycetes is their ability to produce secondary metabolites, including natural antibiotics, particularly species within the genus Streptomyces. These compounds help regulate microbial competition within the compost matrix by suppressing pathogenic and fast-growing opportunistic organisms, thereby stabilizing the microbial ecosystem (Cerda et al., 2018).

4 Archaea and Minor Microbial Groups

Although composting systems are primarily aerobic, localized anaerobic microenvironments can develop due to compaction, high moisture content, or limited oxygen diffusion during rapid decomposition phases (Cerda et al., 2018; Wang et al., 2022). These microzones support specialized microbial processes, particularly those mediated by archaea.

In such conditions, methanogenic archaea, including Methanosarcina and Methanobacterium, interact syntrophically with fermentative bacteria to convert substrates such as acetate, hydrogen, and carbon dioxide into methane gas. While this process is natural, it represents a loss of carbon from the system and contributes to greenhouse gas emissions. Operational practices such as adequate aeration, proper moisture regulation, and the incorporation of bulking agents are therefore essential to minimize anaerobic conditions and reduce methane formation (Huzir et al., 2026).

Composting Process Optimization Strategies

Aerobic composting is a widely applied biological process that converts biodegradable organic waste into stable, nutrient-rich soil amendments (Noor et al., 2024). It is a self-heating system driven by successive microbial communities that degrade complex organic matter through distinct thermal phases (Pezzolla et al., 2021).

To enhance degradation efficiency, improve stabilization, and reduce environmental impacts such as greenhouse gas emissions and nutrient losses, composting performance must be optimized through integrated control of physicochemical conditions, aeration, structure, and biological inputs (Rastogi et al., 2020).

1 Physicochemical Optimization

Physicochemical optimization focuses on regulating environmental conditions that support microbial activity and efficient organic matter transformation. These parameters directly influence microbial metabolism and process kinetics (Noor et al., 2024).

2 Aeration and Oxygen Transfer

Aeration maintains aerobic conditions essential for efficient decomposition and energy metabolism. Passive aeration relies on natural diffusion and turning but often results in uneven oxygen distribution and localized anaerobic zones (Azis et al., 2023). Active aeration uses forced airflow systems that improve oxygen distribution, enhance moisture control, and accelerate stabilization.Adequate oxygen supports aerobic respiration, producing CO_2, water, and stable humic compounds. Oxygen limitation shifts metabolism to anaerobic pathways, leading to methane, nitrous oxide emissions, and odor generation (Noor et al., 2024).

3 Particle Size and Structural Optimization

Physical structure controls airflow, microbial access, and decomposition efficiency.Smaller particle size increases surface area and enhances microbial enzymatic degradation, accelerating early-stage decomposition (Azis et al., 2023).Excessive size reduction reduces porosity, restricts oxygen flow, and increases compaction risk. Bulking agents such as wood chips or straw are used to maintain structure, improve aeration, and prevent anaerobic conditions (Pezzolla et al., 2021).

4 Inoculum Optimization (Bioaugmentation)

Bioaugmentation enhances composting by introducing selected microbial strains to improve degradation efficiency.Targeted microbial inoculants (e.g., cellulolytic fungi and Bacillus spp.) accelerate breakdown of complex organic compounds, shorten lag phases, and enhance thermophilic activity (Noor et al., 2024).Microbial consortia provide functional diversity and metabolic cooperation, improving resilience and stability under variable composting conditions (Rastogi et al., 2020).

5 Additives and Amendments

Additives improve nutrient balance, process stability, and final compost quality. Biochar enhances aeration, moisture retention, and nutrient adsorption. It reduces ammonia volatilization, limits odor emissions, and supports microbial activity through porous habitat formation (Omoni et al., 2024).

Mineral additives such as gypsum, bentonite, and wood ash stabilize pH, reduce nutrient losses, and improve fertilizer quality through nutrient binding and buffering effects. Exogenous enzymes directly accelerate hydrolysis of complex substrates, bypassing microbial lag phases and reducing overall composting time (Noor et al., 2024).

Mechanisms of Organic Waste Degradation

Organic waste is a complex and heterogeneous material composed mainly of carbohydrates, proteins, lipids, and lignin-rich structural compounds. The decomposition of these components occurs through coordinated biochemical activities mediated by diverse microbial communities. During composting and other biological treatment processes, microorganisms produce extracellular and intracellular enzymes that convert complex organic materials into simpler compounds suitable for microbial uptake and metabolism. These degradation pathways play important roles in carbon and nitrogen cycling, nutrient recovery, and organic matter stabilization (Luo et al., 2024).

1 Carbohydrate Degradation

Carbohydrates constitute a major portion of organic waste, particularly in agricultural residues and municipal solid waste (Huzir et al., 2026). Cellulose and hemicellulose are the principal structural polysaccharides within plant cell walls and are relatively resistant to degradation because of their complex architecture (Jatoi et al., 2026). Cellulose is composed of linear chains of D-glucose linked by β-1,4-glycosidic bonds, whereas hemicellulose consists of branched heteropolymers containing pentose and hexose sugars (Zhou et al., 2024).The degradation of cellulose requires the synergistic action of cellulolytic enzymes, including endo-β-1,4-glucanases, exo-β-1,4-glucanases, and β-glucosidases, which collectively hydrolyze cellulose into glucose units (Dey et al., 2025; Jatoi et al., 2026). Hemicellulose degradation involves enzymes such as xylanases, β-xylosidases, and accessory debranching enzymes that target the heterogeneous xylan structure (Zhou et al., 2024).

Microbial succession strongly influences carbohydrate degradation during composting. Genera such as Bacillus and Cellulomonas dominate during mesophilic and thermophilic phases due to their high cellulolytic capacity (Dey et al., 2025; Jatoi et al., 2026). Under anaerobic conditions, hydrolytic bacteria convert structural carbohydrates into volatile fatty acids, which subsequently serve as intermediates for methane production (Wang et al., 2022).

2 Protein Decomposition

Proteins are important nitrogen-containing components of food waste, sewage sludge, and slaughterhouse residues. Their degradation is essential for nitrogen recycling and microbial growth. However, excessive protein concentrations may lead to ammonia accumulation and inhibit anaerobic digestion processes (Dey et al., 2025).

Protein degradation begins with extracellular proteases and peptidases secreted by bacteria and fungi, which hydrolyze proteins into peptides and amino acids. The resulting amino acids are further metabolized through deamination and decarboxylation pathways. Deamination releases ammonia or ammonium, while the remaining carbon skeletons enter metabolic pathways such as the tricarboxylic acid cycle for energy production (Wang et al., 2022).

3 Lipid Degradation

Lipids, including fats, oils, and greases, are highly energy-rich constituents of food waste. Despite their high biodegradability potential, lipids can inhibit waste treatment processes by forming hydrophobic layers that reduce mass transfer and microbial accessibility (Cerda et al., 2018).

Lipid degradation is primarily mediated by extracellular lipases, which hydrolyze triglycerides into free fatty acids and glycerol. Lipolytic microorganisms such as Bacillus, Pseudomonas, and several filamentous fungi produce these enzymes to utilize lipid substrates efficiently. Industrial applications also employ stable microbial lipases for biodiesel and ester production from waste oils (Dey et al., 2025).

Following hydrolysis, glycerol enters glycolytic pathways, while fatty acids are degraded through β-oxidation to generate acetyl-CoA units. In anaerobic digestion systems, syntrophic interactions between fatty acid-oxidizing bacteria and methanogens are essential for preventing the accumulation of toxic long-chain fatty acids (Wang et al., 2022).

4 Lignin Breakdown

Lignin is one of the most recalcitrant components of organic waste because of its irregular aromatic structure and resistant carbon-carbon and ether linkages. It surrounds cellulose and hemicellulose fibers, thereby limiting microbial access to structural carbohydrates and slowing waste degradation (Jatoi et al., 2026).

Unlike polysaccharides, lignin cannot be degraded through hydrolytic reactions. Its decomposition depends mainly on extracellular oxidative enzymes such as lignin peroxidase, manganese peroxidase, and laccase. These enzymes generate reactive radicals that cleave complex aromatic structures and destabilize lignin polymers (Zhou et al., 2024).White-rot fungi and actinobacteria, particularly Streptomyces species, are major lignin degraders in composting systems (Jatoi et al., 2026).

5 Nitrogen and Carbon Cycling

Carbon and nitrogen transformations are fundamental to organic waste. During microbial metabolism, organic carbon is mineralized into carbon dioxide under aerobic conditions or converted into methane and carbon dioxide under anaerobic conditions. Simultaneously, nitrogen compounds undergo several biochemical transformations that influence nutrient retention and compost quality.Ammonification is the initial stage of nitrogen conversion in which organic nitrogen compounds are transformed into ammonium or ammonia through microbial deamination processes (Luo et al., 2024). This process is carried out by heterotrophic microorganisms producing intracellular deaminases and amidases.

Excessive ammonification may increase pH and promote ammonia volatilization, leading to odor generation, nitrogen loss, and environmental pollution. Therefore, maintaining suitable moisture conditions and balanced carbon-to-nitrogen ratios is necessary for efficient nitrogen conservation during composting(Huzir et al., 2026).

Environmental Applications of Optimized Compost Systems

1 Soil Fertility Enhancement

Optimized composting converts food waste and other organic residues into stable humic substances that improve soil quality and long-term fertility. The application of mature compost increases soil organic carbon, enhances soil aggregation, and improves water-holding capacity. Engineered microbial consortia accelerate the degradation of complex compounds such as lignocellulose, proteins, and lipids, thereby producing nutrient-rich organic matter that supports soil structure and resilience (Huzir et al., 2026).

Composting promotes the recovery and reuse of essential nutrients from food waste and agricultural residues. Microbial communities mineralize organic compounds and convert nutrients into plant-available forms, particularly nitrogen, phosphorus, and potassium. This process reduces dependence on synthetic fertilizers and minimizes environmental problems such as groundwater contamination, atmospheric pollution, and eutrophication caused by excessive chemical fertilizer use (Dey et al., 2025; Jatoi et al., 2026; Luo et al., 2024).

2 Bioremediation of Contaminated Soils

Optimized compost systems can reduce the mobility and bioavailability of heavy metals in contaminated soils. Microbial activity and humic substances within compost facilitate biosorption and stabilization of toxic metals, thereby limiting their uptake by plants. This contributes to the restoration of polluted agricultural lands and improves environmental safety (Jatoi et al., 2026).

Engineered microbial consortia possess diverse metabolic pathways capable of degrading toxic organic pollutants in industrial and agricultural soils. Through synergistic microbial interactions, complex contaminants are transformed into less harmful compounds. These processes also support rhizosphere health by reducing toxic stress and suppressing harmful pathogens (Jatoi et al., 2026).

3 Greenhouse Gas Mitigation

Composting stabilizes organic carbon in the form of humic substances, preventing its rapid release into the atmosphere as carbon dioxide or methane. When applied to soil, compost acts as a long-term carbon reservoir by increasing soil carbon storage. This contributes to climate change mitigation while improving soil productivity (Huzir et al., 2026; Luo et al., 2024).

4 Circular Bioeconomy Integration

Optimized composting supports the circular bioeconomy by converting food waste and biomass residues into valuable products such as biofertilizers, bioenergy, bioplastics, and biofuels. Engineered microbial systems enhance resource recovery and provide an environmentally sustainable alternative to landfilling and incineration (Ansari et al., 2025; Dey et al., 2025; Jatoi et al., 2026).

The integration of compost-based microbial systems into agriculture promotes sustainable food production and aligns with global sustainability goals, particularly SDG 12 on responsible consumption and production. Compost application reduces the use of chemical inputs, improves crop productivity, and supports environmentally safe agricultural practices (Dey et al., 2025; Jatoi et al., 2026).

Challenges and Limitations

1 Environmental Sensitivity

The efficiency of microbial composting systems depends strongly on environmental conditions such as temperature, moisture content, pH, and nutrient availability. Fluctuations in these factors can inhibit microbial activity and reduce composting efficiency (Huzir et al., 2026).

2 Community Collapse Risk

Microbial imbalance may occur when compost substrates change abruptly or environmental stress increases. Such disturbances can disrupt microbial interactions, reduce degradation efficiency, and lead to odor generation and process instability (Jatoi et al., 2026).

4 Lack of Uniform Inoculum Protocols

The absence of standardized microbial inoculum formulations limits the consistent performance of engineered compost systems. Variations in waste composition often affect the adaptability and effectiveness of microbial consortia across different composting conditions (Jatoi et al., 2026).

5 Safety Concerns in Compost Products

Inadequate composting conditions may allow pathogens to survive in the final compost product. Maintaining thermophilic temperatures and implementing regular microbial monitoring are therefore essential to ensure biosafety and product quality (Jatoi et al., 2026).

6 Cost of Optimization Technologies

The adoption of advanced composting technologies, including automated aeration systems and molecular monitoring tools, requires substantial financial investment. Limited infrastructure and funding remain major barriers to large-scale implementation, particularly in developing countries (Dey et al., 2025).

Conclusion

Food waste-derived microbial consortia play a crucial role in optimizing composting through enhanced organic matter degradation, nutrient stabilization, and compost maturation. Engineered microbial consortia further improve composting efficiency and support sustainable environmental management through waste valorization, soil health improvement, and pollution reduction. Therefore, integrating advanced microbiological approaches with innovative composting technologies is essential for developing efficient and sustainable waste management systems.

Recommendations

1. Advanced microbial consortia engineering should be integrated into composting systems to enhance food waste degradation efficiency and compost quality.
2. Future studies should employ metagenomic and omics-based tools to better understand microbial interactions during composting processes.
3. Optimization of key physicochemical parameters such as temperature, aeration, moisture, and C/N ratio should be prioritized for sustainable compost production.
4. Governments and environmental agencies should promote large-scale composting technologies as part of circular bioeconomy and waste management policies.
5. Interdisciplinary collaboration among microbiologists, environmental scientists, and biotechnologists is necessary to develop smart and efficient composting systems.

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